Copy № 27

APAE-115
Volume III
AEC Research and
Development Report
UC-81, Reactors-Power
[Special Distribution]

PL-3 phase I task 3 R & D report

Contract No. AT[30-1]-2900
with U. S. Atomic Energy Commission
New York Operations Office

ALCO NPED

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT

APAE-115
Volume 3
AEC Research and
Development Report
UC-81, Reactors, Power
(Special Distribution)

PL-3 PHASE I TASK 3
R & D REPORT

G. E. Humphries, Project Engineer, PL-3

Issued: March 12, 1962

Contract No. AT(30-1)-2900
with U.S. Atomic Energy Commission
New York Operating Office

ALCO PRODUCTS, INC.
Nuclear Power Engineering Department
Post Office Box 414
Schenectady 1, N. Y.

DISTRIBUTION

External Copies	
1 - 2	New York Operations Office U. S Atomic Energy Commission c/o Alco Products, Inc. 1 Nott Street Schenectady 5, New York Attention: Resident Engineer, PL-3
3 - 4	New York Operations Office U. S. Atomic Energy Commission 376 Hudson Street New York 14, New York Attention: Project Engineer, PL-3 Reactor Division
5 - 9	U.S. Atomic Energy Commission Washington 25, D. C. Attention: Chief, Water Systems Branch (Army Reactors) Division of Reactor Development Mail Station F-311
10	U.S. Atomic Energy Commission Washington 25, D.C. Attention: Chief, Water Reactors Branch Civilian Power Division of Reactor Development Mail Station F-311
11	U.S. Atomic Energy Commission Chief, New York Patent Group Brookhaven National Laboratory Upton, New York Attention: Harmon Potter

External Copies	
12	U.S. Atomic Energy Commission Office of the General Counsel Washington 25, D. C. Attention: Mr. Roland Anderson
13	U.S. Atomic Energy Commission Idaho Operations Office P. O. Box 2108 Idaho Falls, Idaho Attention: Director, Division of Military Reactors
14	U.S. Atomic Energy Commission Reports and Statistics Branch Division of Reactor Development Washington 25, D. C.
15 - 19	Bureau of Yards and Docks Navy Department Washington 25, D. C. Attention: Director, Nuclear Power Division Code E-300
20	Office of the Chief of Engineers Department of the Army Building T-7 Washington 25, D. C. Attention: Chief, Projects Branch Nuclear Power Division
21	Nuclear Power Field Office U.S. Army Engineer Reactors Group Fort Belvoir, Virginia Attention: Chief, Nuclear Power Field Office

DISTRIBUTION (CONT'D)

External Copies	
22	Sundance Air Force Radar Station P.O. Box 80 Sundance, Wyoming Attention: AEC Representative, PM-1
23	Nuclear Power Field Office U.S. Army Engineer Reactors Group Fort Belvoir, Virginia Attention: O.I.C. SM-1
24	Chief, U.S. Army Reactors Group Fort Greeley, Alaska APO 733 Seattle, Washington Attention: O.I.C. SM-1A
25	Commanding Office U.S. Army Polar Research and Development Center Fort Belvoir, Virginia Attention: Nuclear Power Officer
26	Commander Air Force Special Weapons Center (AFSWC) Albuqerque, New Mexico Attention: SWVP
27 - 29	Office of Technical Information Extension P.O. Box 62 Oak Ridge, Tennessee
30	Union Carbide Nuclear Corporation Oak Ridge National Laboratory Y-12 Building 9704-1 P.O. Box "Y" Oak Ridge, Tennessee Attention: Mr. L. D. Schaffer

DISTRIBUTION (CONT'D)

External Copies

31 Director
U.S. Army Cold Regions
Research and Engineering Laboratories
P.O. Box 282
Hanover, New Hampshire

Attention: Dr. R. W. Gerdel

32 Advanced Technology Laboratories
Division of American-Standard
369 Whisman Road
Mountain View, California

Attention: Director, Research and Development

33 Aeroject General Nucleonics
Military Products Division
Box 77
San Ramon, California

Attention: Manager

34 The Babcock & Wilcox Company
Atomic Energy Division
1201 Kemper Street
P.O. Box 1260
Lynchburg, Virginia

Attention: Manager

35 Combustion Engineering, Inc.
Nuclear Division
Prospect Hill Road
Windsor, Connecticut

Attention: Mr. J. B. Anderson

36 General Atomic
Division of General Dynamics
P.O. Box 608
San Diego 12, California

Attention: Assistant Laboratory Director

DISTRIBUTION (CONT'D)

External Copies	
37	General Electric Company Atomic Power Equipment 2151 South First Street San Jose 12, California Attention: Manager, Engineering
38	Lockheed-Georgia Company Lockheed Nuclear Products Marietta, Georgia Attention: Director, Nuclear Laboratories
39	The Martin Company P.O. Box 5042 Middle River, Maryland Attention: AEC Contract Document Custodian
40	United Nuclear Corporation Development Division 5 New Street White Plains, N. Y. Attention: Library Custodian
41	Westinghouse Electric Corporation Atomic Power Department P.O. Box 355 Pittsburgh 30, Pennsylvania Attention: Director of Projects
42	Internuclear Company 7 North Brentwood Blvd. Clayton 5, Missouri Attention: Mr. O. J. Elgert

43	Jackson and Moreland Company Park Square Bldg. Boston 16, Massachusetts Attention: Mr. Harold Vann	

Internal Copies

44	W. D. Leggett
45	K. Kasschau
46	J. G. Gallagher
47	J. F. Haines
48	G. E. Humphries
49	N. F. Taylor
50	J. H. Mackin
51	D. G. Ott
52	J. W. Niestlie
53	W. R. Pearce
54	E. R. Schmidt
55	P. E. Bobe
56	W. O. Enright
57	R. E. Williams
58	E. L. Cofrances
59	R. M. Ryan
50	H. N. Roberts
61 - 75	NPED File

ABSTRACT

This report summarizes the results of research and development tasks performed during Phase I of this contract and presents recommendations for future development work. Work is reported in the areas of plant assembly and relocation, housings and footings, waste heat dissipation, instrumentation, refueling systems, waste disposal, shielding, core nuclear thermal and hydraulic studies, gaseous waste processing (BWR), and critical experiments on a 5 x 5 array of Type 3 fuel elements.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

TABLE OF CONTENTS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF TABLES

INTRODUCTION

Under Task 3 of Phase I of Contract AT(30-1)-2900, Alco Products performed studies to develop improvements to present portable nuclear power plant designs, directed specifically toward fulfilling the rigid environmental, schedule and logistic requirements involved in installation and operation of the PL-3 plant at Byrd Station, Antartica. These studies consisted of design and development areas universally applicable to BWR and PWR plants and some specific to one of the plant concepts.

The universal development areas were plant assembly and relocation, housings and footings, waste heat dissipation, instrumentation, refueling systems, waste disposal and shielding. Individual development areas involved core nuclear thermal and hydraulic studies for each type of plant and gaseaou waste processing for the BWR concept. In addition a critical experiment was performed on a 5 x 5 array of plate type, Type 3 fuel elements.

This report summarizes the results of these tasks and presents recommendations for continued development work during Phase II of this contract.

Some of the major results of this development effort are:

1. Skid and module weight and size have been optimized to meet the requirement of air transportability for the entire plant.

2. A reliable waste heat rejection system has been developed to meet the extreme climatic conditions.

3. Packaging techniques have been optimized to give maximum protection consistent with weight and cost.

4. Studies of various housing and footing designs and construction materials have resulted in reduction in weight, cost and erection time.

5. Gaseous waste processing studies have produced several suitable methods for handling radioactive gases for BWR and PWR plants.

6. Refueling system development effort has resulted in a simplified fuel handling technique requiring fewer and lighter spent fuel shipping casks.

7. Shielding studies have identified combinations of shielding materials and configurations resulting in an overall reduction of shielding weight. Advanced shielding codes applicable to PL-3 have been identified and will be used during the final design.

A resume of the recommendations for new or continued development work under Task 4 of Phase II follows:

1. Study, analysis and verification testing of shielding configurations should be continued in Phase II in order to further optimize the shielding arrangement, reduce weight and decrease erection time.

2. Critical mockup experiments and analysis should be performed to provide detailed power distributions, control rod calibrations, temperature coefficient and defect, reflector and material worths.

3. Zero power experiments and analysis will be performed on the two as-fabricated cores to determine stuck rod positions, core loading procedures, critical bank positions and calibrations.

4. A full scale flow test will be performed to determine orifice sizes, channel flow rates and velocities, and to measure pressure drops.

5. Gaseous waste disposal development should be continued to develop a method of working over the spent fuel pit and reactor shield tank while handling ruptured fuel emitting fission product gases.

6. A series of packaging materials tests should be conducted to determine the most suitable material for this service.

7. Reactor vessel material samples should be prepared for irradiation surveillance tests in the PL-3 reactor.

SUMMARY

The research and development studies accomplished during Task 3 of Phase I are briefly summarized below. Further details are included in the respective chapters of this report, and in separate topical reports.

I Skid Structure Study - (Subtask 4.2.1)

This study was undertaken to determine the most suitable material and design of skid structure for PL-3 application. The study concluded that T-1 steel (U.S. Steel Corporation) was best suited for this application, from a standpoint of weight, strength at low temperature, and cost. For maximum module package weight of 20,000 lb, a maximum skid length of 20 ft was determined to be optimum.

II Waste Heat Rejection System (Subtask 4.2.3.1)

Because plant waste heat must be ultimately dissipated to air, this study was performed to determine the most reliable and compact system. The study concludes that an indirect cycle, glycol - coupled condenser and air blast cooler is best suited for this application.

III Packaging Studies (Subtask 4.2.1.2)

A study of packaging techniques was undertaken to determine the most suitable method of packaging PL-3 equipment and modules to assure maximum consistent with weight, cost, and environmental conditions. The study concludes that two methods of packaging appear suitable:

1. Synthetic fabric covering over a light metal frame.

2. Stiff panel covering over a light wooden frame.

The report recommends that a program of packaging material tests be performed during Phase III.

IV Nuclear Instrumentation Simplification (Subtask 4.2.4.1)

The objective was to simplify nuclear instrumentation by eliminating one or more channels of instrumentation. The study concludes that it is feasible to simplify this instrumentation but to do so, an extensive research and test program would be required. Because of schedule considerations, this could not be accomplished under the PL-3 program. It is recommended that a research and test program be carried out to benefit future projects under a separate R & D contract.

V Housings and Footings (Subtask 4.2.2)

Jackson and Moreland, Inc. under subcontract to Alco Products performed preliminary design studies during Phase I covering analysis of housings and footings, foundation leveling and tunnel cooling. The analyses investigated available materials and methods, and resulted in the following preliminary recommendations:

1. Stressed skin wood panels are preferred for building construction. Metal siding and plastic faced stressed skin panels offer alternative choices.

2. Positive vapor barriers should be installed at the interior surface of walls and ceiling.

3. Joints between building panels should be gasketed tongue and groove joints.

4. The minimum panel thickness should be 4 in. based on insulation requirements.

5. Foundation leveling should be accomplished by electrically operated screw jacks under the primary buildings and conventional building jacks under the secondary buildings.

6. Air wells should be used for tunnel cooling to maintain tunnel temperatures at -80^{O}F.

Continuing work at Jackson & Moreland, Inc. is concerned with final design and procurement of mateials for buildings, footings and tunnel cooling.

VI Antifreeze Coolant Study (Subtask 4.2.3.2)

This study consisted of a literature search and manufacturer survey to find a possible substitute antifreeze solution for the ethylene-glycol presently being considered for the PL-3 heat rejection system. The study disclosed several solutions which offer improved stability in medium and high radiation service such as might be encountered in a BWR plant, but offer little or no advantage in a PWR plant. The study recommends continued investigation of radiation effects on glycol solution during Phase II.

VII Gaseous Waste Processing (Subtask 4.2.6)

The stringent restriction on release of radioactivity in the Antarctic required development of a reliable gaseous waste processing system for the PL-3 plant. During this task a system was developed to continuously process the BWR plant concept waste gases during normal and abnormal operation. A method of collecting and containing radioactive waste gases during refueling operations was also developed for the PWR concept. This study indicates that additional development work should be carried out during Phase II to optimize and verify results of this task.

VIII Refueling System Development (Subtask 4.2.5)

This task was undertaken to simplify fuel handling, minimize weight and decrease refueling time. A study and evaluation of existing refueling systems was conducted which resulted in the following conclusions:

1. For PWR plants the fuel transfer chute arrangement is recommended.

2. For BWR plants the fuel transfer flask arrangement is recommended.

3. For both plants, it is recommended that spent fuel be stored in the fuel shipping casks located in the peripheral shield tanks.

IX Shield Optimization (Subtask 4.2.7.1)

The objective was to develop shielding concepts which would produce safe and reliable shielding with minimum shipping weight and maximum ease of construction at the site. The studies pursued thus far indicate that less shielding weight is involved in a lead-water shield than in a steel-water shield. Furthermore, a range of shield configurations which calculations indicate are adequate, have been determined. It is recommended that continuing effort in the area of shield optimization studies (Subtask 4.2.7.1) and experimental evaluation of shielding effectiveness, (Subtask 4.2.7.2) be performed as part of Primary Shielding Studies under Task 4 of Phase II. It is also recommended that shield verification testing be performed under Task 12 of Phase II.

X Shielding Effectiveness (Subtask 4.2.7.2)

The objective was to evaluate available data and generate new data for evaluation of the effectiveness of various shielding materials and various material combinations, for utilization in the PL-3 shield design. A survey of shielding codes has been made to determine the best codes available for shielding calculations. A survey of facilities capable of performing shielding experiments was completed and the most desirable facility, based on PL-3 requirements, selected. Continuing effort in this area is recommended, as noted above.

XI Critical Experiments on a 5 x 5 Array of Type 3 Fuel Elements (Subtask 4.2.8)

A 5 x 5 core containing Type 3 (SM-2) fuel elements was investigated during Task 1 of Phase I in an effort to develop a core of minimum weight, size and complexity. Unfortunately, experimental nuclear data available on a core this size was limited, in addition severe limitations were imposed on extrapolation of data obtained from measurements performed on larger size cores. Thus, limited critical mock-up experiments were performed on a 5 x 5 array of Type 3 fuel elements. These experiments indicate that the 5 x 5 arrangement would be adequate for the PL-3 plant, but this arrangement was dropped from further consideration due to its present status of development and the tight PL-3 schedule. It is recommended that development work be continued on this core for possible application in future reactor designs, under a separate development contract.

SKID STRUCTURE STUDY

CHAPTER I
SKID STRUCTURE STUDY (SUBTASK 4.2.1)

A. Treiss

1.0 STATEMENT AND DISCUSSION OF TASK

During initial installation and subsequent relocations of the plant, it is essential that individual modules can be handled safely, rapidly and efficiently with a minimum of construction equipment. Accomplishing these objectives and anticipating severe conditions of climate and terrain will require careful attention to skid design details. The requirement that provision be made for plant relocation to another Antarctic site after a period of operation introduces additional considerations in the design. Skid designs will be standardized to the greatest extent possible, especially forlifting, tiedown and handling devices or attachments.

2.0 OBJECTIVES OF TASK

The objectives of this study are to evaluate skid structure designs, cost and materials and to make recommendations for minimizing the weight of the skid structures for the PL-3 nuclear power plant.

3.0 DESCRIPTION OF WORK

The guidelines imposed by the AEC on the design and construction of the PL-3 nuclear power plant, destined for installation at Byrd Station, Antarctica, place heavy emphasis on selecting skid designs and materials which minimize the weight of the structure, thus establishing weight savings which can be applied to module equipment.

Preliminary investigations evaluated:

1. Existing skid structure.

2. Design guidelines.

3. Lightweight construction materials and cryogenic applications.

4. Cost and weight relationships of various materials.

3.1 Existing Skid Structures

Skid structures used for previously constructed portable nuclear power plants may be classified as either pallet-type or truss type. Each type of skid structure has its advantages and disadvantages.

The truss-type skid structure is characterized by a relatively light platform to which trusses are fastened to provide necessary strength during shipment. The trusses also provide an easy means of attaching covering material, but this design is heavier than the others considered. Originally, the design was intended to save weight; the trusses were to be used for support of piping, wiring and equipment. It has been found impractical to use trusses for equipment support because they hinder equipment operation and maintenance. Truss-type skids cannot be moved or handled without the truss in place. Compression stresses are developed in structural members under dynamic loading conditions and location and attachment of lifting and tie-down devices becomes a complex problem. Even with the shallower main beams allowed by the truss-type skid, the cost of construction is significantly higher than for other skid designs.

The pallet-type skid is characterized by a relatively heavy platform structure using deep side beams to obtain the strength required for dynamic loading conditions. The skid is easier and less costly to construct and provides ample room for attachment of lifting and tie-down devices. Protective covering may be easily applied over a light conduit frame fastened to the main skid beams.

Skid designs investigated were:

PM-1	Martin Company
PM-2	Martin Company
PL-1	Combustion Engineering
PL-2	Combustion Engineering
PM-2A	Alco
PM-4A Advanced	Alco
Unattended Power Plant	Alco

The skid designs could be readily classified as truss-type (typical of PL-2 & PM-1) or pallet-type (typical of PM-2A).

3.2 Design Guidelines

PL-3 skid design guidelines have been defined as follows:

1. Sub-surface plant installation in cut-and-cover tunnels.

2. Tranportation in pre-assembled modules by C-130 aircraft operating under Antarctic conditions.

3. The volume and weight of the skid and equipment should be at a minimum (see below).

4. Design life of 20 years.

5. Field welds shall be minimized and limited to seal welds.

6. Shippings requirements.

   a. Modules - To facilitate handling, shipping erection and interconnection, each assembled module shall have a rigid base.

   b. Module Statistics - The normal, maximum, allowable package shall be equal to or less than 8' x 8' x 30'' and weigh 20,00 lbs or less. No module shall be larger than 8' 6'' x 8' 6'' x 30' or weigh in excess of 30,000 lbs. It may be allowable to have one package to the latter dimensions and weights. A C-130A airplane can take a cargo load of 25000 lbs; a C-130B, 35000 lbs. However, fuel load and structual load factors in Antarctic conditions impose limits on aircraft capacity.

   c. Thrust Loadings - The magnitudes of permissible thrust loadings are tabulated as follows:

      8 G - Forward (emergency landing)

      8 G - Aft (flight)

      3 G - Vertical (flight)

      1.5 G - Lateral (flight

      9 G - Maximum (vector sum foward, vertical and lateral loading)

   d. Packaging - Packaging shall be constructed to withstand handling, shipping and storage in transit and at the site. Duration of on-site storage is one year. Heating during transportation and storage should be avoided.

   e. Materials - Materials selected should minimize the danger of brittle fracture under all environmental conditions to be encountered.

7. Environmental data is as follows:

Maximum temperature for plant design	+34°F
Minimum temperature, Antarctic conditions	
Static (storage)	-90°F
Dynamic (transport)	-40°F

3.3 Lightweight Construction Materials

3.3.1 Materials Investigated

The steels investigated for possible PL-3 application included:

Type	Designation	Company
Structural carbon	A7	
Structural high strength-low alloy	Cor-ten	U.S. Steel
	Tri-Ten	U.S. Steel
Heat-treated construction alloy	T-1	U.S. Steel

The aluminum alloys investigated for possible PL-3 application were:

Designation	Company
2014-T6	Alcoa
6061	Alcoa
5456-H321	Alcoa

3.3.2 Materials Characteristics

A cryogenic process utilizes low temperature to produce a physical change in a liquid, gas or solid. However, as the process temperature lowers, the problem of selecting process equipment materials for low temperature applications becomes more complex. This applies also to materials which will be used for equipment, components and structures in low temperature environments.

While PL-3 will not operate in a low temperature environment, it will not be possible to install the plant modules at once in a heated environment, and the plant will not be heated during transportation or storage. Thus, plant materials must be chosen that can withstand temperatures as low as -40°F (dynamic) and -90°F (static) without danger of brittle fracture.

Low temperatures improve some physical properties of metals. Yield, tensile and fatigure strengths all increase with decreasing temperature. However, with the exceptions of iron, zinc and manganese, ductility and impact strength decrease. Many materials, including most ferrous metals, lose toughness and the ability to behave in a ductile manner as temperatures are lowered.

Thus, low temperatures create conditions favorable to the propagation of brittle fracture, which can result in the catastrophic failure of complex engineering structures and equipment.

Usually, construction metals will not fail without stretching, sagging, bulging or other warnings of imminent plastic failure. However, under certain conditions, metals which are ordinarily ductile may suddenly fail at very low stress levels without evidence of prior plastic deformation. These metals fail in a completely brittle manner, and this type of failure is generally manifested at low temperatures. To overcome the brittle failure problem, structures and equipment are designed to minimize stress concentrations and to utilize materials that have proven toughness based on tests and service condtions.

Toughness is the ability of a material to deform plastically under conditions of high stress concentration. This property is the prime requisite of materials specified for low temperature application. A tough material will resist the initiation of a crack at points of stress concentration, and will resist the propogation of a crack should one be initiated under abnormally high stress concentrations.

The tendency toward brittle behavior is further aggravated by notch effects (weld inclusions, nicks, scratches, changes of sections, geometric design interruptions and the like), which localize and concentrate stresses and restrict the ability of the material to yield plastically. Ductility is also impaired to a high degree by strain induced by the effects of cold working.

Since decreasing temperature is one of the major factors affecting toughness, the notch toughness of a material is most conveniently measured by lowering the temperature of notched test specimens to a point where behavior changes from predominantly ductile to predominantly brittle. The point at which this behavior change takes place, which varies with test conditions and criteria employed, is generally expressed in terms of a transition temperature.

Of the various tests which have been devised to measure toughness, the Charpy impact test is the most widely used for materials (especially steels) intended for low temperature service. In the Charpy tests, the criterion of toughness is frequently an arbitrarily selected value of energy absorption in breaking the specimen, such as 15 foot pounds at a designated service temperature using either a V-notch or a keyhole notch. While a foot-pound impact energy value is used in specification, the investigator can also employ a selected percentage of fracture appearance such as 50 percent shear, or a designated value of lateral contraction or expansion in a fractured specimen. In evaluating this transition from ductile to brittle behavior, it must be understood that no one transition temperature exists for any material except under a particular set of conditions and one criterion of brittleness.

The difficulty with any of these tests lies in attempting to apply the results in terms of expected service behavior in full-size structures. While these tests reflect the behavior of small specimans, they should not be construed as providing data which can determine the service performance of an actual structure, where design, fabrications, residual and applied stresses and other factors can influence behavior. Such tests are considered useful, however, as a basis for comparing the toughness of different metals and for evaluating the effect of metallurgical variations in the same material on its toughness.

It is generally acknowledged that a steel demonstrating good notch toughness (a low transition temperature) in a Charpy impact test will probably exhibit good behavior in actual service at or above that temperature. That is, it will possess greater toughness than a material with a higher transition temperature. Consequently steels with low transition temperatures are preferred for services involving service stress concentration, shock loading, low temperatures or combinations of these conditions.

3.3.3 Material Selection

It is important to select materials that stand up to shocks and vibrations. Generally, a minimum Charpy value of 15 foot-pounds (keyhole notch) is called for at the operating temperature. For severe shock loading, a value of 20 foot-pounds or above is recommended.

Temperature Range 0°F to -20°F

Some forms of carbon steel can be used up to -50°F for static conditions, but for vibration and light shock services, the maximum limit is -20°F (dynamic conditions).

Temperature Range -20°F to -50°F

Generally, carbon steels become hard, brittle and prone to brittle fracture below -20°F, although killed carbon steels can be used for 8 G shock service.

In most steelmaking processes, carbon combines with oxygen to produce gases. If the oxygen is not removed before or during solidification, gases are entrapped in the ingot. When this steel is used at temperatures below -20°F, the gas pockets can be focal points for brittle failure. A so-called killed steel has a small amount of aluminum added to scavenge the oxygen before casting. While the resulting metal is relatively homogeneous, the temperature limit of -50°F should be raised if there is a possibility of vibration or shock loading.

High strength, low carbon alloy steels can be used to -30°F. The so-called super high strength steels (heat treated, low carbon alloy) can be used up to -50°F in dynamic conditions, because they exhibit a minimum value of 15 foot-pounds in a Charpy keyhole test at this temperature.

Temperature Range -50°F to -150°F

While this temperature range eliminates all carbon steels, ferritic alloy steels with 3-1/2 percent nickel content can be used. This type of steel possesses good ductility and impact strength (20-25 foot-pounds Charpy value at -265°F), making it suitable for static or dynamic applications.

Temperature Range -150°F to 320°F

1. Stainless steel (particularly Type 304)

2. Brass and copper.

3. Aluminum.

4. Low carbon 9 percent nickel steel.

3.3.4 Aluminum

Until the advent of high strength aluminum alloy, aluminum was used sparingly in cryogenic applications. For pressure vessels, for instance, low strength aluminum is about 1/3 as strong as stainless steel and about 1/3 as heavy, while costs are the same on a weight basis.

The new, high strength aluminum alloys, used in conjunction with new welding techniques, will have a sound future in cryogenic applications. For structural application in low temperatures, these high strength aluminums possess an unusual ability to maintain ductility and resistance to shock loading. Their tensile and yield strengths actually improve as temperatures decrease. However, a comparison of the aluminum alloys with the high strength, low alloy steels and the super high strength, heat treated alloy steels for low temperature applications up to -50°F shows that the lower strength of aluminum, and the resulting increase in the amount of metal required, more than doubled the cost of a given structure.

3.3.5 Welding

Low temperature applications often involve complex welding problems. Dissolved gases in welds must be minimized by using low-hydrogen, coated electrodes. Submerged materials with austenitic electodes will usually result in a brittle fusion zone structure. Type 310 electrodes will alleviate this condition somewhat, and weld annealing is recommended for grain refinement.

The problem of joining aluminum to other metals has received much attention. Welding techniques available include:

1. Copper-plated aluminum to stainless steel.
2. Tinned aluminum to stainless steel.
3. Aluminum to copper to stainless steel.

3.3.6 Materials Tabulation

Materials which can serve safely and adequately at sub-zero temperatures are shown on Table I-1 and I-2.

3.4 Cost & Weight Relationships of Various Materials

3.4.1 Summary

Material Weight Savings, Skid Structures

1. T-1 steel vs. carbon steel - 30%
2. Aluminum vs. carbon steel - 35.9%
3. Aluminum vs. T-1 Steel - 5.9%

Weight Savings of Various Skid Designs

1. Truss-type (T-1) vs. pallet-type (T-1) - 7.93%
2. Truss-type (T-1) vs. pallet-type (aluminum) - 1.88%

Percentage of Weight Available for Equipment

The following is a summary tabulation of weights available for equipment on skids. The 15 and 20 ft skids are based on a total weight of 20,000 lbs; the 30 ft skid is based on a total weight of 30,000 lbs.

Skid Length (ft)	PL-3 Pallet-Type T-1 Steel (%)	Truss-type T-1 Steel (%)	Pallet-Type Aluminum (%)
30	72.29	80.22	78.34
20	84.43	89.26	89.61
15	88.66	92.99	93.73

Weight Savings Relative to Skid Lengths

Skid Lengths (Ft)	Weight Factors (%)	Weight Savings (%)
20 vs. 30	84.43 - 72.29	12.14
15 vs. 30	88.66 - 72.29	16.37
15 vs. 20	88.66 - 84.43	4.23

TABLE I-1
LIMITS OF LOW TEMPERATURE APPLICATION
OF CONSTRUCTION MATERIALS
(Suitable For Vibration & Shock Loading)

Metal	ASTM Spec.	Relative Cost Factor of Structure Members	Minimum Service Temperature °F
STEEL			
a-Carbon Steels	A7	1.00	-20
	A373	1.10	-20
	A36	1.10	-20
b-High Strength Low Alloy Steels	A440	1.34	-30
	A441	1.34	-30
	A242	1.34	-30
c-Super High Strength Heat Treated, Low Carbon Alloy Steel	None At Present	2.54	-50 (Toughness: 15 ft. lb min. Charpy Keyhole Value)
ALUMINUM:	2040-T6	12.0	-320°F
	6061-T6	8.0	-320°F
	5456-H321	10.0	-320°F
	Average	10.0	

TABLE I-2
LIMITS OF LOW TEMPERATURE APPLICATION OF METALS
(For Pipes in Low Temp. Processing)

Metal	ASTM Spec.	Relative Cost Factor of Pipe	Minimum Service Temperature °F
CARBON STEELS			
Plain	A53 Gr. A	1.00	-20
Killed (A1)	A106 Gr. A	1.10	-40*
Killed	A333 Gr. C	1.91	-50*
FERRICTIC ALLOY			
3-1/2% Ni	A333 Gr. 3	3.33	-150
5% Ni	A333 Gr. 5	3.92	-150
8-1/2% Ni	To A333	5.83	-320
AUSTENITIC ALLOYS			
18 Cr - 8 Ni	A312 - TP304	8.76	-320
18 Cr - 8 Ni	A312 - TP316	14.06	-320
18 Cr - 8 Ni	A312 - TP321	10.10	-320
18 Cr - 8 Ni	A312 - TP347	12.81	-320
25 Cr - 12 Ni	A312 - TP309	12.05	-320
25 Cr - 20 Ni	A312 - TP310	17.09	-320
NON-FERROUS			
Brass		4.47	-320
Copper		4.59	-320
Aluminum	6061-T6	1.47	-320
Aluminum	3013	1.28	-320
Aluminum	5083		-320

* Without Vibration & Shock Loadings

Material Cost, Unit Prices

Material costs are presented in Tabulation X, in the following section of tabulations.

Fabrication Costs

Tabulation IX presents a cost comparison of:

1. Carbon steel - A7.
2. U.S.S. Tri-Ten
3. U.S.S. T-1
4. Aluminum.

It is evident from the tabulation that a pallet-type skid structure made from aluminum would cost approximately 200 percent more than the same skid structure fabricated of U.S.S. T-1 steel. This amounts to a cost ratio of 1.3, which means that the fabrication costs of the aluminum structure is three times the cost of the steel structure, and yields only a 6 percent reduction in weight which clearly cannot justify the higher cost.

4.0 CONCLUSIONS & RECOMMENDATIONS

4.1 Materials

The use of a heat-treated construction alloy steel (U.S.S. T-1) is recommended for the PL-3 skid structures. This is considered to be the best material for low temperature application and is much less expensive than aluminum.

4.2 Skid Length and Module Weight

For a maximum module package weight of 20,000 pounds, a maximum skid length of 20 ft, has been determined to be optimunum. This arrangement results in a weight saving of 12.14 percent compared to a 30 ft, 20,000 lb skid and 14 percent to a 30 ft, 30,000 lb skid.

4.3 General

1. No substantial savings can be established through alterning of skid design structures.
2. Standardizing skid designs does not appear a fertile area for cost or weight reduction.

3. A weight reduction of skids can be affected only by using high strength steels or light weight materials (aluminum).

4. A further cost and weight saving can be affected by consolidating equipment functions and eliminating skids.

5.0 WORK IN PROGRESS

1. Design rules for skid bases

2. Handling rules

3. Study of tiedown devices and rules for placement

Work in progress is about 50 percent complete and will be completed as a part of the final plant design activities.

ALCO PRODUCTS INC.

BY J. REISS DATE 12/1/61
CHKD. BY ______ DATE ______
SUBJECT FEED WATER SKID
PALLET TYPE - 30,000 Lbs. -
HERCULITE COVER - PRESENT DESIGN.
SHEET NO. I OF ____
JOB NO. TABULATION

	ITEM	CONFIGURATIONS / TITLE	30,000 Lbs. - PALLET TYPE SKID (WITH HERCULITE COVER & TUBE FRAME STRUCTURE)											
			a - CARBON STEEL - A7				b - US. - TRI TEN STEEL				C - US. TI - STEEL			
			30'	27' PM-2A	20'	15'	30'	27' PM-2A	20'	15'	30'	27' PM-2A	20'	15'
	1	TOTAL PACKAGE WEIGHT	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %	30,000 # 100 %
7+8	2	TOTAL WEIGHT: SKID-BASE + VERT. EQU. SUPPORT + COVER & COVER FRAME	58.0 %	50.2 %	32.2 %	22.78 %	42.0 %	36.7 %	23.7 %	17.0 %	29.57 %	26.15 %	17.34 %	12.49 %
1-2	3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT ETC.	42.00 %	49.8 %	67.8 %	77.22 %	58.0 %	63.3 %	76.3 %	83.0 %	70.43 %	73.85 %	82.66 %	87.51 %
*	4	SKID BASE - ONLY	44.43 %	36.52 %	20.43 %	12.26 %	30.16 %	24.85 %	13.8 %	8.3 %	19.28 %	15.86 %	8.93 %	5.33 %
O	5	MAIN - BEAMS (TWO)	11.6 %	9.54 %	5.33 %	3.2 %	7.87 %	6.48 %	3.62 %	2.17 %	5.03 %	4.14 %	2.32 %	1.39 %
	6	VERTICAL EQUIPMENT SUPPORT STRUCTURE	5.95 %	5.95 %	5.95 %	4.13 %	4.13 %	4.13 %	4.13 %	4.13 %	2.59 %	2.59 %	2.59 %	2.59 %
	7	COVER & COVER-FRAME	7.7 %	7.7 %	5.82 %	4.57 %	7.7 %	7.7 %	5.82 %	4.57 %	7.7 %	7.7 %	5.82 %	4.57 %
4+6	8	SKID BASE + VERTICAL EQU. SUPPORT STRUCTURE	50.3 %	42.5 %	26.38 %	18.2 %	34.3 %	29.0 %	17.90 %	12.43 %	21.87 %	18.45 %	11.52 %	7.92 %

NOTES: % = PERCENTAGE OF ITEM 1 = 100% (FOR ITEMS 2 THRU 8)

O WEIGHT FACTORS FOR STRUCT. STEELS:

a = CARBON STEEL = 1.47 × b
b = TRI TEN - STEEL = 1.
c = Ti - STEEL = 0.64 × b

* LENGTH FACTORS OF SKIDS:

30' = 1.216 × 27'
27' = 1.
20' = 0.559 × 27'
15' = 0.3354 × 27'

	CONFIGURATIONS		20,000 Lbs. - PALLET TYPE SKID (WITH HERCULITE COVER & TUBE FRAME STRUCTURE)											
			a - CARBON STEEL A-7				b - US. TRI TEN STEEL				c - US. T1 - STEEL			
	ITEM	TITLE	30'	27' PM-2A	20'	15'	30'	27' PM-2A	20'	15'	30'	27' PM-2A	20'	15'
	1	TOTAL: PACKAGE - WEIGHT.	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %
7+8	2	TOTAL WEIGHT: SKIDBASE + VERT. EQUIPM. SUPP. STRUCT. + COVER & COVER FRAME	59.93 %	51.72 %	33.04 %	23.49 %	43.22 %	37.61 %	24.29 %	17.54 %	30.41 %	26.85 %	17.55 %	13.04 %
1-2	3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT ETC.	40.07 %	48.28 %	66.96 %	76.51 %	56.78 %	62.39 %	75.71 %	82.06 %	69.59 %	73.35 %	82.45 %	86.96 %
*	4	SKID BASE - ONLY	46.23 %	38.02 %	21.26 %	12.49 %	31.47 %	25.86 %	14.46 %	8.49 %	20.11 %	16.55 %	9.17 %	5.44 %
o	5	MAIN BEAMS (TWO)	12.07 %	9.93 %	5.55 %	3.26 %	8.21 %	6.75 %	3.78 %	2.22 %	5.25 %	4.32 %	2.42 %	1.42 %
	6	VERTICAL EQUIPMENT SUPPORT STRUCTURE	6.0 %	6.0 %	6.0 %	6.0 %	4.05 %	4.05 %	4.05 %	4.05 %	2.6 %	2.6 %	2.6 %	2.6 %
	7	COVER WITH COVER FRAME	7.7 %	7.7 %	5.78 %	5.0 %	7.7 %	7.7 %	5.78 %	5.0 %	7.7 %	7.7 %	5.78 %	5.0 %
4+6	8	SKID BASE + EQUIPM'T. SUPPORT STRUCTURE	52.23 %	44.02 %	27.26 %	18.49 %	35.52 %	29.91 %	18.51 %	12.54 %	22.71 %	19.15 %	11.77 %	8.04 %

NOTES: % OF ITEMS 2 THRU 8 MEANS / PERCENTAGE IN RELATION TO ITEM-1 = 100%

o WEIGHT FACTORS FOR STRUCT. STEELS:

a = CARBON STEEL = 1.47 × b

b = TRI TEN STEEL = 1.

c = T1 STEEL = 0.64 × b

* LENGTH FACTORS OF SKIDS:

30' = 1.216 × 27'

27' = 1.

20' = 0.559 × 27'

15' = 0.3354 × 27'

ALCO PRODUCTS INC.

BY T. REISS DATE 12/1/61
CHKD. BY ____ DATE ____
SUBJECT FEED WATER SKID
TRUSS TYPE - 30,000 Lbs. -
3/8" PLYWOOD COVER - PRESENT DESIGN
SHEET NO. III OF ____
~~JOB NO.~~ TABULATION.

	CONFIGURATIONS		30,000 Lbs. - TRUSS TYPE SKID - (WITH 3/8" PLYWOOD COVER)											
			a - CARBON STEEL - A7				b - US. TRITEN - STEEL				c - US. TI - STEEL			
	ITEM	TITLE	30'	27' PL-2	20'	15'	30'	27' PL-2	20'	15'	30'	27' PL-2	20'	15'
	1	TOTAL PACKAGE WEIGHT	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %	30,000 # / 100 %
7+8	2	TOTAL WEIGHT: SKID BASE + TRUSSES + COVER	32.6 %	27.3 %	16.25 %	10.41 %	24.19 %	20.38 %	13.05 %	8.09 %	17.74 %	15.08 %	9.47 %	6.31 %
1-2	3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT ETC.	67.4 %	72.7 %	83.75 %	89.59 %	75.81 %	79.62 %	86.95 %	91.91 %	82.26 %	84.92 %	90.53 %	93.69 %
*	4	SKID BASE-ONLY.	12.56 %	10.33 %	5.75 %	3.47 %	8.55 %	7.03 %	3.93 %	2.36 %	5.47 %	4.5 %	2.52 %	1.51 %
o	5	MAIN BEAMS (TWO)	6.01 %	4.95 %	2.77 %	1.66 %	4.01 %	3.37 %	1.88 %	1.12 %	2.63 %	2.16 %	1.21 %	0.73 %
	6	TRUSSES - ONLY	13.74 %	11.3 %	6.3 %	3.79 %	9.34 %	7.68 %	4.92 %	2.58 %	5.97 %	4.91 %	2.75 %	1.65 %
	7	COVER - 3/8" PLYWOOD	6.3 %	5.67 %	4.2 %	3.15 %	6.3 %	5.67 %	4.2 %	3.15 %	6.3 %	5.67 %	4.2 %	3.15 %
4+6	8	SKID BASE + TRUSSES	26.3 %	21.63 %	12.05 %	7.26 %	17.89 %	14.71 %	8.85 %	4.94 %	11.44 %	9.41 %	5.27 %	3.16 %

NOTES: % OF ITEMS 2 THRU 8 MEANS / PERCENTAGE IN RELATION TO ITEM 1 = 100%

o WEIGHT FACTORS FOR STRUCT. STEELS

a - CARBON STEEL = 1.

b - TRITEN - STEEL = 0.68 × a

c - Ti - STEEL = 0.64 × b

* LENGTH FACTORS FOR SKIDS:

30' = 1.216 × 27'

27' = 1.

20' = 0.559 × 27'

15' = 0.3354 × 27'

ALCO PRODUCTS INC.

BY TREIBS DATE 12/1/61
CHKD. BY ...... DATE ......
SUBJECT FEED WATER SKID
TRUSS TYPE - 20,000 Lbs.
3/8" PLYWOOD COVER - PRESENT DESIGN.
SHEET NO. IV OF ......
JOB NO. ......
TABULATION.

		CONFIGURATIONS	20,000 Lbs. - TRUSS TYPE SKID - (WITH 3/8" PLYWOOD COVER)											
			a - CARBON STEEL A7				b - TRITEN STEEL (US)				c - US. TI - STEEL			
	ITEM	TITLE	30'	27' PL-2	20'	15'	30'	27' PL-2	20'	15'	30'	27' PL-2	20'	15'
	1	TOTAL PACKAGE - WEIGHT	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %	20,000 # / 100 %
7+8	2	TOTAL WEIGHT: SKID BASE + TRUSSES + COVER	37.21 %	31.28 %	19.04 %	11.95 %	28.84 %	24.45 %	15.22 %	9.66 %	21.83 %	18.71 %	12.01 %	7.71 %
1-2	3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT, ETC.	62.79 %	68.72 %	80.96 %	88.05 %	71.16 %	75.55 %	84.78 %	90.54 %	78.17 %	81.29 %	87.99 %	92.29 %
*	4	SKID BASE - ONLY.	11.84 %	9.69 %	5.42 %	3.25 %	8.57 %	7.05 %	3.94 %	2.37 %	5.48 %	4.51 %	2.52 %	1.51 %
o	5	MAIN - BEAMS (TWO)	7.44 %	6.12 %	3.32 %	2.05 %	4.66 %	3.83 %	2.14 %	1.29 %	3.92 %	2.4 %	1.34 %	0.8 %
	6	TRUSSES - ONLY	15.92 %	13.09 %	7.32 %	4.4 %	10.82 %	8.9 %	4.98 %	2.99 %	6.9 %	5.7 %	3.19 %	1.9 %
	7	COVER - ONLY 3/8" PLYWOOD	9.45 %	8.5 %	6.3 %	4.3 %	9.45 %	8.5 %	6.3 %	4.3 %	9.45 %	8.5 %	6.3 %	4.3 %
4+6	8	SKID BASE + TRUSSES	27.76 %	22.78 %	12.74 %	7.65 %	19.39 %	15.95 %	8.92 %	5.36 %	12.38 %	10.21 %	5.71 %	3.41 %

NOTES: % OF ITEMS 2 THRU 8 MEANS PERCENTAGE IN RELATION TO ITEM 1 = 100%

o WEIGHT FACTORS FOR STRUCT. STEELS:

a - CARBON STEEL = 1.
b - TRITEN STEEL = 0.68 × a
c - TI - STEEL = 0.64 × b

* LENGTH FACTORS FOR SKIDS:

30' = 1.216 × 27'
27' = 1.
20' = 0.559 × 27'
15' = 0.3354 × 27'

ALCO PRODUCTS INC.

BY T REISS DATE 12/1/61
CHKD. BY ____ DATE ____

SUBJECT FEED WATER SKID
PALLET TYPE - 20,000 Lbs - HERCULITE COVER - RECOMMENDED DESIGN PL-3

SHEET NO. V OF ____
JOB NO. TABULATION

	CONFIGURATIONS		20,000 Lbs. - PALLET TYPE SKID - (WITH HERCULITE COVER - RECOMMENDED PL-3 DES.)											
			a - CARBON STEEL A7				b. - US. TRI TEN - STEEL				c - US. T1 - STEEL			
	ITEM	TITLE	30'	27'	20'	15'	30'	27'	20'	15'	30'	27'	20'	15'
	1	TOTAL PACKAGE - WEIGHT.	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %	20,000 # 100 %
7+8	2	TOTAL WEIGHT: SKID BASE + VERT. EQUIP. SUPP. STRUCT. + COVER WITH COV. FRAME	57.23 %	48.15 %	31.06 %	21.79 %	40.52 %	34.04 %	22.31 %	15.84 %	27.71 %	23.28 %	15.57 %	11.34 %
1-2	3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT ETC.	42.77 %	51.85 %	68.94 %	78.21 %	59.48 %	65.96 %	77.69 %	84.16 %	72.29 %	76.72 %	84.43 %	88.66 %
*	4	SKID BASE - ONLY	46.23 %	38.02 %	21.26 %	12.49 %	31.47 %	25.86 %	14.46 %	8.49 %	20.11 %	16.55 %	9.17 %	5.44 %
0	5	MAIN BEAMS (TWO)	12.07 %	9.93 %	5.55 %	3.26 %	8.21 %	6.75 %	3.78 %	2.22 %	5.25 %	4.32 %	2.42 %	1.42 %
	6	VERTICAL EQUIPMENT SUPPORT STRUCTURE	6.0 %	6.0 %	6.0 %	6.0 %	4.05 %	4.05 %	4.05 %	4.05 %	2.6 %	2.6 %	2.6 %	2.6 %
	7	COVER WITH COVER FRAME	5.0 %	4.13 %	3.8 %	3.3 %	5.0 %	4.13 %	3.8 %	3.3 %	5.0 %	4.13 %	3.8 %	3.3 %
4+6	8	SKID BASE + VERT. EQUIP. SUPPORT STRUCT.	52.23 %	44.02 %	27.26 %	18.49 %	35.52 %	29.91 %	18.51 %	12.54 %	22.71 %	19.15 %	11.77 %	8.04 %

NOTES: % OF ITEMS 2 THRU 8 MEANS PERCENTAGE IN RELATION TO ITEM 1 = 100%

VALUES FOR ITEMS 4, 5, 6 & 8 TAKEN FROM TABULATION II (20,000 Lbs. - PALLET TYPE SKID)

ITEM 7 CALCULATED AT 1000 Lbs FOR 30' SKID LENGTH; 20' LENGTH = 75% OF 30'; 15' LENGTH = 65% OF 30'

(SEE EVALUATION "HANCOCK" - RECOMMENDED PL-3 COVER)

ALCO PRODUCTS INC.

BY T. REISS DATE 12/1/61
CHKD. BY ____ DATE ____
SUBJECT DESIGN COMPARISON & WEIGHT SAVINGS FOR VARIOUS SKID DESIGNS OF FEED WATER SKID
SHEET NO. VI OF ____
JOB NO. TABULATION.

20,000 Lbs. SKIDS – OF VARIOUS DESIGNS – SEE NOTE ①

ITEM	LENGTH OF SKIDS	a – CARBON STEEL A7			b – US. TRITEN – STEEL			C – US. TI – STEEL		
		WEIGHT SAVINGS IN PER CENT			WEIGHT SAVINGS IN PER CENT			WEIGHT SAVINGS IN PERCENT		
		II	V	IV	II	V	IV	II	V	IV
	30' LONG									
① 3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT, ETC.	40.07 %	42.77 %	62.79 %	56.78 %	59.48 %	71.16 %	69.59 %	72.29 %	78.17 %
		0 %	2.55 % OF II	20.02 % OF V SAVINGS	0 %	2.70 % OF II	11.68 % OF V SAVINGS	0 %	2.70 % OF II	5.88 % OF V SAVINGS
	20' LONG									
① 3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT, ETC.	66.96 %	68.94 %	80.96 %	75.71 %	77.69 %	84.78 %	82.45 %	84.43 %	87.99 %
		0 %	1.98 % OF II	12.02 % OF V SAVINGS	0 %	1.98 % OF II	7.09 % OF V SAVINGS	0 %	1.98 % OF II	3.56 % OF V SAVINGS
	15' LONG									
① 3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT, ETC.	76.51 %	78.21 %	88.05 %	82.06 %	84.16 %	90.54 %	86.96 %	88.66 %	92.29 %
		0 %	1.70 % OF II	9.84 % OF V SAVINGS	0 %	2.10 % OF II	6.38 % OF V SAVINGS	0 %	1.70 % OF II	3.63 % OF V SAVINGS

NOTES: ① SKID DESIGNS: II = PRESENT PALLET TYPE SKID (SEE TABULATION II – FIGURES OF ITEM 3, a, b & c & SKID LENGTHS 30', 20' & 15')

IV = PRESENT TRUSS TYPE SKID (SEE TABULATION IV – FIGURES OF ITEM 3 – a, b & c, & SKID LENGTHS 30', 20' & 15')

V = RECOMMENDED PALLET TYPE SKID – PL-3 (SEE TABULATION V – FIGURES OF ITEM 3 – a, b & c AND SKID LENGTHS 30', 20' & 15')

→ GENERAL: FIGURES FROM C – 20' LONG, SHOW THAT SAVINGS BETWEEN TRUSS TYPE SKID IV VS. PALLET TYPE SKID – PL3 (V) ARE ONLY 3.56% = 712 Lbs.

ALCO PRODUCTS INC.

BY T. REISS DATE 12/1/61
CHKD. BY .... DATE ....
SUBJECT FEEDWATER SKID - PALLET TYPE - 30,000 Lbs. - 30' LONG - WEIGHT SAVINGS: ALUMINUM VS. TI-STEEL
SHEET NO. VII OF ....
JOB NO. TABULATION

	CONFIGURATIONS		30,000 Lbs. - PALLET TYPE SKID (WITH HERCULITE COVER & TUBE FRAME STRUCTURE) - 30' LONG			
			C - U.S. TI - STEEL △	d1 - ALUMINUM 2014-T6 △		d2 - ALUMINUM 6061-T6	
	ITEM	TITLE	30'	30'		30'	
	1	TOTAL PACKAGE - WEIGHT.	30,000 # / 100 %	30,000 # / 100 %		30,000 # / 100 %	
7+8	2	TOTAL WEIGHT OF SKID-BASE + VERT. EQUIPM. SUPP. STRUCT. + COVER WITH COVER FRAME	29.57 % ▲	20.12 %	= 9.45 % SAVING VS. C ▲	23.21 %	= 6.36 % SAVINGS VS. C ▲
1-2	3	TOTAL WEIGHT TO BE USED FOR EQUIPMENT ETC.	70.43 %	79.88 %		76.79 %	
*	4	SKID BASE - ONLY	19.28 %	10.95 %		13.67 %	
o	5	MAIN - BEAMS (TWO)	5.03 %	2.87 %		3.57 %	
	6	VERTICAL EQUIPMENT SUPPORT STRUCTURE	2.59 %	1.47 %		1.84 %	
	7	COVER WITH COVER-FRAME	7.7 %	7.7 %		7.7 %	
4+6	8	SKID BASE + VERTICAL EQUIPM. SUPP. STRUCT.	21.82 %	12.42 %		15.51 %	

NOTES: △

MECH. PROPERTIES OF MATERIALS:	C U.S. TI - STEEL - PSI -	d1 ALUMINUM 2014-T6 - PSI -	d2 ALUMINUM 6016-T6 - PSI -
ULTIMATE TENSILE:	115,000	60,000	45,000
YIELD STRENGTH:	100,000	53,000	40,000
ALLOWABLE STRENGTH FOR STRUCTURES	54,000 = 1.85 SAFETY FACT.	28,700 = 1.85 S.F.	21,620 = 1.85 S.F.

* VALUES OF ITEMS 1 THRU 8 TAKEN FROM TABULATION IC - 30' FOR C = TI STEEL
d_1 & d_2 VALUES - IT. 2-8 CALCULATED FOR ALLOWABLE AL-STRESS

o MAIN BEAMS IT. 5 - d_1 & d_2 CALCULATED " " " "

▲ SAVINGS USING ALUMINUM VS. TI - STEEL; AVERAGE = 6.0%

ALCO PRODUCTS INC.

BY I REISS DATE 12/1/61
CHKD. BY ____ DATE ____
SUBJECT FEED WATER SKID - PALLET TYPE - 20,000 & 30,000 Lbs. - 30' LONG - MATERIALS WEIGHT COMPARISON.
SHEET NO. VIII OF ____
JOB NO. TABULATION

		20,000 & 30,000 Lbs. PALLET TYPE SKID - 30' LONG (WITH HERCULITE COVER & TUBE FR. - PRES. DES)					
		a - CARBON STEEL A7		b - US. TRI TEN STEEL		C - US. Ti - STEEL	
ITEM		SKID LENGTH 30'		SKID-LENGTH 30'		SKID-LENGTH 30'	
	20,000 Lbs		VALUES TAKEN FROM TUBULATION IIa - 30'		VALUES TAKEN FROM TABULATION IIb - 30'		VALUES TAKEN FROM TABULATION IIc - 30'
1	TOTAL PACKAGE-WEIGHT.	20,000 # 100 %		20,000 # 100 %		20,000 # 100 %	
8	SKID BASE + VERTICAL EQUIPMENT SUPPORT STRUCTURE	52.23 %		35.52 %	SAVINGS = 16.71% OF a	22.71 %	SAVINGS = 29.52% OF a = 12.81% OF b
	30,000 Lbs.		VALUES TAKEN FROM TABULATION Ia - 30'		VALUES TAKEN FROM TABULATION Ib - 30'		VALUES TAKEN FROM TABULATION Ic - 30'
1	TOTAL PACKAGE-WEIGHT	30,000 # 100 %		30,000 # 100 %		30,000 # 100 %	
8	SKID BASE + VERTICAL EQUIPMENT SUPPORT STRUCTURE	50.3 %		34.3 %	SAVINGS: = 16% OF a	21.87 %	SAVINGS: = 28.43% OF a = 12.43% OF b.

NOTE: ALUMINUM SKID - (SEE TABULATION VII) AMOUNTS TO A SAVING OF:

34.3 - 35.4% VS. a - CARBON STEEL

AND 5.9% VS. C - Ti - STEEL

Ti - STEEL SKID SAVINGS V.S. CARBON STEEL = ~ 29% (SEE ABOVE TABULATION)

		UNIT - PRICES			ITEM: 8			+ MORE ; - LESS		
INDEX	MATERIAL	UNIT PRICE	FACTOR	PER CENT OF UNIT PRICES	WEIGHT SAVINGS IN PER CENT VS. a	b	c	ACTUAL COST IN PER-CENT. VS. a	b	c
a	CARBON STEEL - A7	28	1	100	0	0	0	0	0	0
b	US. TRI TEN STEEL	30	1.07	107	16.71	0	0	-9.71	0	0
c	US. Ti - STEEL	40	1.43	143	30	12.81	0	+13	+23.2	0
d	ALUMINUM	97.1	3.47	347	35.9	18.71	5.9	+211.1	+221.3	+191.1

NOTE: ABOVE PERCENTAGES ARE FOR MATERIALS COST ONLY FOR ITEM 8 (= SKID BASE & VERTICAL EQUIPMENT SUPPORT - STRUCTURES) AS CALLED OUT IN COLUMN "CONFIGURATIONS" OF THE TABULATIONS.

ALCO PRODUCTS INC.

BY TREISS DATE 4/12/61 SUBJECT COST FOR FABRICATED STRUCTURES (UNIT PRICES) (FOR VARIOUS MATERIALS) SHEET NO. X of 1

CHKD. BY ______ DATE ________ JOB NO. ________

TABULATION

REF: ① CIVIL ENGINEERING MAGAZINE - NOV. 1961 - PAGE 45

② PER ALCO - PURCHASING DEP. - MR. YOUNG & CLARK WILLIAMS (ALCOA - ALUMINUM)

③ USS. - NEW CONCEPTS IN STEEL DESIGN - ADUCO 04004 - 1961

A. - STEELS: 1. TYPE OF STEEL	2. US, STEEL BRAND	3. MILL PRICE ¢/Lb	4. WARE HOUSE PRICE ¢/Lb	5. MACHINING & WELDING ¢/Lb	6. UNIT PRICE 4+5 ¢/Lb
a - CARBON STEEL - A7	A7	6.4	7.5	20.5	28
b_1 - HIGH STRENGTH LOW ALLOY STEEL A 242	COR TEN	8.7	10	20	30
b_2 - HIGH STRENGTH LOW ALLOY MANGANESE - VANADIUM STEEL A 141	TRITEN	8.4	10	20	30
c - HEAT TREATED CONSTRUCTION ALLOY STEEL	T1	15.5	19	21	40

NOTES: 4. - WAREHOUSE PRICES = + 17% OF MILL PRICES ②

5 - MACHINING & WELDING ETC. + 20¢/Lb - AVERAGE ①

1 + 2 - TYPES & BRAND NAMES = ③

6 - UNIT PRICES = ①

REF. (4) ALCOA ALUMINUM HANDBOOK-1959

B - ALUMINUM:

	1. TYPE OF ALUMINUM (ALLOY & TEMPER)	2. BRAND NAME	3. MILL PRICE ¢/Lb.	4. WAREHOUSE PRICE. ¢/Lb	5. MACHING & WELDING ¢/Lb	6 UNIT PRICE 4+5 ¢/Lb
d_1	2014-T6 WELDABILITY B (ARC)	ALCOA	—	90	20	110
d_2	6061 - T6 WELDABILITY A (ARC)	ALCOA	—	60.3	20	80.3
d_3	5456 - H 321 WELDABILITY B (ARC)	ALCOA	—	76	25	101
d	ALUMINUM AVERAGE PRICES & COST OF d_1, d_2 & d_3			75.4	21.7	97.1

NOTES: 1 - WELDABILITY: SEE REF. (4)
A = GENERALLY WELDABLE BY ALL COMMERCIAL PROCEDURES & METHODS
B = WELDABLE WITH SPECIAL TECHNIQUE OR ON SPECIFIC APPLICATIONS WHICH JUSTIFY PRELIMINARY TRIALS OR TESTING TO DEVELOP WELDING PROCEDURE & WELD PERFORMANCE.

4 - VALUES OF WAREHOUSE PRICES - SEE REF. (2)

2 - SEE REF. (4)

5 - ESTIMATED FROM STEEL WELDINGS - SEE TABLE A - STEELS

6 - CALCULATED.

WASTE HEAT
REJECTION SYSTEM

HOUSINGS AND FOOTINGS

CHAPTER V
HOUSINGS AND FOOTINGS (SUBTASK 4.2.2)

Jackson and Moreland, Inc.

1.0 STATEMENT AND DISCUSSION OF THE TASK

This task determines the most applicable housing materials and footing designs for the PL-3 environment. The general environment considered is a remote area characterized by low temperatures, a short construction period and construction surfaces upon which foundation settling can be expected.

2.0 OBJECTIVES OF TASK

The objectives of the task are twofold; first, review of construction materials to select the optimum materials for use in the PL-3 environment; second, development of support jacking devices to minimize access requirements in radioactive areas.

3.0 DESCRIPTION OF WORK

3.1 Foundations and Jacking

3.1.1 Foundations and Floor Systems

To insure a uniform bearing pressure on the snow surface, foundations will be proportioned and located so that the centroid of bearing areas is coincident with the centroid of superimposed loads.

A maximum allowable snow bearing pressure of 1000 psf will be used for foundation design. This value will dictate the foundation bearing area required for structures in the primary system tunnel, which will be about 20 ft deeper than the other plant tunnels. Reduced allowable bearing pressures will be used to proportion foundation bearing areas for plant components in the less deep tunnels. By accounting for the increase in natural densification of the deeper snow by loading the foundation at different levels in proportion to the preconstruction loads of overlying snow, it is expected that the annual change in vertical separation between foundations at the two levels will not exceed the natural contraction of the snow mass.

Figure V-1 shows snow densification data taken from U. S. Army Cold Regions Research and Engineering Laboratory Technical Report 78 entitled, "Drill-Hole Measurements and Snow Studies at Byrd Station, Antarctica," by A. J. Gow. Densification data for snow at Pole Station are not yet available.

With the passage of time, it is probable that the floor of the tunnel cross section will change from a level to a crowned surface in which the outer edges will be depressed from their original elevation relative to the building floor, and the centerline will be raised. Where practicable, foundations will be located near the quarter points of the tunnel width where the change in relative elevation is minimal.

To allow free circulation of tunnel air under the buildings or other potential heat sources and in accordance with contract requirements, floor systems will be elevated to maintain a minimum clearance of 2 ft-6 in. between the tunnel floor snow surface and the lowest point on buildings or drain pipes. Foundations and jacking equipment will utilize this under floor space.

Where metal beams or trusses are used to elevate the buildings and distribute loads to the foundation bearing surface, wood, or other insulating material, bearing blocks and sills will be used as required to break any direct path which might conduct heat to the snow bearing surface.

Wood-framed, stressed-skin plywood panels will be used to form the foundation bearing surfaces. In addition to ease of erection and the advantage of providing a bearing surface with desirable heat transfer properties, the comparison of shipping weights and volumes of spread footing members shown in Fig. V-2 indicates a weight saving in favor of stressed-skin panels over cellular steel panels or wood planking. The bottom of panels will be located at least 6 in. below the tunnel floor snow surface so as to bear on snow undisturbed by construction traffic, and to provide further insurance against heat transmission to the snow bearing surface.

Wood, aluminum and steel all have a place in an economical design of the foundations and buildings. The modulus of elasticity and the tensile strength of each of these materials increases at low temperatures. Many steels, however, exhibit a tendency to brittle behavior as the temperature is decreased. The following tabulation lists some readily available materials which are suitable for structural purposes in cold climates. Minimum Charpy V-notch longitudinal impact test values and test temperatures are listed for the steels. Those steels which can absorb not less than 15-ft lb of energy when subjected to a longitudinal Charpy V-notch impact test at a temperature of $-90^{O}F$ or colder are considered acceptable for use in snow tunnels at Byrd Station.

Material	Density (pcf)	Elastic Modulus (psi)	Allowable Tensile Strength (psi)	Coldest Service Temperature
Douglas Fir, Coast Region, Construction Grade	33	1,760,000	1,200	No lower limit
6061-T6 Aluminum	170	10,000,000	15,000	-320°F
2014-T6 Aluminum	175	10,600,000	22,000	-320°F
ASTM-A203, Grade E; 3-1/2 % Nickel Steel	490	29,000,000	24,500	15 ft lb @ -150°F
ASTM-A242, Normalized (To 1/2-in. thick)	490	29,000,000	30,500	15 ft lb @ -50°F
ASTM-A441, Normalized (To 3/4-in. thick)	490	29,000,000	30,500	15 ft lb @ -50°F
ASTM-A353, Grade B; 9% Nickel Steel	490	29,000,000	39,500	20 ft lb @ -320°F
U. S. Steel HY-80 Steel	490	30,000,000	48,500	70 ft lb @ -120°F
U. S. Steel T-1 Steel	490	30,000,000	60,500	*

* Impact test values for welded and unwelded specimens and for various thicknesses of U. S. Steel "T-1 Steel" are being investigated.

The selection of optimum materials, which satisfy the stress and deflection requirements of a particular design situation, will be made during the final design.

Information accumulated to date indicates that spread footings are more economical and efficient for supporting buildings on snow than pile foundations. Long piles are required to obtain a significant increase in bearing capacity of the snow. Since the rate of settlement of the surrounding snow varies along the length of a pile, it is possible that the snow surrounding the upper portion of a long pile could settle faster than the loaded pile itself, causing negative skin friction forces that effectively add load to the pile. In any event, the resultant of skin friction forces is unpredictable; therefore, end bearing resistance only can be safely counted on for design purposes.

The reactor building will be suspended at all times from jacks located under the building. To facilitate the remote control of jacking and level measurement required, only 4 jacks will be used. The building dimensions are consistent with the use of its framing as a stiff box truss to deliver the building and primary equipment loads to the foundations. By taking advantage of the stiffness of the building superstructure, the height of the building floor from the tunnel floor will be less than would be required otherwise. A lined pit, stiffened to resist the side pressure of the snow and surcharge loads, will be provided at each jack screw rod. Pyramidal cribs or trusses will be used to deliver the jack loads to the snow bearing panels.

The secondary and service buildings will be of light construction, and will ordinarily be supported directly by their foundations. Jacking stations along the length of the buildings will be used as required for local leveling, or to raise the entire building, until shims or cribbing members are inserted to bear the load. To avoid buckling of the building walls or other damage from the settlement of foundations, a continuous truss of triangular cross section will be provided along each side of the building to deliver loads to the snow bearing panels. Floor framing members will cantilever beyond the top chord of the truss on each side.

3.1.2 Level Measurement

Means of detecting changes in level due to settlement of the snow foundation are required. There are two problems: One, to detect the small settlements of the buildings themselves and, two, to detect uneven settlement of individual foundations under the primary building which might affect the operation of the jacks.

For detecting changes in building level, no system offers greater reliability or simplicity than a liquid-filled manometer, provided that a satisfactory fluid suitable for the operating temperature range can be found.

Other systems were considered, but all suffer either from complexity or from inability to establish a suitable reference level. Lacking such a reference, any mechanical system would have to depend on angular displacement, such as measuring the angle between a building member and a reference pendulum. Due to the lengths of the buildings involved, such angles are too small to measure accurately. Another possible system consists of a collimated light source on a gimbal-mounted platform, aimed at distant photocells. This would be complex, and it would be difficult to collimate a light beam well enough to provide sufficient accuracy. Also, neither of these methods is suitable to measure the relative movement between the primary and secondary buildings, since the presence of the snow wall precludes either a line of sight or a rigid mechanical connection between the buildings.

In a search for manometer fluids, pentane, which is used in thermometers for very low temperatures, and the silicones were investigated first. The best available silicone, Dow Corning 330 Fluid, while pourable below -100^{O}F, has too high a viscosity to be suitable as a measuring fluid. Pentane has excellent viscosity characteristics, but it is highly inflammable and has a flash point of approximately -40^{O}F, making it hazardous to handle.

A survey of some 9000 organic compounds listed in the Handbook of Chemistry and Physics resulted in the selection of ten which had suitable melting and boiling points. Methanol is one of these, and would be usable. It is inflammable, but not too dangerous. Most of the others are not readily available. One of the most promising is tetraethyl tin, but the total commercial production to date is 400 grams (less than one pint) and this is for sale at $100, a prohibitive price. However, this might be reduced if a larger quantity were to be made, and this material is still a possibility.

Humble Oil Company has stated that either kerosene or Varsol, a petroleum-based solvent, would remain mobile at these temperatures, but would contain some particles of waxy materials. Both are volatile but, like methanol, not too hazardous. Another fluid which Humble suggests is a commercially available product known as C8-Oxi-Pelargonate.

The most promising fluid so far is a fluorochemical liquid produced by Minnesota Mining and Manufacturing Company and designated F6-75. It is inert, stable, non-toxic, and has a pour point as low as -150^{O}F. Its viscosity at -80^{O}F is 6.5 centistokes. This is the lowest temperature for which viscosity data is available, and the viscosity at lower temperatures must be checked. However, this value indicates that its viscosity should be satisfactory. In gamma radiation tests, this material experienced a 22 percent increase in viscosity after 1×10^{8} roentgens, indicating very adequate radiation resistance for this application.

To minimize temperature effects, the system should be entirely outside the buildings. For the system piping, either aluminum or copper would be suitable, and the system could be standard pipe or thin walled tubing. The choice depends primarily on the possibility of accidental damage and can be made only when the final layout is more definite.

For the secondary buildings, direct visual reading is planned, using flat glass, reflex-type gages for safety and to increase readability.

For the primary building, remote reading is necessary. Buoyancy displacer level indicators and magnetic types having moving parts and are undesirable where they are inaccessible for maintenance. The magnetic types would be difficult to arrange for remote, continuous indication. Liquid conduction probes and ultrasonic probes are limited to on-off type readings. The capacitance-type level indicator, made by Robertshaw-Fulton, and others, will provide remote, continuous indication and appears most suitable for this service. Although some of the fluids being considered, pentane, for instance, have very low dielectric constants, Robertshaw assures us that the instrument can operate with these values.

This instrument, as presently manufactured, has a bridge detector and oscillator circuit which would have to be located in the inaccessible area. This unit contains an electron tube and its reliability for this service is questionable. However, a revised model is being developed using solid state components which should be satisfactory. We are presently investigating the guaranteed attention-free operating life of this unit. The remaining components of this instrument can be remotely located so that accessibility is no problem.

A single remote indicator, with a selector switch to select the point being read and simultaneously light an indicating light on a panel diagram showing the point, is presently planned. This is considered to be the simplest system to read and minimizes the chance of error in reading. The system would have five reading points, one at each corner of the reactor building and one, for reference, at a point on one of the secondary buildings.

As an operating convenience and to avoid spillage when filling the system, use of a supply tank and one or more pumps is being considered so that fluid could be added to, or removed from, the system without handling. By using a small displacement pump, such as a metering type plunger pump, this would allow precise adjustment of the fluid to a reference level before readings.

Should radiation damage to the fluid be a matter of concern, this system would also allow the primary building system to be kept empty, and to be filled only when a reading was to be taken.

For detecting uneven settlement of individual primary building foundations, only the angle must be determined. The jack system is planned to tolerate up to 5 degrees misalignment. Therefore, a pendulum type instrument is practical. It is planned only to indicate whether the 5 degree limit has been reached.

Since the available standard instruments of this type are apparently all designed for use in servosystems in moving vehicles and therefore incorporate costly features not necessary for this application, we have designed a pendulum type instrument which will close a contact when the 5-degree limit has been reached in any direction. The contact would light an indicating light, probably through a sensitive relay, in order to reduce the current through the contacts.

3.1.3 Jacking

For the secondary buildings where the foundations are accessible, a system using ordinary building jacks and foundation shims is adequate and nothing more complicated is justified.

For the remote jacking of the primary building, the jacking mechanism must be simple, reliable, and self locking. These requirements eliminate hydraulic or air-jacking systems, because they depend on maintaining fluid pressure to support the load. The Texas Tower jacking system was investigated but it also depends on maintaining fluid pressure.

The above requirements are met by screw jacks. One possibility is the bench stand used for operation of sluice gates, built by Rodney Hunt Machine Company, and others. These are available as catalog items up to 60-ton capacity, and as semi-custom designs in larger capacities. They are suitable for power operation with various types of motors; for example, we customarily install them to be driven by portable air motors. However, for remote electric operation, it would be necessary to provide additional gear reduction in the motor to obtain a suitable operating speed and to provide limit switches to prevent overtravel. For these reasons, Rodney Hunt Company feels that a valve operator specifically designed for motor operation would be more suitable than the bench stand.

Electric motor operation appears most desirable. Mechanical linkage would obviously be most reliable,but is impractical due to the plant layout. Air motors are subject to freezing of the air lines, making them unreliable in this service. Hydraulic motors would be practical if a suitable hydraulic fluid can be found. Several manufacturers have been asked for opinions on this, but have not replied as yet. However, a hydraulic system would be expensive and it is doubtful that it would be any more reliable than electric motors.

For electric motor operation, a suitable unit is the Limitorque SMA-4X valve operator, manufactured by Philadelphia Gear Works, which will provide 200,000 lbs thrust with a travel rate of 1/4-in per minute. These units are designed to operate large gate valves having a threaded stem which is raised or lowered by operation of a nut within the operator. For this application, the operator would be mounted on the foundation and the valve stem would be replaced by a jack screw which would support the building.

These operators are supplied with geared limit switches which can be set to limit the total travel, and torque switches which can be used as a back-up protection to cut the power if the jack is overloaded. These operators can be supplied with Beacon 325 lubricant, which is recommended for service at -65°F and has performed satisfactorily at -100°F, and Dow Corning 33 silicone grease, with a usable range to -100°F or below, is also being investigated.

With a five-foot range on the jack, we prefer to hang the building load from the jack. This places the screw in tension and avoids subjecting it to column action.

Because of the possibility of uneven settlement, it is necessary to provide flexibility so that tilting of the support will not bend the jack screw. Various means of accomplishing this have been considered, including cable snubbers to transfer load to the high side of the foundation, and a system using a drum hoist and cable support in place of the screw jack. While both are feasible, the first suffers from complexity and the second from instability.

The solution which is, at present, most attractive is to mount the jack on a spherical Lubrite bearing with a system of guides, also with Lubrite bearings to hold the jack in adjustment.

Lubrite, a product of Merriman Brothers Company of Boston, is extensively used in bridge construction for machinery bases and for other high-pressure bearing applications. It consists of a bronze bearing surface containing holes into which lubricant is forced at high pressure. While performance tests at -110^{o}F have not been conducted, it is in use successfully in Alaska, and its characteristics are such that low temperature operation is expected to offer no difficulty.

It is proposed to operate the motors by momentary pushbuttons, which must be held continuously while operating. A single set of pushbuttons would be used, with a selector switch to connect the buttons to any one jack and, at the same time, indicate on the panel diagram which jack was operable. This would compel the operator to make a jack selection before operating and lessen the chance of operating the wrong jack. These, together with the slow operating speed of 1/4-in. per minute, should avoid misoperation. As an additional safeguard, the system could be interlocked. Probably the best way to accomplish this would be with a "supervisor's key" on the selector switch, thus insuring that a qualified person is always aware of operation.

3.2 Building Superstructure

3.2.1 Purpose and Scope

This study was made to develop concepts and evaluations which will, in final design, aid to producing building superstructures best suited to house the components of Nuclear Power Plant PL-3 as installed in snow tunnels at Byrd Station on the continent of Antarctica.

Three major tasks were performed in arriving at concepts to be incorporated in the final superstructure design.

1. Data Collection

   A survey was made of all sources of information which were known or thought to be of value. The objective was to benefit from the experiences of others in this type of work; to obtain cost, performance, and availability data on various possible construction materials, and to solicit new ideas which might be used. A secondary objective was to develop a list of firms that might desire to bid on the final design.

2. Data Evaluation

   Conditions to be satisfied by the building superstructures were studied and, in the light of data collected, a basis for final design was established.

3. Analysis of Building Components

All components of the superstructures were studied and compared. Definite recommendations were made, where possible, and later evaluations were indicated for components where the selection will depend on final design details or on bid prices.

3.2.2 Data Collection

Three methods of attacking the data collection phase of the work were used: research, personal contact and solicitation by mail.

Research consisted of a review of all available published materials and drawings believed to be pertinent to the subject.

Personal visits were made to the following governmental agencies:

1. U. S. Navy, Department of Yards and Docks, Arlington, Virginia.
2. U. S. Army, Engineer Research and Development Laboratories, Fort Belvoir, Virginia.
3. U. S. Army, Polar Research and Development Center, Fort Belvoir, Virginia.
4. Cold Regions Research Laboratories, Hanover, New Hampshire.

At each of these installations, conferences were held with individuals who had first-hand and up-to-date knowledge of the problems involved in the type of construction contemplated. Considerable excellent data and advice were received. Since such information is as authoritative as may be obtained, acceptance of designs based thereon should be expedited.

In addition, industrial firms and trade associations were canvassed for data and ideas. This was done by mail. A document entitled "Project PL-3 - Building Study" was prepared, describing the conditions and considerations governing the PL-3 building installation and requesting any information or suggestions which might be helpful. This was mailed to over sixty organizations. Included in this number, were firms and agencies thought capable of supplying information in the following categories: prefabricated, panelized buildings of wood, steel and plastics, insulation of various types, gasket materials and insulated doors.

The results of this solicitation were extremely helpful. Many answers were received and, although a few of these indicated that they could not be of help, the majority sent valuable information and suggestions. In addition to written replies, several firms sent representatives to make personal contacts. In general, it is believed that the sampling was large enough to obtain a good knowledge of materials to be considered, and information was also gathered regarding the capabilities of various potential vendors.

3.2.3 Data Evaluation

Based on the requirements for the project, as contained in "Technical Provisions, Portable Nuclear Power Plant, Byrd Station, Antarctica (PL-3)" of the New York Operations Office of the U. S. Atomic Energy Commission and data obtained as described above, various factors in regard to the project were studied. The objective was to evaluate the factors to obtain knowledge of their relative importance. Although the development of such "yardsticks" is an integral part of every building design, the unique conditions here imposed make such work of more than ordinary importance. The following paragraphs discuss these factors and the conclusions reached:

3.2.3.1 Design Loadings

Since the buildings are in snow tunnels, they will be protected from the wind and snow loads normally associated with buildings above ground. The only external loads to which they will be subjected will probably be the weight of a man on the roof and possibly a loading due to differential air pressure caused by tunnel or building ventilation systems. This differential pressure cannot amount to much more than 1" of water or about 5 psf.

Since the building shells will also support a certain amount of heating, ventilating, and lighting equipment, a light loading on the ceiling should be adequate for the bulk of the area. Any heavier loading to account for fan units or other equipment would appear to unduly penalize the over-all design.

In addition, some measure of lateral resistance should be designed into the structure. Theoretically, a structure designed only for vertical or balanced horizontal loads could fail as soon as any unbalanced load were applied. The structure must therefore be designed to provide assurance of stability against accidental lateral forces such as those produced by eccentric connections, temperature differentials or the leaning of heavy items against the wall. The only force of nature that might act in a lateral direction inside the tunnels would be seismic. The maximum force normally considered in this repsect is about 0.1 times the weight of the components in areas of medium earthquake intensity. With the light weight of the structures considered, this would amount to a very small loading. However, the Pacific Coast Uniform Building Code uses a minimum of 5 psf unbalanced lateral loading for bearing walls. It is recommended that an unbalanced 5 psf loading be applied to PL-3 buildings as a lateral load to compensate for accidental lateral forces and to provide reasonable lateral rigidity to the buildings.

The above-described loadings are summarized on the sheet titled, "Design Criteria" (see Fig. V-3), and are to be applied to all building shells; however, it should not be construed that such loadings are the maximum to be encountered. Heavier items to be supported by the superstructure shall receive special consideration. Structural components shall be designed for the dead loads and all reasonably possible combinations of live and equipment loads which will most severely load the member, or portion thereof, under consideration.

Crane loadings for the reactor building crane shall be in accordance with the current AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings.

Wind loadings for items protruding above the snow surface will be taken at 30 psf of projected area.

3.2.3.2 Structural Design

Allowable stresses for various materials of construction shall be as recommended by the many applicable recognized authorities.

Provided the characteristics of the materials permit, allowable stresses for conditions of loading in which differential air pressure loadings or the 5 psf lateral loading are used may be increased one-third over the allowable stresses otherwise permitted for dead and live loadings.

Deflections of beams or panels acting as beams shall be limited to 1/240 of the span and horizontal deflection of structures shall be limited to 1/200 of the height.

Design procedures shall be in accordance with recommendations of recognized authorities for the material or type of construction used.

Reliance on fixity at floor level to assist in the stability of the superstructure should be avoided. If used, details shall be so designed and computations submitted to ensure that such fixity shall be developed and that additional erection time will be minimized.

3.2.3.3 Equipment Handling (Maintenance and Repair)

Except for the metal-framed buildings (i.e., reactor and cooler buildings), it does not appear warranted to design the building superstructures to support monorails, bridge cranes or lifting lugs capable of supporting the heavy items of equipment which must be removed at more or less infrequent intervals for maintenance and repair. Longitudinal bridge cranes or monorails provided to handle such items would require a complete framing system which, in addition to the extra cost involved, would increase space requirements, transportation problems, and erection requirements. Fixed transverse monorails or lifting lugs would require less framing but the same objections would ensure. The use of a light, portable A-frame supported monorail capable of being erected and moved to the location needed, and disassembled after use, is recommended. On this basis, and except for the special framed buildings, such loads need not be considered in the superstructure design.

3.2.3.4 Movability

The design conditions state that the plant shall be capable of being moved to another location. Because of this, details should provide for the use of suitable bolts or other types of fasteners which can be removed and reused. The use of nails, welding, or rivets should be avoided for all field connections.

3.2.3.5 Snow Tunnel Excavation

The construction of the snow tunnels in which the plant will be installed is an integral part of the work. In order to compare different constructions which might vary in dimension and, therefore, require greater or lesser amounts of tunnel building, some yardsticks were necessary. Without a quantitative knowledge of the effort required to construct the tunnels, such studies would be indefinite.

Figures are available from a portion of the work at Camp Century. This work was expressed in equipment hours and manhours. For the purposes of comparison, dollar figures were more or less arbitrarily estimated and costs per cubic yard computed. The unit costs estimated were 93¢ per cubic yard for the deep tunnels and 62¢ per cubic yard for the normal depth tunnels. It appears that the entire plant area could be lowered one foot for a cost of about $400.

Although such figures should be applied to comparisons involving major changes in building dimensions or layout, the unit costs are so small as to have a negligible effect in minor dimensional changes. For example, excavation costs need not be considered in comparing wall thickness costs.

3.2.3.6 Fire Resistance

Resistance to fire, as given hour ratings in most building codes, it not applicable to the PL-3 construction. Such ratings are concerned with confining the fire to a particular area. With the light wall construction contemplated, such ratings, if applicable, would be very low. For example, untreated stressed-skin wood panels have been rated at 20 minutes. There is no reason to believe that metal sliding types of panels would have a noticeably better rating, because they are of light construction and would be framed with wood for cold-region construction. Furthermore, such confinement of fire insofar as exterior walls and roof are concerned would not result in spread of fire to other structures.

Fire is, of course, a considerable hazard in these structures and should be guarded against. A fire-protection system will be provided. From the building materials' standpoint, the two principal factors are combustibility and the ability to retain structural strength with exposure to heat. The materials normally used for insulated panel construction are not ideal in regard to these properties.

Only metal, of the materials considered suitable in other respects, is incombustible. The other materials, i.e., wood, plywood, molded Fiberglass,

Fiberglass batts and the insulating foams, are combustible to a greater or lesser degree. Most of these materials may be treated to render them less combustible.

In regard to ability to maintain its strength under exposure to heat, wood would probably rate the highest of the materials listed. Wood will retain a considerable portion of its strength until actually consumed. Steel, for example, loses strength very rapidly above temperatures in excess of 800°F.

Wood is the principal cold regions' construction material and is utilized in all of the types of panels considered. In metal siding type panels, it is used as framing largely because of its insulating properties. Although metal siding panels, using transite studs, have been fabricated, there appears to be little enthusiasm for this construction and its cost, weight, and high conductivity make it undesirable for the PL-3 Project. Wood may be made virtually noncombustible with pressure impregnation treatment; however, there is some question about the deleterious effect that such impregnations would have on the glue bond in stressed-skin panel construction. At the time of this writing, this question had not been resolved.

Various types of fire-resistant finishes have been used with wood and considerable success has been reported with intumescent paints, which foam when exposed to heat, to act as an insulator to protect the wood. Similarly finishes and/or fabrication procedures have been developed for Fiberglass laminates, which have fire-resistant properties.

One important consideration relative to the use of plywood faces is that, being an insulator, plywood tends to protect the insulation behind to a better extent than would metal siding.

Of particular interest in connection with flammability is the possible emission of toxic gases from both polyurethane and polystyrene foams. In this regard, special inquiry was made to manufacturers of both of these products. The answers in both cases were similar; that is, the toxic gas given off was the same with these products as with other organic compounds; namely, carbon monoxide.

Without attempting to minimize the importance of resistance to fire, it should be remembered that an adequate fire-protection system is a part of the installation and that the hazards are not extreme. If the optimum construction involves combustible materials, they should be treated to be fire resistant. It is not recommended that complete incombustibility be required at the expense of insulation or structural considerations.

3.2.3.7 Wall and Roof Penetrations

Locations for the passage of piping, ducts or electric lines through the shells of the buildings must be designed with considerable care to minimize heat losses. The major concern is to keep moisture vapor out of the insulation and to avoid "holidays" in the insulation which will produce cold spots with resultant icing.

Pipes subject to freezing must be enclosed in an insulated encasement. Since such enclosures normally run from one building to another, they may be considered as extensions to the building, and vapor seals and insulation may be virtually continuous from the building through the enclosure. Other than consideration necessary to provide for expansion and settlement, such penetrations should offer little problem. It is recommended that particular effort be made to utilize such enclosures to the maximum extent for all services. In regard to the junction of such enclosures with the buildings, the principal problem will be due to the possibility of expansion and differential settlement. In order to avoid damage to the building wall, it might be appropriate to rigidly attach the first section (4 ft or so) to the building. Expansion joints could then be installed in the small enclosure as desired. It may be desirable to make such pipe enclosures large enough to permit personnel to walk through them for building and piping maintenance.

In locations other than as described above, penetrations might be flanged and gasketed to the vapor barrier. Where penetrations are subject to movement, they should be equipped with expansion joints on either side of the wall, if possible. In cases where the penetrations cannot be tightly fitted the vapor barrier should be carried through from the inside face of the wall to its outer face to protect contiguous insulation from moisture saturation.

Because of their high thermal conductivity, metal penetrations should be avoided where it is practical to do so. In some cases, wood or plastic having a lower conductivity may be effectively substituted. If it is necessary to extend metal through the wall, the possibility of wrapping with insulation for a distance outside the wall to avoid interior frost spots should be considered.

Considerable care and workmanship is desirable at penetrations. However, it is not particularly difficult to perform this work under normal fabricating shop conditions. The proper performance of such work in the field will be difficult. For this reason, all penetrations should be carefully planned and located prior to the fabrication of the building panels.

3.2.3.8 Materials

The following structural materials are considered suitable for the environmental conditions:

Wood
Plywood
T-1 Steel and Nickel Alloy Steels
Molded Fiberglass
Aluminum
Polystyrene Foam)
Polyurethane Foam) as structural elements

Materials other than these, if suggested in bid proposals, should be accompanied by definite proof of satisfactory performance at the low temperatures contemplated.

The foam materials listed above have been used as core materials in sandwich panels. They are, however, subject to creep and should not be depended upon for panels subject to long term or permanent stress. Such materials in supported panels subject only to occasional loads, such as the differential air pressures considered, should be satisfactory structurally.

The use of ordinary carbon structural steels (A7 and A36) is not considered suitable because of their brittle characteristics at low temperatures.

3.2.3.9 Fabrication

Cost and quality are the two major factors to be considered in discussing fabrication.

The designer will, of course, realize that easier fabrication will result in lower costs and govern his work accordingly. The fabricator, however, has a much more intimate knowledge of the costs involved. It is recommended that the fabricator be urged to submit, as part of his proposal, any suggestions or designs which would reduce the cost of the work or make it more suitable.

The inaccessibility of the construction site means that no compromise with the quality of the work can be made. Construction in Antarctica virtually prohibits the replacement of defective items. Needed replacements could delay the project for an entire year.

Prefabricated building units, being generally of enclosed construction, cannot be fully inspected after completion. Past experience with such work has revealed that deficiencies in workmanship usually occur in locations not visible in the finished product. Poorly fitted joints and improperly installed insulation are the most common defects. The only effective means of quality control is inspection by a qualified individual throughout all phases of the work. The presence of such a person in the fabrication shop is recommended.

As with any type of prefabricated construction, the prime requisite is fit. Even minor field revision at the remote site will be difficult because of the working conditions and inexperience of the erection personnel. While fabrication in suitable jigs under adequate inspection may insure uniformity of product and workmanship, the only sure way to insure proper fit and detailing is by pre-erection. It is recommended that all buildings be pre-erected and piece marked in the fabricator's plant. In this connection, it may be desirable to mount mechanical and electrical equipment supports on the building components. Such work might save considerable time in the field.

3.2.3.10 Packaging

At various stages enroute to the construction site, components will be freighted by truck, rail, ship and air, and will be subject to the handling and storage associated with each. In addition, they may be stored for greater or lesser periods of time in weather conditions ranging from tropical to Antarctic. Proper packaging must be provided to give reasonable protection to the items involved. Because of the relatively low cost, on a cubage basis, of the materials of the superstructure, crating costs for such items can be of considerable significance. For example, packaging costs for components of materials and configuration which need only be banded, will not be the same as for those which require weather-proofed closed crating. Component design should recognize this cost and bid comparison should be based on costs of materials adequately crated.

3.2.3.11 Transportability

The cost of freighting the superstructure components to the site will amount to an appreciable portion of the cost and should be considered in design. The fact that transportation (from the port of embarkation) will be by the Government does not eliminate consideration of transportation expense from relative evaluations. However, since military carriers will be used over difficult and hazardous routes for which freight rates are not established, the process of evaluation is somewhat conjectural. As a preliminary approach to this problem, established freight rates for commercial carriers for similar distances may be used.

For ship cargo transport, rates for an equivalent distance are approximately $50.00 for 2000 pounds or measurement ton (40 CF) whichever is the greater. Since the density of the superstructure components will amount to about 10 lb per cu ft, the cubage would govern and would cost $1.25 per cubic foot. For air freight in the continental United States, rates for 800 miles are approximately $300 per ton. At 10 lb per cu ft, this would amount to about $1.50 per cubic foot. The sum of these figures is $3.75 per cubic foot, which would be 31¢ per square foot for each inch thickness of wall or roof.

A recent publication of the National Research Council of Canada, indicated costs of $1,000 per ton for air freight in northern Canada. If this price was applicable, the over-all cost would amount to $6.25 per cubic foot or to 52¢ per square foot for each inch of thickness.

For preliminary evaluation purposes, the assumption was made that freight costs from the port of embarkation to the construction site would amount to about $4.50 per cubic foot or 38¢ per board foot.

3.2.3.12 Erection

The short (60 days at Pole Station) construction season will allow a very short time for the erection of the building superstructures considering allowances for tunnel construction and foundation installation. Because of this, components should be designed to be erected in the shortest possible time. Factors influencing the speed of erection are number of pieces, size of pieces, ease of erection and ease of making connections.

Designs requiring a large number of small pieces are not desirable, not only from the standpoint of additional time of assembly, but also because small parts are subject to being lost or mislaid.

Insofar as major components are concerned, size, number of pieces, and ease of erection are interrelated. Items that are so large or heavy as to require the use of mechanical equipment for transporting and erecting should be avoided because of the limited space within the tunnels. The gain made in the erection of larger components would be more than offset by the difficulty in maintaining working space for such equipment. If the use of equipment is eliminated, the size of components must be such that they can be carried and put in place by the erection personnel. This indicates a practical maximum weight of about 250 lb for two men, or about 400 lb for four men to handle. Units markedly different in weight from these ranges will result in slower erection times. Very small items will require too much time consumed in making connections. Very heavy items, if hand-carried, will require a large number of men with resulting loss of efficiency.

The work of making up the panel joints with the light panelized construction contemplated will consume a major part of the erection time. If difficulties in fitting panels arise, the entire erection crew might be held up. Care should be exercised in panel joint detailing to avoid close tolerances which might make field fits difficult.

Metal building frames will probably be required for the reactor building. For buildings of such relatively small size, it does not appear feasible to provide motorized hoisting equipment for erection. Steel design should contemplate that erection will be done with hand-operated tackle and rigging. In this regard, it should be noted that such items as chain hoists will be provided as part of the plant maintenance equipment and that such equipment should be utilized to the maximum extent for erection purposes to avoid expense and extra shipping weight.

Except for plant equipment, possibly the largest single weight to be lifted in place will be the bridge for the reactor building crane. Frame design should provide for a means of hoisting this in place. A roof beam with a lifting eye strong enough to allow this equipment to be lifted by a chain hoist is recommended. The chain hoist would become part of the maintenance equipment but should be sized to perform this erection function.

3.2.3.13 Insulation

The main function of the walls and roof of the buildings, from the insulation standpoint, is to bar the passage of heat from the inside of the building to the snow tunnels. The tunnels provide the necessary protection from wind and snow. Therefore it may be considered that the principal function of the building shell is to provide support for the insulation. With this thought in mind, it would defeat the purpose of the design to compromise the insulation in favor of the building panel thickness.

The aim of the design is to achieve the best performance consistent with the lowest cost.

Insulations may be classified as mass type or reflective type. The mass type is the common one and is composed of various bulk materials either loose or in boards or batts. The reflective insulation consists of sheets of bright metal or foil placed perpendicular to the heat flow and separated by air spaces.

The mass types of insulation are materials of low conductivity and are of such bulk and texture that convection currents are reduced. These insulations receive radiant energy into their interstices and rely on their low conductivity to slow down the passage of heat.

The reflective types of insulation reflect the bulk of the radiant heat and rely on air spaces to reduce conduction. Convection is controlled by limiting the size of the air spaces.

Moisture increases the thermal conductivity of insulation. There appears to be little information, however, on the amount of such increase. It is generally agreed that saturated insulations are useless.

Moisture can get into insulation in various ways. It may be installed wet. The insulation itself may have a natural moisture content which would remain unless dried out. It may be caused by leakage during open storage. It may be carried in by moist air leakage through the wall. And lastly it may be caused by vapor pressure differential.

Vapor pressure differential is the most serious source of moisture infiltration for the PL-3 buildings since it will be working for the entire life of the structure. This differential is primarily due to the difference in inside-outside temperatures and humidities. There is a continuous drive of vapor from the warm, moist inner air to the cold outer air. With a 70-degree inside temperature at 35 percent humidity, and a minus 20-degree outside temperature at 2 percent humidity, a pressure of approximately 20 psf is exerted to drive water vapor through the walls. Even in impermeable insulations, joints and cracks afford access for vapor travel.

In a more temperature climate, insulation may have some chance of drying out during periods of above-freezing temperatures if properly ventilated and thus enjoy some measure of rejuvenation. This does not appear likely in the continuously sub-freezing temperatures of the snow tunnels.

If moisture can be prevented from entering the wall, the difficulties described above can be eliminated. In order to approach this, it is recommended that considerable care be exercised during the fabrication and shipping phases to ensure that the insulation arrives at the site in a dry condition. Of more importance, it is further recommended that a vapor barrier be incorporated into the building design. The vapor barrier should aim at completely sealing the air and vapor in the interior of the building from the insultation, and should be at least equal in impermeability to the standards suggested in Publication 759 of the National Academy of Sciences - National Research Council.

Moisture affects various insulations in different ways.

1. Permeable, hygroscopic insulations, such as corkboard, are susceptible to thermal and physical deterioration due to moisture. Hygroscopic materials absorb moisture into their cell structure where it increases thermal conductivity, thereby reducing its insulation capabilities. If it is in the freezing zone, as it will be in this project, the retained moisture may turn to ice and so cause physical damage.

2. Permeable, nonhygroscopic insulations, such as Fiberglass, have not suffered serious physical damage due to moisture since moisture is not absorbed into the cell structure. Ice may form in the insulation, but will not normally exert excessive pressures. Moisture will increase the thermal conductivity of these materials.

3. Impermeable, nonhygroscopic insulations, such as cellular glass, are little affected by moisture. Moisture will not enter the insulation proper; however, ice formation has been observed in joints between layers and on the surface of the insulation.

4. Nonhygroscopic insulations of foamed plastic or elastomeric materials, such as polystyrene and polyurethane, may or may not be completely impermeable. It has been stated that they can be made so; however, those considered were permeable to a small degree. If moisture does permeate the insulation, its thermal efficiency will be reduced. Deterioration of the insulation due to moisture is not believed to occur. In the event of ice formation, it is doubtful that serious damage would result since the compressible nature of these materials would not be conducive to the build-up of excessive pressures.

5. Reflective insulations are usually made of aluminum or stainless steel; moisture does not normally affect these metals. These materials combine their high reflectivity with air spaces. Condensation and ice can form in these spaces. Tests have indicated that moisture condensation or ice formation occur on only one surface of an enclosed reflective air space, still leaving one effective surface. It has been found that if the ice formation reduces the air space to less than one-half inch in walls, or one and five-eighths inches in horizontal spaces with downward heat flow, that there is significant increase in heat conduction.

The foregoing emphasizes the importance of a vapor barrier. Experience has proven, however, that some moisture leaks in with even the most carefully constructed barriers. Because of this, and because of the continuously freezing conditions at PL-3, it appears that the more impermeable insulations on the reflective type would provide the best performance.

In regard to the most economical insulation, the considerations involved here are somewhat different than is normally encountered. The usual procedure in an evaluation of insulations is to make comparisons based on the fuel costs to heat the structure insulated. In this project, however, we are housing power plant equipment which will have certain heat losses utilized for building heating. In this insulation study it would be incorrect to apply heating fuel costs to the relative evaluations.

The tunnel temperatures are limited to a 10^{O}F rise and tunnel cooling must be provided. In order to cool the tunnels, sufficient cold air must be pumped. The cost of pumping is proportional to the heat leakage through the building panels and should be considered in evaluating insulation costs.

A preliminary insulation study was made which was aimed at determining the economics of various amounts and kinds of insulation. The procedure used was to compare the total annual costs of various thicknesses of building panels. The annual cost was taken as the sum of the fan power cost and the amortized wall panel costs. The power cost was based on Camp Century experience and was the cost of the fuel required to produce the power for the tunnel cooling blowers. The amortized wall panel costs reflected freight expense and wall panel costs as affected by various thicknesses of insulation. Comparisons were thus made using a low cost insulation with medium conductivity value (Fiberglass, K = .27, cost $.08 bfm), and a high cost, high performance insulation (urethane, K = .16, cost $.20 bfm).

The study yielded two preliminary conclusions: first the high performance insulation was more economical despite its higher price and second, the optimum thickness of panel was slightly more than four inches (see Fig. V-4).

3.2.4 Analysis of Building Components

In order to reduce the foregoing, and other considerations to a concept of the finished structure, the major building components were studied item by item. Six components were so considered: framing, wall and roof panels, vapor barriers, panel joints, exterior doors, and insulation. All reasonable possibilities for each component were compared and evaluated.

3.3 Preliminary Design

A rough preliminary design was made for the purpose of determining the approximate panel thicknesses required, from a structural standpoint. Although

CHAPTER II
WASTE HEAT REJECTION SYSTEM (SUBTASK 4.2.3.1)

C. J. Thurnau

1.0 STATEMENT AND DISCUSSION OF TASK

Waste heat from the plant must be dissipated ultimately to the air. About 95 percent of the heat to be removed is from the latent heat of vaporization of the turbine exhaust steam. The remaining 5 percent of waste heat is from cooling devices such as shield tanks, spent fuel tank and lubr oil coolers. About 10 to 15 percent of the gross electrical output must be used to power the fans and pumps of the waste heat removal apparatus.

2.0 OBJECTIVES OF TASK

The main objective of the task was to select the optimum heat rejection system for PL-3 nuclear power plant. A parallel effort with this task was development work concerning the use of manufacturers' heat transfer surfaces that are new or still under development for a single skid design. The use of these new surfaces was to produce increased heat transfer efficiency with a resultant decrease in the number of required modules.

3.0 DESCRIPTION OF WORK

To select the optimum heat rejection system for PL-3, evaluations of various direct and indirect cycle heat rejection systems were made, descriptions of the systems are given in APAE Memo-308*.

In addition to evaluation work on heat rejection systems, analysis was made of the various systems, based on manufacturer's standard surfaces, and including heat transfer rate, fluid pressure drop, air pressure drop, heat rejected, air velocity, fluid velocity and freeze-up problems. Developed system parameters were submitted to manufacturers along with requests for proposals based on multiple skid and single skid heat rejection systems.

---

* Thurnau, C. J., "Evaluation of Heat Rejection Systems for PL-3," Alco Products, Inc., APAE Memo-308, March, 1962.

4.0 CONCLUSIONS

APAE Memo-308 recommends use of an indirect cycle glycol coupled condenser and air blast cooler for the PL-3 heat rejection system. This system was chosen because of its inherent reliability and freedom from freeze-up problems.

At this time, negative answers have been received concerning the single skid design and positive answers concerning the multiple skid design. The actual proposed units are expected to be received shortly and will contain firm equipment and price data.

PACKAGING STUDIES

CHAPTER III
PACKAGING STUDIES (SUBTASK 4.2.1.2)

J. M. Hancock

1.0 STATEMENT & DISCUSSION OF TASK

To assure maximum module protection within the limits of weight, cost and environmental conditions, a study of packaging techniques was undertaken. The study centered around packaging used for existing portable nuclear power plants, present industrial packaging techniques and present military packaging techniques.

2.0 OBJECTIVES OF TASK

The objectives of this task were to minimize weight of package protective coverings so that maximum percentage of the permissible module weights will be made up of functional plant equipment and components, to minimize packaging and unpacking time.

1. Study packaging techniques employed on existing plants, investigate possible application of other packaging techniques presently being employed in other areas of the armed services or industry (including "mothball" approach) and recommend a method for module packaging for PL-3.

2. Recommend tests, if necessary, and implement a test program to determine suitability of materials, etc., for this application (i.e., PL-3 Project).

3. Special consideration is to be given to weight of packaging, supporting structure required (if any), and ease of installation and removal.

4. Also investigate application of quick disconnect fittings or connectors for piping and wiring.

2.1 Areas of Investigation

Several areas of investigation were undertaken to carry out these objectives, including assembly of environmental criteria, study of previous packaging, a manufacturer's literature search for new materials, and evaluation of provisional packaging designs. Study has been completed in the areas of environmental criteria, review of previous packaging and literature searching. Final evaluations are tentative pending the outcome of environmental testing planned for Phase II.

3.0 DESCRIPTION OF WORK

3.1 ENVIRONMENTAL CRITERIA

Several modes of transportation will be used to move PL-3 modules to their destination. The initial mode of transportation will be by rail to the port of embarkation. During this part of the trip, packaging materials would be subjected to wind loading, storms, mechanical shock, abrasion, and tearing or puncturing. Following this, the plant will be transported by cargo ship to McMurdo Sound, Antarctica. As some modules may be loaded on the ship's deck, it is necessary for the packaging to withstand salt spray, spilled gasoline or oil, weak acids or alkalis, as well as of the physical hazards of rail shipment. In tropical areas, protection must be afforded against high temperature and humidity; in polar regions, low temperature protection is vital. In addition, snow, ice, freezing rain and high winds will impose further stress on packaging.

TABLE III-1
SUMMARY OF ENVIRONMENTAL CONDITIONS EXPECTED DURING TRANSPORTATION OF PL-3 MODULES

Factor	Maximum Value	Minimum Value
Temperature	125°F	-90°F
Humidity	100% Rel.	0% Rel.
Wind	115 Mph	0 Mph
Wind Loading	52#/Ft^2 @-59°F	0#/Ft^2
Precipitation Load	32" Snow	

Note: Average sustained wind velocities to be encountered are:

12 - 14 Mph at McMurdo Sound
12 - 17 Mph at Byrd Station
12 - 50 Mph during rail or sea transport

For modules such as the switchgear and control skid, protection from dampness is a factor to be considered. Materials used in the construction of switchgear and instrumentation are generally more sensitive to corrosion and corrosive atmospheres than other materials used in plant construction. Because of their complex construction, direct protection of critical surfaces is impractical; a vapor-proof container exclosing dessicants provides a more effective, readily applicable solution. Dampness and corrosive atmospheres can arise from numerous sources, the most common of which are normal atmospheric humidity, rain or salt water spray and condensation due to temperature change.

TABLE III-2
COMPARISON OF PACKAGING FOR EXISTING PLANTS

Item of Comparison	Martin Co. PM-1 & PM-3A	Combustion Engineering PL-2	Alco Products PM-2A
1. Qualitative Description Packaging	Prefabricated Truss-type panels constructed of plywood, squarc steel tubing, angle iron & etc. Some panels were used in building construction at the plant site. Other items (primary components & etc.) were shipped with no Covering or with only a paper wrap.	Packaging used timber skids under large components. Components wcrc protcctcd by a cover wrap (canvas or "Herculite") over a light pipe frame. Some secondary system modules (feed and condensate skid shipping package, for instance) used truss-type panels. Apparently these panels were not used in construction at the plant site.	Packaging consisted of a cover wrap of "Hcrculite" over a light pipe frame, Miscellaneous interconnecting piping and wiring was shipped in specially constructed wooden boxes.
2. Estimated Weight of Packaging	For modules using the truss-type panel covering, weight is estimated as 7000# to 8000# per module (8'6" x 8'6" x 30'0"). This represents about 26% of total module weight for a 30,000# module.	Available information indicates that packaging for several skids represents 5.1% to 14.3% of total skid weight. For a 30,000# module, this represents 1530# to 4290#.	Total plant shipping weight was 903,930# compared to 834,230# total erected weight. From this, it is seen that packaging is 7.7% of total plant shipping weight. Individual module packaging is estimated at 700# to 1000# (8'6" x 8'6" x 30'0" Module).
3. Estimated Time of Application and/or removal	3 to 4 man-days to construct panels and 1 to 1.5 man-days to apply panels to a module. Handling difficulties may be encountered during removal due to the weight and size of the panels.	1 to 1.5 man days per module for covering all modules. An additional 3 to 4 man days to construct truss-type panels would be required per panel covered module. Panels may present a handling problem.	2 to 3.5 man-days per module would be required to install this type of packaging. Removal would be relatively easy and would not require any special tools or skills.
4. Estimated Cost of Packaging	Greater than $500.00 per module.	a. $200.00 to $300.00 for modules using timber skids and a cover wrap. b. Greater than $500.00 per module for panel covered modules.	$325.00 to $400.00 per module.
5. Estimated Degree of Protection	Degree of Protection offered by panel covered skids is very good. On other items (primary components and etc.) where only a paper wrap is used, there is some possibility of damage during handling.	Degree of Protection is generally satisfactory. Questions arise in regard to the strength of the cover wrap when it is subjected to low temperatures and high winds.	Degree of protection is generally satisfactory.
6. Suitability for PL-3 Advantages	a. Good Protection b. Panels may be used in building construction at the Plant site.	a. Weight of wrapped packages is low for the degree of protection given. b. Cost of wrapped packages is low for the degree of protection given.	a. Ease of installation and removal. b. Low cost in relation to the protection offered. c. Low weight in relation to the protection offered.
Disadvantages	a. Excessive weight b. Handling equipment required to apply or remove panels. c. High Cost d. Labor required to fabricate panels. e. Poor protection for some primary components.	a. Excessive weight of truss-type packaging. b. Truss-type panels were not used in construction. c. High cost of truss-type packaging. d. Handling equipment required for truss-like panels.	a. Strength of packaging materials may not be sufficient for the conditions expected.

Upon arrival at McMurdo Sound, the plant modules will be stored unprotected, except for their packaging, for a period of six months to one year. During this time, they will be subjected to low temperatures, high winds, abrasion and tearing, and snow loads up to 25 pounds per square foot. After this period of storage, the modules will be tranported by air to the installation site at Byrd Station. The probable threats to packaging during this phase of the trip are expected to be no more serious than those encountered during previous parts of the trip.

3.2 Previous Packaging Schemes

Packaging schemes and materials used for PL-1, PL-2, PM-1 and PM-2A and PM-3A were evaluated for applicability to PL-3 packaging requirements. Table III-2 gives results of this study and indicates pertinent characteristics of various package types.

3.3 Manufacturers' Literature Search

To obtain information on materials that might be applicable to packaging of PL-3 modules, manufacturers' literature was reviewed. Manufacturers were contacted to obtain specific data and recommendations for their materials. A partial list of the manufacturers from whom information was obtained includes:

Ace Plastic Company
Albano Honeycomb Division
Barco Manufacturing Company
Calumet and Hecla, Inc.
Dow Corning Corp.
Dresser Industries, Inc.
E. I. DuPont De Nemours and Company
The Duetsch Company
Hansen Manufacturing Company
Herculite Protective Fabrics, Inc.
Hexcel Products, Inc.
Koppers Company, Inc.
Met-L-Wood Corporation
Minnesota Mining and Manufacturing Company
North American Avaiation, Inc.
Permali, Inc.
Raybestos-Manhattan, Inc.
Reeves Brothers, Inc.
Southern Electric, Inc.
Spraylat Corporation
Weyerhauser Timber Company
Wheeling Corrugating Company

Data obtained from these companies have shown that many suitable materials are available for use in packaging.

3.4 Military Packaging

Military packaging techniques examined utilized complete coutour following materials, the covering compounds applied by spraying, brushing, flow-coating, or dipping. The compounds give satisfactory protection against most expected hazards. Special handling may be required in some cases because the materials are susceptible to abrasion damage from tie-down ropes. Coatings are generally applied in several layers; at the destination, the covering is stripped or peeled off. The coatings are soft and flexible over a normal range of temperatures (freezing to 125°F), but may be brittle and hard to peel at very low temperatures (below -50°F). Solvents are used to remove some of these compounds, but this type of removal is tedious and messy. These compounds provide absolute vapor protection as long as the integrity of the cover is maintained; however, their lack of reusability makes them impractical for PL-3 application.

3.5 Proposed Package Designs

Initially, seven package designs were considered. They made use of soft, flexible materials over a light frame, stiff panels, and sprayed or flow-coated materials. Fig. III-1 illustrates some of the details associated with a package constructed of light flexible materials over a light frame. The frame may be constructed of 3/4-in. pipe or conduit, or from 1-in. x 1-in. x 1/4 in. aluminum "T" or channel. Flexible synthetic materials are made by several manufacturers, including Herculite Protective Fabrics, Minnesota Mining and Manufacturing Co., Reeves Brother, Inc. and E. I. DuPont de Nemours and Co. The various fabrics combine nylon or glass cloth with polyvinylchloride, neoprene, "Hypalon"* or one of several fluorocarbon resins to obtain strength, flexibility and water resistance.

Because of their varying composition, the fabrics have different physical characteristics. Generally, vinyl-coated nylon fabrics lose flexibility at temperatures above the PL-3 design minimum (-40°F as compared with -90°F). Varying the vinyl compound to attain low temperature flexibility sacrifices desirable high temperature characteristics. The material may lose abrasion resistance or become soft and tacky.

A fabric made of nylon cloth coated with Hypalon on one side and neoprene on the other maintains flexibility to temperatures as low as -50°F. Neoprene surfacing on both sides extends low temperature flexibility to -67°F.

* E. I. DuPont de Nemours and Co. registered TM

A Dupont fabric called Armalon, compounded of glass cloth and a fluorcarbon resin, maintains flexibility as low as -100°F. However, it lacks the strength of nylon fabrics and is also considerably more expensive.

Several types of stiff panel type materials were considered. These included commercial plywood, a kraft paper-fir veneer laminate, metal and veneer laminates, honeycomb metal, and fiber-glass panels. All of these materials have desirable characteristics. All will provide sufficient protection for the modules if properly applied. In applying panel-type materials, weight becomes a problem; the estimated material weights required for equivalent protection of an 8 ft x 8 ft x 30 ft module are given in Table 3.3.

TABLE III-3
ESTIMATED PACKAGE WEIGHTS IN POUNDS FOR PANEL MATERIALS

Commercial Plywood	2000
Paper-Veneer Laminate	1200
Metal-Veneer Laminate	2000
Honeycomb Metal	650
Fiberglass Panels	2400

Since weight is an important factor in packaging, plywood, metal-veneer laminates and fibreglass panels eliminate themselves from further consideration.

The basis of comparison for the two remaining panel materials is cost since the effect of temperature variation on these materials is negligible. Honeycomb metal panels have a high strength to weight ratio, but would be impractical for packaging because of their high cost. A paper-fir veneer laminate known as Plyvenner* provides desirable characteristics at low cost. It can be obtained with a resin-impregnated paper surface which gives almost complete vapor protection.

Panel materials require support of some sort, though not as extensive as required for the synthetic fabrics. Fig. III-2 shows some details associated with a package designed around panel materials. Simple mechanical fasteners should be used where possible. Compression-type seals are applicable where vapor sealing is required.

* Weyerhouser registered TM

Spray or flow coatings are available from several manufacturers. These materials were to be applied over wire screen or expanded metal grating tied to supports around the package. When it became obvious that the material would not fill the interstices, the idea of applying the material directly to skid-mounted components was considered. Because of the complexity of some skids, this idea was considered impractical. Compounds intended to be strippable under normal conditions would be difficult, if not impossible, to remove from complex shapes under adverse conditions. Preparation of components and surfaces would be a time-consuming process, because screw heads, joints and other complex shapes must be filled with caulking compound or covered with masking tape prior to applying the spray compound. At normal temperatures (32^{o}F to 125^{o}F), the compounds retain their integrity and physical characteristics and can be easily pulled from covered surfaces. In a Polar environment, these coatings would become brittle and virtually unstrippable.

The last factor considered for the various initial package designs is reusability. For maximum reusability, packaging material should be applied so that removal is non-destructive. To meet this criteria, panel-type covering, simple mechanical fasteners, compression seals, prefabricated packaging supports and interchangeable package assemblies represent optimum packaging materials. Storage facilities within the snow tunnels or in a separate building should be provided. Materials to be avoided are: sticky or gummy adhesives, materials that deteriorate with time, one-time packaging materials, non-standard packaging units and packaging materials that require special handling equipment, all of which may hinder reusability.

3.6 Selected Package Designs

Two package designs have been considered worthy of further investigation and evaluation. The first of the two packages (see Fig. 3.1) utilizes a soft, synthetic fabric covering over a light frame. Several fabrics with similar physical characteristics are available. The advantages which led to the retention of this packaging scheme include ease of application and removal, reusability, light weight and low cost in proportion to strength, and adaptability to techniques of pre-fabrication. Disadvantages center around unknowns in regard to extreme low temperature behavior of the materials.

The second package (see Fig. 3.2) utilizes a stiff panel covering over a light frame. The panel covering considered is a laminate of resin-impregnated kraft paper and Douglas fir veneer marketed under the tradename of Plyveneer.* The advantages of a package utilizing this material include reusability, ease of application and removal, relatively low weight and high strength in proporation to cost, retention of strength a low temperatures and adaptability to techniques of pre-fabrication. Disadvantages lie in the difficulty of obtaining a completely

* Weyerhauser registered TM

vapor-tight package if required and the necessity of supporting frame-work of some type.

3.7 Flexible Pipe & Quick Couplings for Skid

Past experience shows that construction problems arise when close alignment tolerances are required between skids that must be interconnected by standard pipe and flanged joints and when work of this sort must be performed under Artic conditions. When construction schedules are short, the advantages of greater tolerance on skid placement are obvious. Thus, the use of flexible pipe and quick connect/disconnect couplings is highly desirable. The couplings allow for rapid connection even under adverse conditions, and may produce time savings of 50 to 75 percent in making or breaking connections. Flexible pipe between connection points allows for a small degree of misalignment at the time of installation, provides vibration cushioning and accepts thermal expansion and contraction during operation and differential settlement of skids.

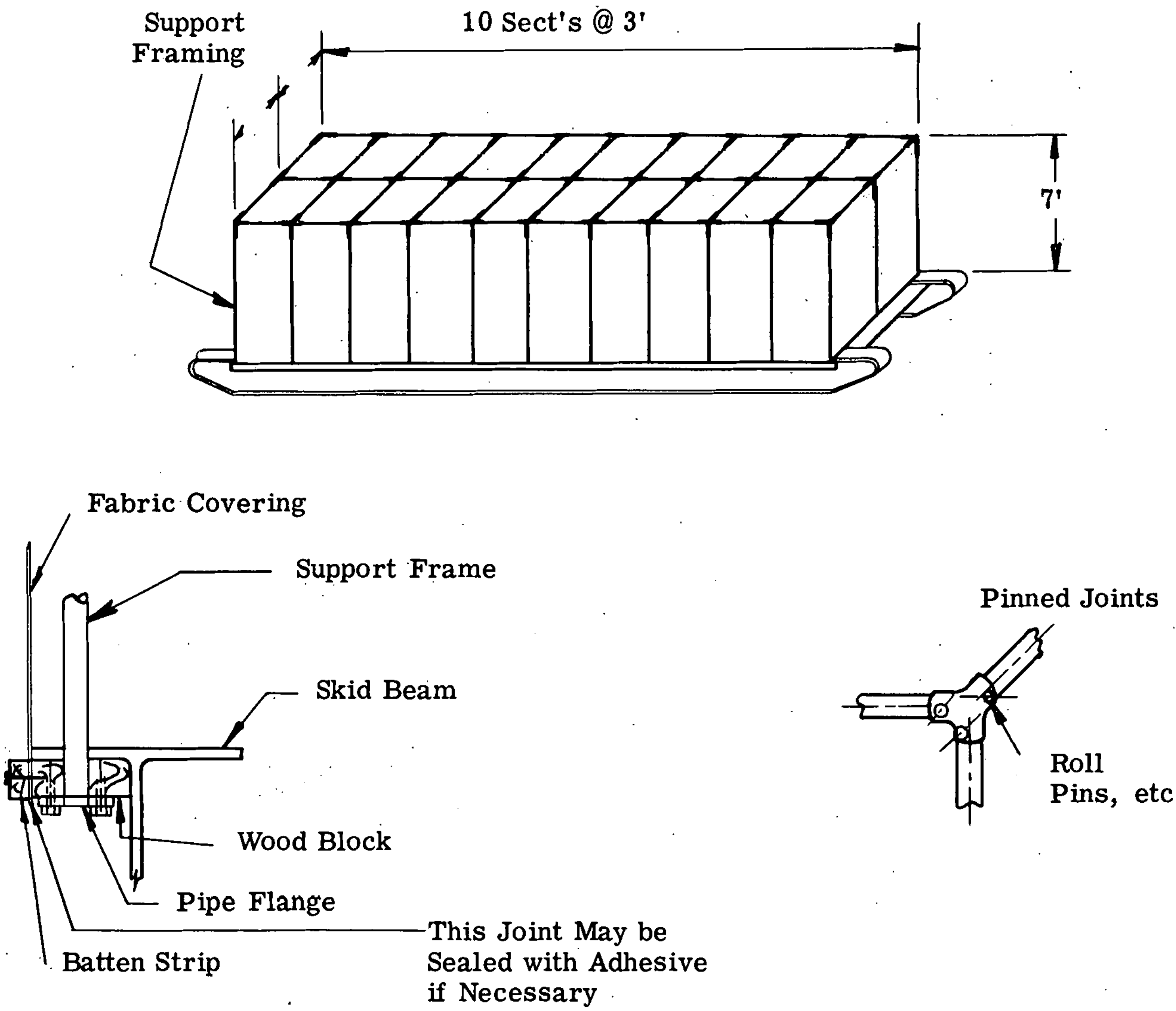
4.0 CONCLUSIONS

From the preceding discussion, it is seen that there are no insurmountable problem associated with final packaging design. The optimum package design will be one of the schemes mentioned in Section 3.6. Its optimization will depend on judicious choice of materials commonly available with particular attention given to simplicity, reusability and light weight.

It has also been found that flexible pipe and quick connect/disconnect couplings are commercially available to meet pressure and temperature requirements expected in PL-3 plant systems. The use of these devices would lead to considerable time savings during plant erection.

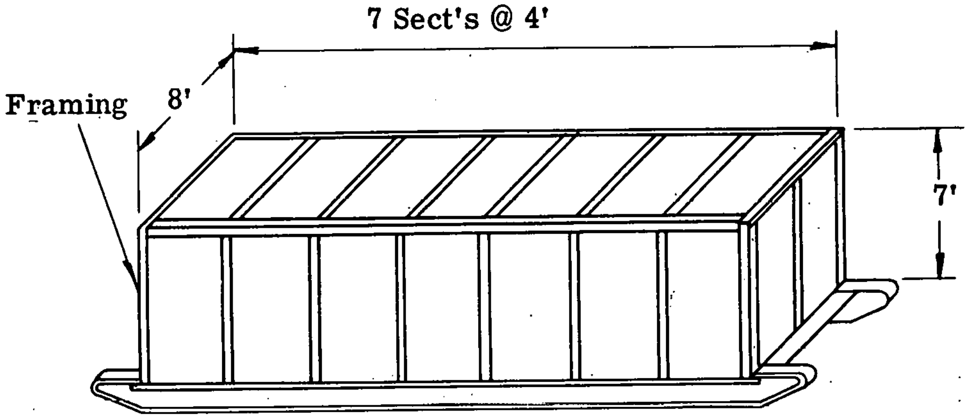
5.0 RECOMMENDATIONS FOR FURTHER STUDIES

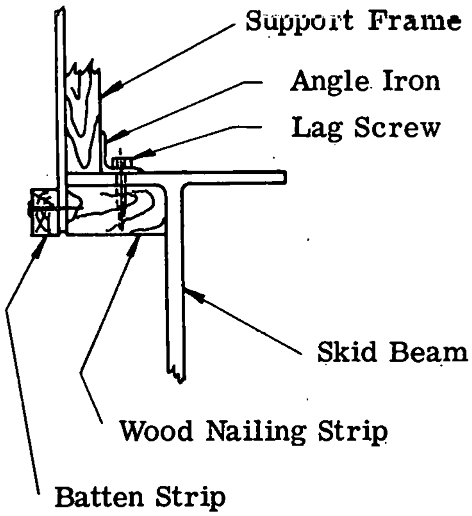
A program of materials testing has been proposed for Phase II. The object is to determine physical characteristics of various packaging materials under the conditions they may have to withstand. With this information, it will be possible to show that the final package design will withstand the expected environmental conditions. From this point, work proceeds to final package design and drawings, issuance of packaging specifications and preparation of a final design report.

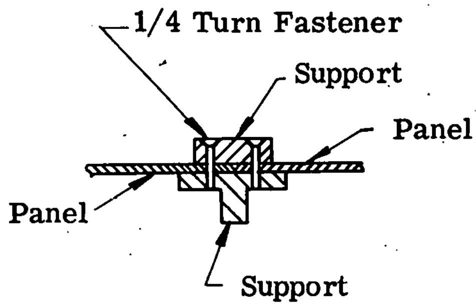


NOTE: Approximate Package Weights
8' x 8' x 15' Module: 600 lb.
8' x 8' x 20' Module: 750 lb.
8' x 8' x 30' Module: 1100 lb.

Figure III-1. Skid Package Using Fabric Material Over Light Frame







NOTE: Approximate Package Weights
8' x 8' x 15' Module: 750 lb.
8' x 8' x 20' Module: 825 lb.
8' x 8' x 30' Module: 1200 lb.

Figure III-2. Skid Package Using Panel Material Over Light Frame

NUCLEAR INSTRUMEN-
TATION SIMPLIFICATION

CHAPTER IV
NUCLEAR INSTRUMENTATION SIMPLIFICATION (SUBTASK 4.2.4.1)

J. A. Barrett

1.0 STATEMENT AND DISCUSSION OF TASK

Appendix B to Contract AT(30-1)-2900 Paragraph 2.1.12 states:

> "Following a scram at power operation, the plant shall be capable of recovery to demand power operation within 20 min, provided startup can be safely initiated within 8 min after the scram."

Paragraph 2.9.12 states:

> "Neutron flux level information shall be provided over a continuous range of from .25 nv at the detector to a flux level corresponding to 150 percent of rated reactor power."

The key word here is "continuous." There must be no gaps or blind areas during operation, shutdown or startup. To meet these criteria, a study of nuclear instrumentation simplification has been undertaken.

2.0 OBJECTIVES OF THE TASK

The objectives of the task are to simplify the nuclear instrumentation by eliminating one or more channels of nuclear instrumentation. This has been done by qualitatively demonstrating the feasibility of using two movable proportional counters for monitoring the reactor neutron flux from startup to a level which will overlap the power range channels and return to shutdown condition.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

3.1 Description of Problem

For an enriched core with stainless steel clad fuel elements, stainless steel pressure vessel and shielding, a high residual gamma dose rate results when the plant has been operated at full power for a considerable time interval. This high gamma dose rate affects all the neutron detection instrumentation in a manner which decreases the signal to noise ratio. (Consider the signal as neutron flux response and the noise as gamma flux response.) This is because the neutron detector chambers are ionization chambers which respond, in varying degrees, to any radiation. Neutron detectors are designed to selectively respond to neutron radiation, but in the presence of high gamma fields, the response to gamma radiation is appreciable.

The effect of gamma radiation on chamber response is shown in the accompanying Fig. IV-1. Representative chambers have been chosen from the "Neutron Detector Handbook," published by Bettis Atomic Power Laboratory. Neutron flux range and gamma dose rate operating limits for signal to noise ratio of 10 to 1 and 1 to 1 are shown. These are usually considered the operating limits for acceptable and unacceptable response.

Thermal neutron density and gamma dose rate at the BF_3 counter position, as a function of time after a scram, at SM-1 is shown in AP Note-128, * Fig. 1. Data have been extracted from this curve and plotted on Fig. IV-1 to show the approximate decay curve followed after a scram. The time marks on this curve correspond to time after scram. It can be seen in Fig. IV-1 that following a scram there is a period of time during which neither the intermediate range nor the source range can operate. This situation can be bettered somewhat by increasing the percent of compensation to a value near 99 percent. The curves drawn are for 95 percent compensation, which is considered normal operation. Higher values of percent compensation require very stable voltage power supply, especially at the low neutron signal levels encountered at the bottom of the intermediate range.

There is the possibility of effecting a recovery to demand power within 20 min following a scram if the neutron flux does not go below the compensated ionization chamber range before the 8 min have elapsed. The experience at SM-1 indicates this can be accomplished. The procedure followed at SM-1 is rather sensitive, (though acceptable) and a more precise scheme for accomplishing the startup after scram is desirable.

3.2 Possible Solutions

There are two methods of solving the problems mentioned. One is to provide shielding which diminishes the gamma dose rate; the other is to provide two movable proportional counter channels and move their chambers out of the high gamma field while remaining within readable neutron flux limits. The first method follows the conventional approach to neutron flux indication and is discussed in the preliminary design reports.

The other method, to provide two movable proportional counter channels to indicate neutron flux over the entire operating range, is not entirely new but is not known to have been applied to power reactor instrumentation as yet. One of several possible reasons for this is unknown technical difficulties. Because of this, a literature survey should be made to ascertain that the tests described

* Page, E., "Gamma Dose and Neutron Levels for Short Times After Shutdown at BF_3 Counter Positions," Alco Products, Inc., AP Note-128, February, 1959.

here have not already been performed at some other facility and the results found unsatisfactory. The balance of this report describes a test program and gives expected results assuming that the work has not been done elsewhere.

3.3 Description of Test Program

The test program consists of two complete individual channels of neutron detection. Both channels are exactly similar insofar as equipment is concerned. The channels will operate in the count range, (or source range) the most sensitive range for neutron detection. Continuous monitoring of neutron flux over the complete range of approximately 12 or 13 decades will be accomplished by moving the detector further away from the core as flux increases. This motion would be effected in the shield tank adjacent to and above the reactor on a line with the core.

The test setup consists of a reactor of the swimming pool research type capable of producing a thermal neutron flux of the order of 10^{13} nv. Two neutron detector chamber wells would be installed on a line with the reactor core. A lift mechanism would be provided above the wells. The chamber assembly and attached cables would be lowered into the well and the cabling connected to the remainder of the neutron detection channel consisting of the amplifying and computing electronics necessary for readout or indication. This electronic circuitry is separate from the facility instrumentation to allow the operation of the reactor by the facility personnel using the normal facility instrumentation.

Several neutron flux plots through a light water moderator have been calculated in APAE Memo-247.* The results of these calculations show an average of about one decade of thermal neutron flux attenuation for five inches of water. Thus, 12 or 13 decades of neutron flux can be covered with approximately 5 or 6 ft of travel.

The tests consist of alternately changing the position of two proportional counters. At the bottom of the range, both counters are full in. As the power is increased to about half the range of both counters, one of them is moved so it indicates a low count rate again. The power is increased further while both channels indicate until the top of the as yet unmoved counter is reached and it is then moved to a position which obtains counts equal to the previously moved chamber. This position is recorded and both chambers are in equal neutron flux position. Then the sequence is continued. The test procedures which follow and Fig. IV-2 illustrate the operation further. The test procedure assumes the installation has been completed and all calibrations have been completed.

---

* Crouch, A. N., "SM-2 Primary Shield Survey," ALCO Products, Inc., APAE Memo-247, February, 1960.

3.4 Test Procedure

1. Both tubes full in. Source inserted and count rate at least 2 cps.

2. Withdraw safety rods, if any - observe new core multiplication on both channels - each channel may not read the same. Part of the development program will require placing the wells in such a position that approximately equal count rates will result in corresponding positions.

3. Increase flux by 3 decades by withdrawing rods observing the usual safety precautions. This should result in a count rate of approximately 2000 cps.

4. Withdraw Chamber 2 to a height which results in a count rate of 20 cps. Record this movement. It should be approximately 15 inches. This corresponds to position 2 on Fig. IV-2.

5. Proceed up in flux rate for 2 more decades. The chamber which was not moved, Chamber 1, should be nearly saturated (2×10^5 cps). The chamber which was moved, Chamber 2, should read approximately 2000 cps. (Still Position 2.)

6. Move chamber 1 up until a count rate of 20 cps is achieved (should required about 25 in. of movement). This corresponds to Position 4. Positions 3 and 5 are for recording purposes only.

7. Increase flux until Chamber 2 reads 2×10^5 cps - Chamber 1 approximately 2000 cps. (Still Position 4.)

8. Move Chamber 2 until the count rate is 20 cps.

9. Increase flux until Chamber 2 reads 2000 cps and Chamber 1 approximately 2×10^5 cps. Continue process until approximately 12 or 13 decades of neutron flux has been traversed (Position 7 or more).

The value of inches stated and shown in Fig. 2 assumes 5 in. of travel for one decade of thermal neutron flux, and is subject to further checks including the results of this test.

3.4 Problem Areas

There are several problem areas associated with this scheme which can be identified at this time. These problems are concerned with the neutron flux difference between the test setup and actual power reactor installation, cable flexing and noise problems, system reliability and human error susceptibility. The following describes procedures which will be used to investigate these problems.

3.4.1 Neutron Flux Investigation

1. Select the test reactor.

2. Obtain unperturbed flux plots and gamma dose rates vs distance from core by means of wire or foil traverse.

3. Compare (2) with calculated values for PL-3 reactor and pressure vessel design.

4. Examine feasibility and necessity of mocking up a portion of the proposed pressure vessel and shielding.

5. Obtain equipment necessary for the instrument channels, such as the detector well, detector lift mechanism, cables, electronic equipment, etc., and install in the test facility.

6. Calibrate instrumentation against foil traverses. New foil traverses may be necessary if the test equipment installation causes serious deformation of the flux plots found in (2).

3.4.2 Flexing Cable Problem

1. Make impedance tests and pulse reproduction tests on the cable before installation, during movement with the lift mechanism, and after installation.

2. Record neutron flux while moving the chambers up and down in the well by using the lift mechanism.

3. Make cycled flexing tests on the cable.

4. Investigate the possibility of converting long cable runs to current instead of voltage systems. This can be done by investigating new concepts in detector types and electronic circuitry.

3.4.3 System Reliability and Human Error Susceptibility

1. Obtain completely proven mil spec equipment or be reasonably sure of its availability during the plant construction.

2. Perform equipment component tests and calibrations at vendors shop and at test facility.

3. Require cycling tests of a fatiguing nature such as temperature, humidity, supply voltage changes, etc. before installation in the plant.

4. Allow individuals to operate the system who have had informal instructions similar to those planned for plant operators. Write operating instructions during this phase to incorporate the comments of the various individuals performing these tests in the test procedure.

5. Purposely perform tests which include errors in operating procedure. See if these errors are immediately made known by obvious malfunctioning. For any stipulated single error, either the malfunction shall be obvious or an alarm or interlock will be incorporated in the system.

4.0 CONCLUSIONS

It is concluded that the nuclear instrumentation system described herein represents a workable, feasible system of instrumentation. However, before a system of this type can be reliably designed, the following pre-requisites must be fulfilled.

1. A literature search to ascertain that this system has not been previously tested and found unsatisfactory.

2. A test program must be carried out to further prove design feasibility. Repeatability and reliability of measurement should also be checked at this time.

3. Although the system described represents a possible nuclear instrumentation design for PL-3, it is impractical because of the large amount of development work required to assure sufficient reliability.

5.0 RECOMMENDATIONS

The nuclear instrumentation system described above represents a simple solution to particular problems associated with measurement of nuclear radiation. Because of its inherent simplicity and flexibility, it is considered worthy of further investigation under a separate research and development contract.

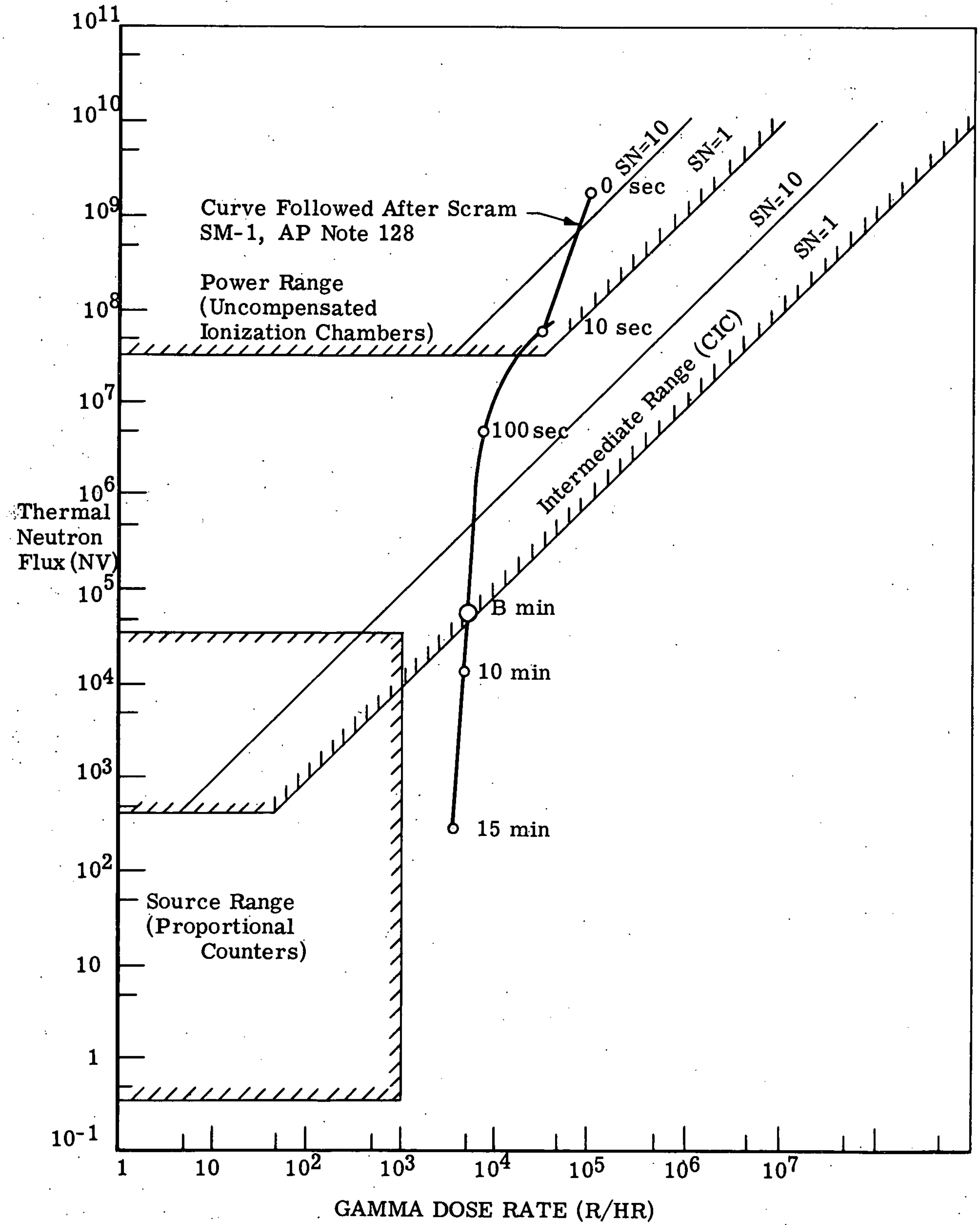


Figure IV-1. Operating Ranges of Nuclear Instrumentation Including Effect of Gamma Flux

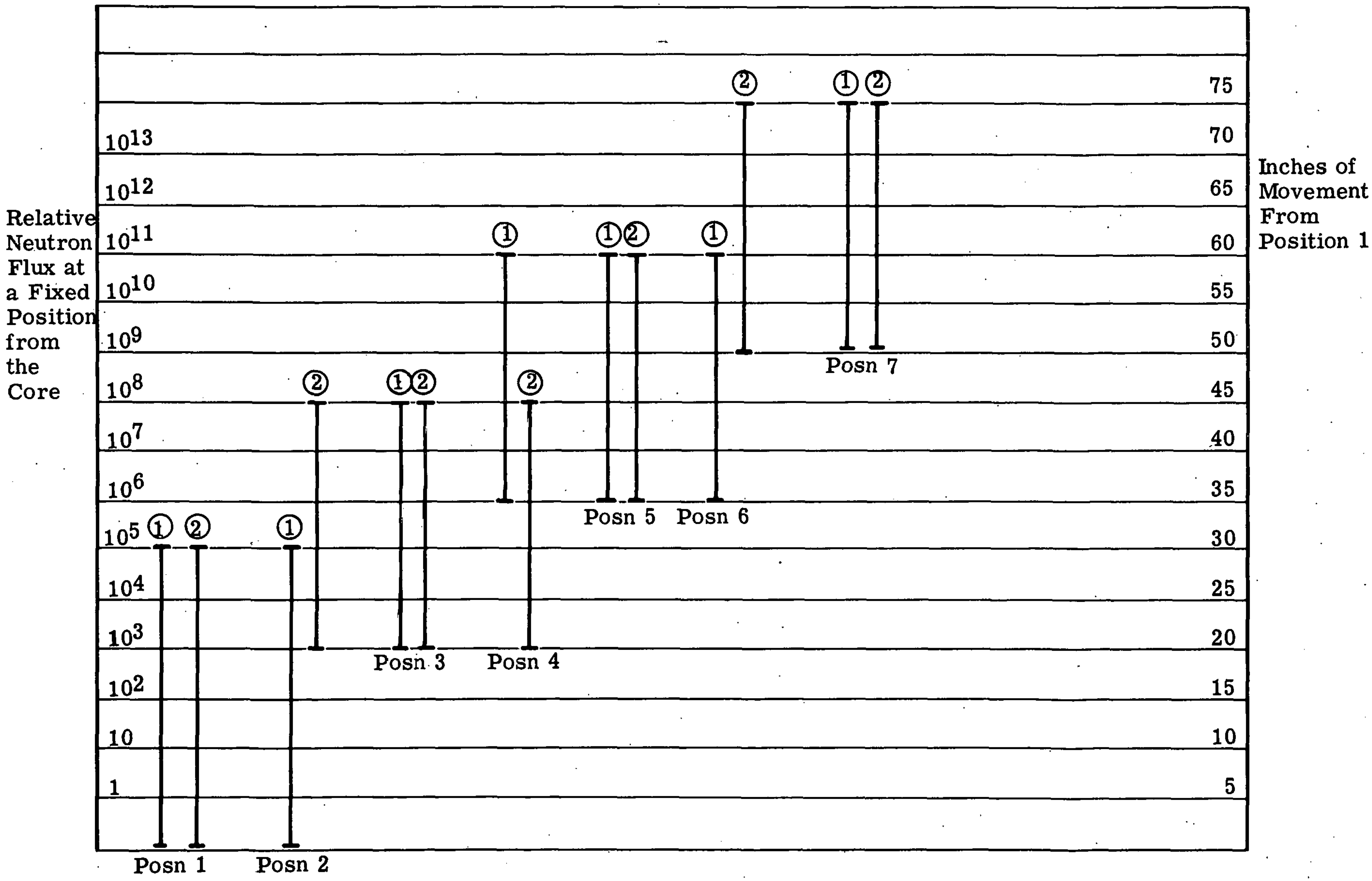


Figure IV-2. Approximate Decay After Scram

PAGES V-9 to V- 20

WERE INTENTIONALLY

LEFT BLANK

wall panels could have been somewhat thinner than four inches, a four-inch panel was used because of insulation requirements. The trial design indicates that a four-inch wall panel and a six-inch roof panel are adequate to support the structural design loadings without auxiliary framing.

4.0 CONCLUSIONS

At the present time, the following conclusions have been reached regarding the building superstructures:

1. All buildings, except the reactor and cooler buildings, shall be frameless structures consisting of moment resisting roof and wall panels assembled as rigid frame bents.

2. The reactor and cooler buildings must be metal-framed structures because of the heavy loads and special considerations involved.

3. Stressed skin wood panels appear to be the optimum construction, but because of cost uncertainties, metal siding panels or plastic-faced stressed skin panels might qualify. Recommended procedure would be to prepare bidding drawings based on stressed skin wood panels, but allow bidders to submit alternative designs to match the stressed skin panel cost and performance and fulfill all specified requirements.

4. Vapor barriers of impervious material and resistant to ripping and abrasion should be installed at the interior surface of the walls or ceiling. Closure between panels should be effected with pressure sensitive tape protected with gasketed battens. A positive electrical ground connection between metal surfacing materials, if used, will be required.

5. Joints between panels should be of the tongue-and-groove type (unless panels are to be removed) with compressible gaskets and held together with cam locks, exterior locks or longitudinal through bolts which do not pierce the vapor barrier (see Fig. V-5).

6. Large doors for equipment erection access are not warranted. Removable panels should be used.

7. Exterior doors should swing out, be gasketed and be equipped with gasket defrosters and quick-acting hardware.

8. Exterior doors should be heat trapped with a vestibule and swinging inner doors.

9. The insulation requirements for the superstructure panels indicate a minimum panel thickness of four inches. Urethane foam or reflective insulation appears to be the best suited and most economical. Bidding documents should allow alternatives based on equalling the performance of urethane-filled stressed skin wood panels.

5.0 TUNNEL COOLING

One factor that must be carefully controlled in snow tunnels is tunnel air temperature. High air temperature will raise the temperature of the snow in the walls and roof arch which will accelerate the rate of arch settling. Tunnel cooling will prevent meeting, and minimize arch settling. The amount of cooling required will be dependent on building and process heat losses and outside ambient temperatures.

In this installation, tunnel cooling will be provided by the use of air wells. These wells, which have functioned at Camp Century, draw air through the porous snow mass and discharge it in the tunnel space. It is difficult to determine what percentage of the air drawn through the air wells originates outside, and what percentage is recirculated through the tunnel walls; however, for preliminary design purposes, it is assumed that all the air originates outside the tunnels. In the summertime, with outside air warmer than tunnel air, this assumption will give conservative results, whereas in the wintertime, the problem is minimized. It is expected that the air wells will be in operation during most of the year. It is possible that during the deep winter months, natural infiltration will effectively cool the tunnel by dissipating at least part of building heat loss so that a reduction in air-well operation may be realized.

Test borings in the Byrd Station region have established that the average snow temperature is -28°C (-18°F) and that at a snow depth of 30 ft this temperature is not affected by summer or winter surface temperatures. It has been decided that tunnel air temperature be limited to a value not to exceed 10°F above snow temperature. This figure of -8°F is considered to be a safe operating operature. Seasonal air temperatures in the vicinity of Byrd Station are reported as +34°F maximum, -82°F minimum, and -18°F mean annual.

An investigation was made to collect data on snow tunnel cooling. Much of the available data are in the possession of personnel at the Cold Regions Research and Engineering Laboratory at Hanover, New Hampshire. These personnel have provided access to both technical bulletins and personal data files. There was no tabulated information on air wells as such; however, first-hand verbal reports on the operation of air wells at Camp Century in Greenland provided information that was used in establishing operational limits.

While it has been established that snow is porous and permeable, values have not been completely developed to determine a numerical pressure gradient through snow.

Snow accumulated during the different seasons of a year tends to have a different density, so that a depth of snow will present a laminated face, with resistance to flow in a horizontal path less than in a vertical path. The snow density also increases with depth within the range considered for air well installations. As a result of the unknowns introduced, preliminary sizing of air wells require estimated values.

The preliminary tunnel heat load at normal operating conditions was calculated to be 224,000 Btu/hr from a building volume of 92,000 cu ft, in a total tunnel volume of 323,000 cu ft. Four air wells were selected based on tunnel volume and configuration. With an outside ambient temperature taken at its maximum condition of +34°F, and an air well discharge temperature of -18°F, tunnel air temperature should not exceed -8°F.

Each air well installation will consist of three basic parts; the well casing, the fan and motor assembly, and the discharge stack. The well casing will be 21-1/4 in. in diameter, and 26 ft long, fabricated of 1/6 in. thick aluminum with welded seams. An aluminum support ring will be located one foot from the top end and will be suitably stiffened with gusset plates. The ring will serve as a support pedestal on the floor of the tunnel with 25 ft of casing extending down into the well hole. In the event that the tunnel floor assumes an expected concave shape, it will be necessary to shim under the support ring with snow.

The fan and motor assembly will consist of a 10 hp motor, suitable for operation at expected minimum tunnel temperatures, with silicone grease on all bearings. The fan will be of the axial flow type vertically mounted with aluminum fan blades, hub, and housing, having a capacity of 7000 cfm at 6 in. total pressure and 3600 rpm. The fan and motor assembly will be such that the motor is totally enclosed in the fan housing, and no V-belt or external drive arrangement will be required.

The discharge stack will be fabricated from 1/16 in. thick aluminum, 21-1/4 in. diameter, and will be 15 ft-4-1/2 in. over-all. This stack will be mounted on the discharge flange of the fan, and will extend straight up for about 13 ft, where it will terminate in a discharge hood provided with turning vanes, the function of which will be to direct the flow of cooled air under the roof arch. Bracing members will be provided securing the discharge stacks to building walls or to the snow walls.

It is expected that the tunnel will be naturally ventilated by infiltration through the various penetrations and bulkheads, and through the snow.

Form No. 308b
20M-3-58

JACKSON & MORELAND, INC.
ENGINEERS
BOSTON NEW YORK

PREPARED DATE
CHECKED DATE
RECORD NO. 7358

ALCO PRODUCTS INC.

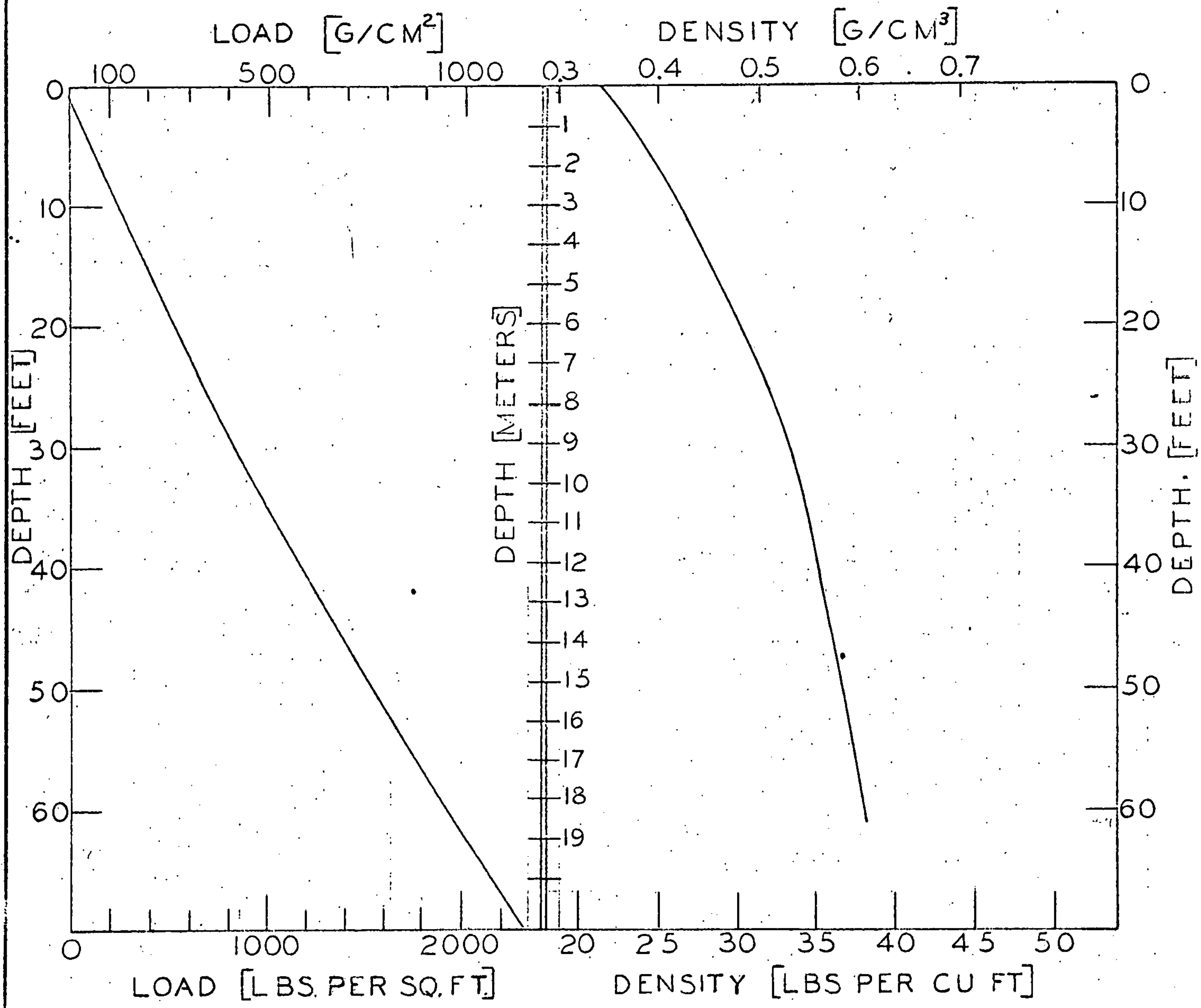
PL-3

FIG. 1

BUILDING FOUNDATIONS

SH. OF

BYRD STATION
SNOW DENSIFICATION DATA
FROM 1960 SURFACE



DEPTH-LOAD CURVE

DEPTH-DENSITY CURVE

SOURCE: U.S.A.—C.R.R.E.L. TECHNICAL REPORT 78, BY A.J. GOW

JACKSON & MORELAND, INC.
ENGINEERS
BOSTON NEW YORK

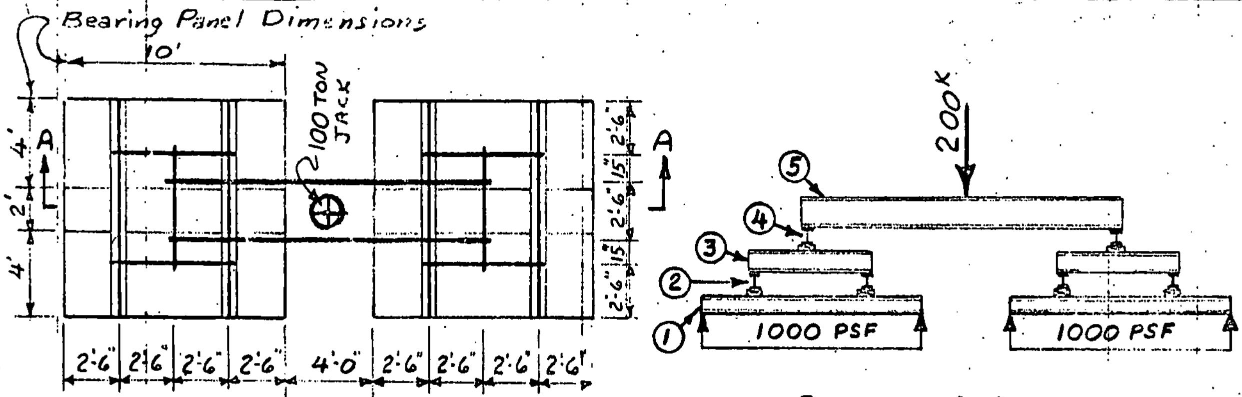
PREPARED Chm. DATE
CHECKED DATE
RECORD NO. 7385

ALCO PRODUCTS INC.
PL-3

FIGURE V-2

COMPARISON OF SHIPPING WEIGHTS & VOLUMES OF SPREAD FOOTING MEMBERS

SH. 1 OF 1



SECTION A-A

PLAN (4 Req'd.)

NOTE: Foundation shown is consistent with support of Primary Building (Total Load ≈ 800K) on 4-100 Ton jacks.

ITEM	QUANTITY	DESCRIPTION	WEIGHT (Lbs.)	CUBAGE (Cu.Ft.)	*SHIPPING DENSITY (Lbs./Cu.Ft.)
1	800 S.F.	Stressed Skin Panels: 2"x8" Joists 6" o.c. with 5/8" Covers.	8000.	584.	14.
		Cellular Steel Panels: Robertson Type FK 12-14.	9280.	304.	31.
		Wood Planking: 5"x12" Douglas Fir, Const. Grade.	9920.	296.	33.
2	160 L.F.	6061-T6 Alum. Beam: 8"x6½" WF @ 8.32#	1330	60	22.
		USS-T1 Steel Beam: 6 I 12.5	2000.	22.	91.
		Wood Beam: 12"x14" Douglas Fir, Const. Grade	5710.	172.	33.
3	80 L.F.	6061-T6 Alum. Beam: 12"x10" WF @ 18.34#	1470.	67.	22.
		USS-T1 Steel Beam: 8 WF 20	1600.	24.	67.
		Wood Beam: (Shear too high)	—	—	
4	40 L.F.	USS-T1 Steel Beam: 8 WF 20	800.	12.	67.
		6061-T6 Alum. Beam: (Shear too high)	—	—	
5	112 L.F.	USS-T1 Steel Beam: 16 WF 58	6500.	105.	62.

* Optimum Air Transport Shipping Density = $\frac{20,000 \text{ Lbs}}{8' \times 8' \times 30'}$ = 10.4 Lbs/Cu.Ft. Note that weight controls plane capacity for all foundation members listed.

JACKSON & MORELAND, INC.
ENGINEERS
BOSTON NEW YORK
PREPARED KLL DATE
CHECKED DATE
RECORD NO. 7336

Alco Products Inc.

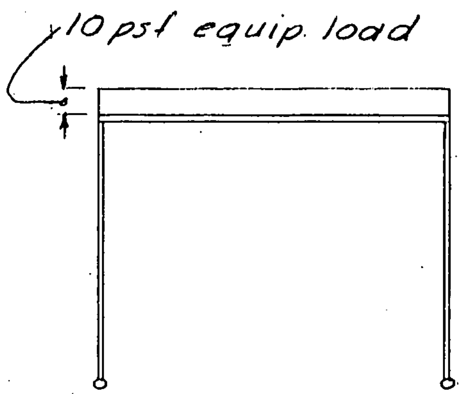
Building Superstructure

Design Criteria

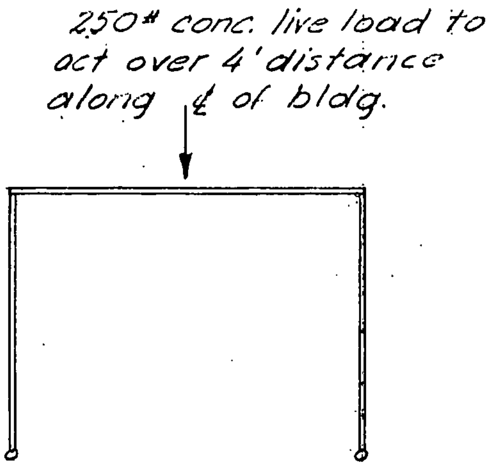
FIGURE. V-3

SH. 1 OF 1

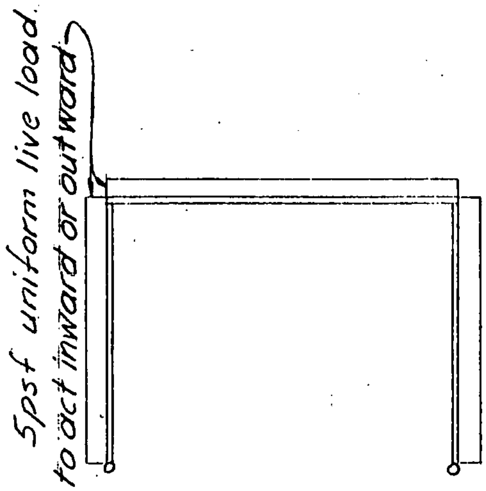
Superstructure Loadings



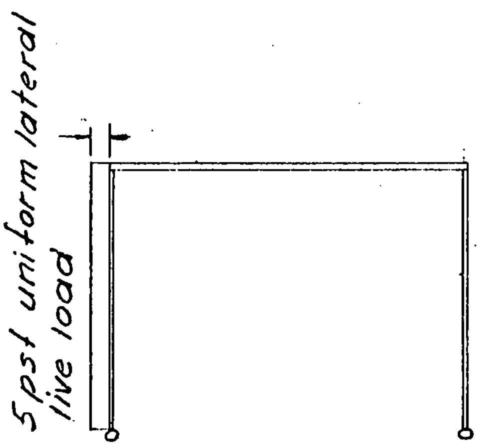
Condition #1



Condition #2



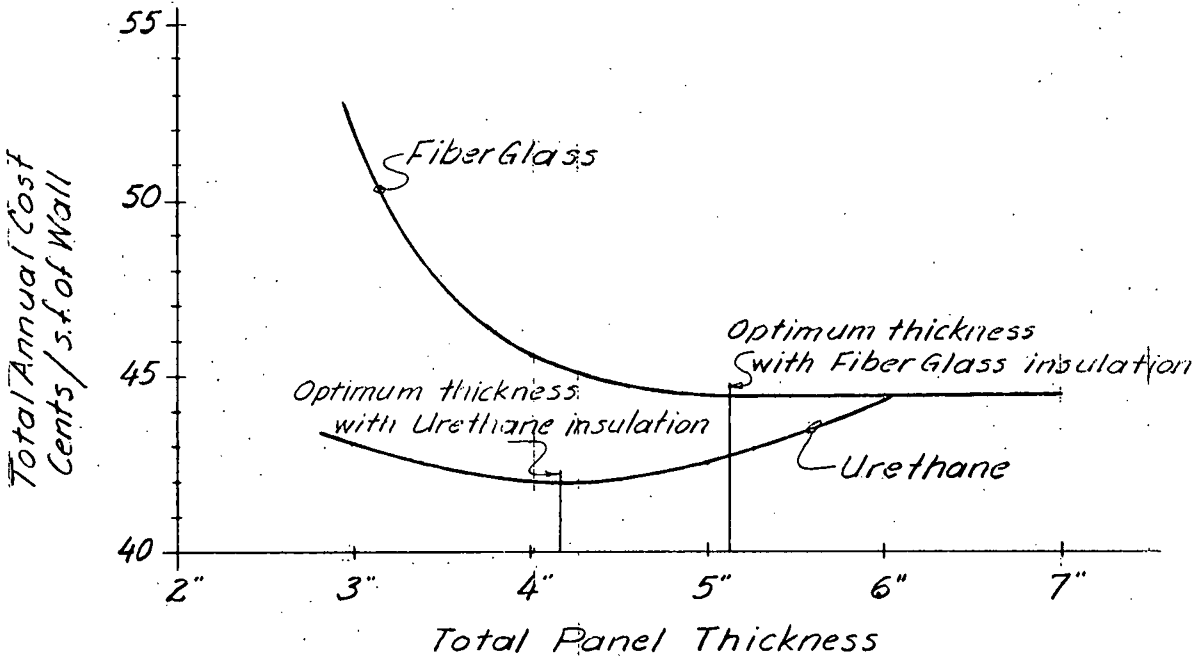
Condition #3



Condition #4

Design of building to be based on that combination of the above loadings with the dead load which will produce the most severe condition for the member under consideration, provided that conditions #3 & #4 do not act simultaneously. If conditions #3 or #4 act in combination with other loadings the allowable unit stresses may be increased by 1/3.

Byrd Station Site - 10°F temperature rise



Panel construction considered as stressed skin design with $\frac{1}{4}$" thick skins and 5-1$\frac{5}{8}$" wood studs per 4' wide panel. For fiberglass insulation $\underline{k}$ factor is 0.27 Btu/hr/s.f./°F/in and cost is 8¢/b.f. For urethane insulation $\underline{k}$ factor is 0.16 Btu/hr/s.f./°F/in and cost is 20¢/b.f..

Annual wall panel cost based on money at 3% for 20 years.

Annual fuel cost based on power required to cool tunnel at rates experienced for PM-2A plant. (Power to run blowers.)

Total annual cost based on fuel cost plus capitalized annual wall panel cost.

Conclusions:

1. Urethane insulation is more economical than fiberglass insulation.
2. Optimum wall panel thickness is 4$\frac{1}{4}$"±.

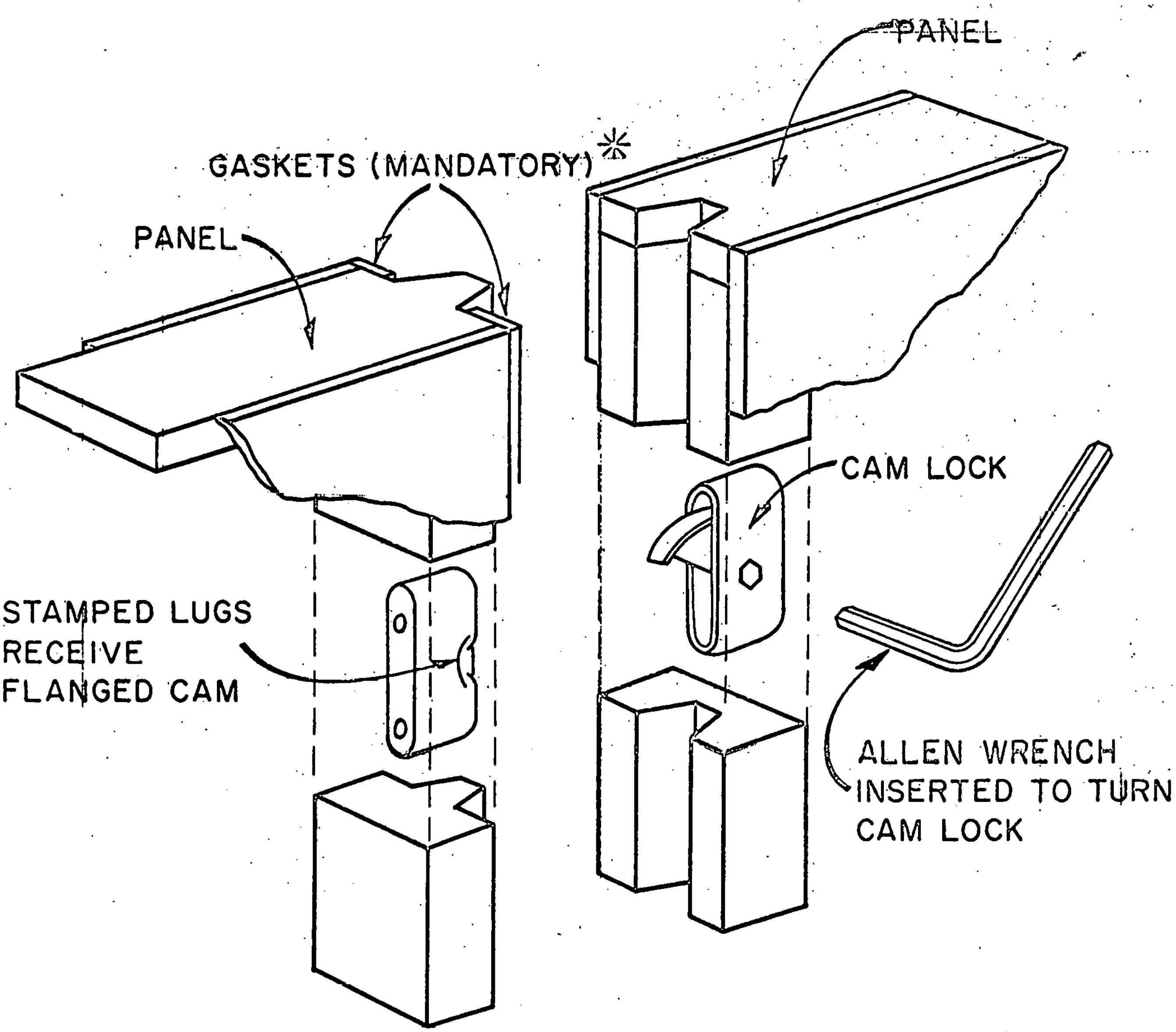


FIGURE V-5 TYPICAL CAM LOCKED JOINT

REPRINTED, BY PERMISSION, FROM "PREFABRICATION IN NORTHERN HOUSING" NRC 6059, A PUBLICATION OF THE DIVISION OF BUILDING RESEARCH, NATIONAL RESEARCH COUNCIL, CANADA

* *SEE FOOTNOTE TO FIGURE 9*

ANTIFREEZE
COOLANT STUDY

CHAPTER VI
ANTIFREEZE COOLANT STUDY (SUBTASK 4.2.3.2)

C. R. Bergen

1.0 STATEMENT AND DISCUSSION OF TASK

The PL-3 condenser and auxiliaries were anticipated to require heat removal through air blast coolers to the atmosphere. A suitable coolant for this purpose had to meet requirements of low temperature operation and radiation stability. Therefore, studies were initiated to evaluate the various coolants available, giving consideration to the special requirements of both BWR and PWR systems. This subject is covered in more detail in AP Note-407.*

2.0 OBJECTIVE OF TASK

The objective of the task is to investigate substitute antifreeze coolant fluids for ethylene-glycol.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

For guidance in coolant selection, the properties listed in Table VI-1 were chosen as a basis for comparison. The investigation of coolants centered on a study of manufacturers' literature. Of thirty coolants initially investigated, only nine had sufficient merit for further consideration. Table VI-1 lists the properties of these coolants.

Low temperature limitations were considered of primary importance. Only those materials which had freezing points below $-65^{\circ}F$ were considered, since this temperature can readily be met by 60 percent aqueous ethylene glycol (used as reference material).

The most stable of the materials, with respect to radiation, were mono-isopropyl biphenyl and silicate ester. These two materials tolerate more than ten times the radiation of the other materials. The other coolants exhibit the usual radiation resistance of organic compounds ($\sim 10^8$ R gamma).

* Bergen, C. R., "Antifreeze Coolants; A Review of Manufacturers' Literature," Alco Products, Inc., AP Note -407.

Ethylene glycol as a 50-65 percent solution in water shows increased acidity, decreased viscosity and increased freezing point with increased exposure to radiation. Materials formed under irradiation include gaseous hydrogen and carbon monoxide and some polymers. The behavior of a small quantity of ethylene glycol in water exposed to radiation is of particular interest to PL-3. However, there were no reported studies in this area and it may be necessary to develop such information.

From the cost standpoint, glycols are the least expensive. Also, the glycols are established as coolants with considerable experience in their use. Only with respect to radiation resistance do the glycols appear below average. Therefore, except for the use in moderate to heavy radiation, glycols appear to be the best choice for coolant use.

4.0 CONCLUSIONS

It was concluded that either ethylene or propylene glycol would be the coolant best suited for use in PL-3 plant condenser and auxiliaries excepting applications involving exposure to moderate or high radiation. Under conditions not involving moderate or high radiation exposure, an appropriate corrosion inhibitor should be used with ethylene or propylene glycol.

Under BWR conditions, where there might be a probability of exposure to moderate or high radiation, monoisopropyl biphenyl appears best. Otherwise, either ethylene or propylene glycol could be used with an inhibitor not subject to activation.

5.0 RECOMMENDATIONS

It is recommended that investigation be continued and include the following areas of study.

1. The effect of radiation on dilute and concentrated glycol solutions with respect to heat transfer.

2. Methods for removal of low concentrations of glycol from water.

3. The determination of glycol inhibitors not subject to activation.

4. Optimum concentrations of glycol to minimize expansion due to freezing and take advantage of increased heat transfer efficiency, providing there is no adverse effect on plant operation. However, concentration should not be less than 15 percent because expansion on freezing could possibly damage the coolant system.

TABLE VI-1
COOLANT PROPERTIES

Property		60% aqueous propylene glycol	60% aqueous ethylene glycol	68% aqueous methanol	coolanol 35 (silicate ester)	FC-75 perfluoro cyclic ether	monoiso-propyl-biphenyl	SF-96 (5) silicone fluid	SF-81 silicone fluid	dibutyl-amine
Density (#/cu ft)	(0^{o})	66.5	68.2	not avail	58.2	not avail	63.4	61.3	62.5	not avail
	(70^{o})	65.1	67.4	57.8	57.1	110.3	61.5	57.2	60.9	47.6
Viscosity (#/ft sec)	(0^{o})	0.0672	0.0208	not avail	0.0310	not avail	0.0512	0.00906	0.0906	not avail
	(70^{o})	0.00591	0.0037	0.00109	0.00625	.000773	0.0070	0.00305	0.0305	not avail
Heat capacity (Btu/#^{o}F)	(70^{o})	0.815	0.75	0.6	0.45	0.247	0.404	0.35	0.36	not avail
Thermal Cond. (Btu/ft ^{o}F hr)	(70^{o})	0.202	0.206	not avail	0.068	not avail	0.070	0.0067	0.087	not avail
Melting Pt (^{o}F)		-80	-65	-100	-120	-80	-65	-120	-120	-80
Flash Pt of pure Mat'l (^{o}F)		225	240	167	370	(3')	315	275	600	125
Toxicity		edible	low	(5')	nontoxic	prob low	low	montoxic	nontoxic	(6')
Radiation Resistance		(2')	10^{8}R	not avail	(1')	10^{9}R	(1')	10^{8}R	10^{8}R	?
Corrosivity		(7')	(7')	(7')	good	good (4')	good	good	good	(7')
Cost per lb		16-1/2	17-1/2	8-1/2	$3.20	$9.35	$2.00	$4.95	$4.17	57¢
Vapor pressure (mm/Hg)	(70^{o})	15	14	69	0.02	low	0.5	very low	very low	1.9

(1') Resists 10^{9}R radiation or 2.5×10^{17} to 10^{18} nvt thermal and fast neutrons.
(2') Probably equivalent to ethylene glycol in radiation resistance.
(3') Nonflammable (boils at 214^{o}F).
(4') Activated alumina absorber plug required to remove corrosive impurities
(5') Max level in air; 200 ppm.
(6') Max level in air; 10 ppm.
(7') Good with inhibitor.

GASEOUS WASTE PROCESSING

CHAPTER VII
GASEOUS WASTE PROCESSING (SUBTASK 4.2.6)

J.H. Noble, E.E. Duke

1.0 STATEMENT AND DISCUSSION OF THE TASK

Air in active concentration in the Antarctic that would adversely affect scientific studies must be avoided. The direct and indirect boiling water reactors and the pressurized water reactor concepts have been investigated for gaseous waste handling to obtain tolerance levels. A complete report of this work is covered in APAE Memo-313.* Areas common to the various concepts are not discussed, as they do not enter into a comparison study. The major differences present are the handling of active gases released to or held in the primary system coolant. The gases which could be present, their possible release from the system, and the necessary processing requirements have been reviewed in detail. Sufficient information has been presented to enable a reader to analyze the methods required to remove gaseous activity present in other size and type pressurized and boiling water reactors.

2.0 OBJECTIVES OF THE TASK

The object of this task was to determine methods of gaseous waste containment, dilution, or dispersion to arrive at tolerance levels from the three proposed types of PL-3 nuclear reactors.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

Each plant was analyzed in turn to provide an understanding of how radioactive gas release affects the operation of a particular plant concept. All possible gases present in the cores contemplated were compiled. The gases present were divided into two segments: (1) the lower atomic weight products produced primarily by induced reactions and radiolytic decomposition and (2) the heavy fission product gases. The quantity, volume, and activity of these gases both in the core and released to the system were calculated. Based upon these data, proposed gas handling plants consisting of cycling adsorber, continuous adsorption, and containment systems were discussed.

---

* Noble, J.H., and Duke, E.E., "Comparison of Gaseous Waste Handling Systems for PL-3", Alco Products, Inc., APAE Memo-313, March, 1962.

4.0 CONCLUSIONS REACHED

It has been determined that the pressurized water concept was most easily adaptable to waste gas handling; the indirect boiling system was simpler in design and operation than the various direct boiling water reactor waste gas schemes. However, specific designs for gas handling in all three plants are feasible.

Under normal operation, all gases from a DBWR can be emitted from the processing equipment after an 80 day xenon hold-up to meet limits of 4×10^{-14} c/cc. However, Kr^{85} will be released under these conditions at 2.7×10^{-13} c/cc. With Kr^{85} release above limit under normal operation it is required to provide complete hold-up of this isotope or raise the discharge level for Kr^{85}. However, further development work could indicate that without complete hold-up, Kr^{85} is within the prescribed specification limits.

During defective operation, a separation of Kr^{85} and the hold-up of all other gases for a period of 423 days will permit continuous operation.

5.0 RECOMMENDATIONS

A research and development program will be required to accurately predict gaseous break-through times to design an activated bed for long periods of operation. Accurate design information of adsorption beds is unavailable; a program similar to that cited by Dr. L. Silverman should be initiated to remody this deficiency. *

Other disposal methods such as clathrate and liquid stripping should be investigated for future application. In addition, the perfection of an accurate system for measuring very low level activity is necessary.

It should also be noted that the equipment required to meet effluent activity at 4×10^{-14} c/cc could be materially reduced if design criteria was that of R.C.G. (1×10^{-10} c/cc) for a mixed reactor gas with guaranteed iodine-129 retention.

6.0 CONTINUING WORK

Work is continuing to provide a complete gaseous waste collection and disposal system for the PL-3 plant.

* Silverman, L. and Krusen, G.C., "Evaluation of Proposed Krypton-Xenon Adsorption System for PL-2 Reactor," Harvard School of Public Health, January 15, 1962.

7.0 HIGHLIGHTS OF WORK

The data listed below tabulates the results of calculations made and proposed design requirements.

TABLE OF RESULTS

1. Total Light Gas Core Activity, μc 2×10^5.
2. Total Light Gas Core Volume Flow Rate, liters/min 17.8 STP.
3. Release to Stack Activity of Light Gas (1 day holdup), $\mu c/cc$ 4×10^{14}.
4. Gas Activity Available in 2 yr core, curies 7×10^6.
5. Activity Released to Steam with Defect, BWR, curies 2.4×10^5.
6. Acitivity Released to Steam with Normal BWR, Operation $\mu c/sec$ 2.0×10^5.
7. Stack Activity with Defect, DBWR, (less Kr^{85}) - 423 day Hold-up, $\mu c/cc$. 4×10^{-14}.
8. Stack Activity Normal, DBWR, (less Kr^{85}) - 80 day Hold-up, $\mu c/cc$ 4×10^{-14}.
9. Stack Activity with Defect; DBWR, - Kr^{85}, $\mu c/cc$ 1.85×10^{-1}*.
10. Stack Activity Normal, DBWR, - Kr^{85}, $\mu c/cc$ 2.7×10^{-13}*.

SYSTEM DESIGN TYPES

DBWR

1. Continuous adsorption.
2. Cycling adsorption with additional krypton hold-up and collection.

IBWR - Containment in primary system and periodic removal.

PWR - Containment in primary system with removal before refueling.

---

* If Kr^{85} was discharged to the stack.

REFUELING SYSTEM
DEVELOPMENT

CHAPTER VIII
REFUELING SYSTEM DEVELOPMENT (SUBSTASK 4.2.5)

G. C. Hauenstein

1.0 STATEMENT AND DISCUSSION OF THE TASK

The PL-3 reactor must be refueled at regular scheduled intervals throughout the anticipated life of the plant. The refueling system to be used in this plant must function properly under adverse climatic conditions and refueling time should be kept to a minimum. The remote plant location necessitates that weights be kept as low as possible without sacrificing reliability or safety. In order to reduce maintenance, the design of components should stress simplicity without loss of structural integrity.

Spent fuel elements will be shipped by an air, sea and land route in lead shielded casks from the plant site to reprocessing stations in the U.S. Air shipment of the casks imposes severe limitations on both their size and weight. The optimum shipping cask design is one in which the total weight of the fuel casks is a minimum. To optimize for a minimum total weight of fuel casks involves determining the shielding requirements and the effects on weight of cooling time and number of elements per cask.

2.0 OBJECTIVE OF THE TASK

The object of this task is the study and evaluation of existing refueling systems in order that an optimum arrangement can be evolved for the PL-3 reactor.

Preliminary shield optimization studies of the spent fuel shipping casks were made with the following guidelines in mind:

1. The total weight of spent fuel casks is to be kept to a minimum.
2. Casks shall conform to Idaho Chemical Processing Plant shipping cask requirements.
3. The number of casks shall be adequate to load two complete cores at one time.
4. Casks and fuel shall be protected to prevent damage by an ambient temperature of $-100^{\circ}F$.

5. Cask will be designed to proposed AEC rule 10, part 72, "protection against radiation in the shipment of irradiated fuel elements."

6. PL-3 shipping requirements.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

A literature search of published articles, including some patents, pertinent to existing refueling and shipping arrangements was conducted. A study was also made of existing and proposed Alco nuclear reactor plants. To supplement this information, a trip was made to the M. I. T. research reactor at Cambridge, Massachusetts for a visual study of the refueling system used on their D_2O reactor. All information collected was factored into the BWR and PWR concepts to arrive at an optimum design for each basic system. The work on fuel transfer system development is presented in APAE Memo-310.* The transfer systems investigated and evaluated are as follows:

1. Fuel transfer by flask
2. Fuel transfer by chute
3. Fuel transfer by carriage

Fuel transfer by carriage was ruled out of contention on the grounds of cost, difficulty of maintenance and complexity. Fuel transfer by flask was considered the most practical method for fuel transfer with the Boiling Water Reactor concepts since reactor vessel penetrations posed problems and added to hazard potential. Fuel transfer by spent fuel chute was considered the most practical approach to spent fuel transfer on the Pressurized Water Reactor concepts, based on economy, ease of maintenance and reliability determined by past usage. A typical system utilizing the transfer cask is depicted in Fig. VIII-1 and a spent fuel chute arrangement is shown in Fig. VIII-2. A conceptual design of the fuel transfer flask is presented in Dwg. AEL-731. Modifications will be made to the systems and components so that they meet final plant design requirements.

Three different approaches to fuel storage during cooldown were investigated for PL-3 application. These methods are:

1. Fuel storage in spent fuel tank
2. Fuel storage in casks in peripheral shield tanks
3. Fuel storage on skids at remote location

* Hauenstein, G. C., Pomeroy, D. L., "Spent Fuel Transfer Storage and Shipping Study for the PL-3 Reactor," Alco Products, Inc., APAE Memo-310, to be issued.

The method of remote storage in a small shield tank mounted on a skid was eliminated because cost, maintenance and hazard potential were excessive. Storage in the shipping casks in the peripheral shield tanks is advantageous because the cask supplies the shielding, thereby greatly reducing the plant shipping weight. The spent fuel tank would require approximately 186,000 pounds of shielding in addition to that required for the shipping casks and the entire reactor plant would probably be lost if this tank were ruptured while elements were stored in it.

Shipping casks were investigated on the basis of total gross weight per cask and fraction of core contained. Efforts were made to optimize shipping casks for each of the four cores proposed. A conceptual design of a shipping cask (Dwg. AEL-735) was made, based on one of these cores.

Shield requirements for four cores were established as part of Phase I. The cores considered were (1) PWR - 7 x 7 Type 2, (2) PWR - 5 x 5 Type 3, (3) BWR - High enrichment plate type and (4) BWR - Low-enrichment rod type.

The shield requirements for sides of the shipping casks were determined by an IBM-650 computer program. These programs considered full cores with infinite operating history followed by a ten day decay period. Hand adjustments were made to the computer output in order to determine side shield requirements for partial cores operated for 2 yr with a variety of decay times. Shield requirements for the shipping cask ends for the selected core were determined by a hand calculated model. APAE Memo-310 gives a complete discussion of the calculations and results.

Figure VIII-3 shows the lead shield required to reduce the dose from a full PWR - 7 x 7 Type 2 core (the reference core) shipping cask to 10 mr/hr at one meter. This curve may be used in determining an optimum shipping time. For example, by delaying shipment from 10 days to 30 days, almost 1 in. of lead may be saved; by waiting from 30 days to 90 days, about 2 in. of lead may be saved, however, waiting from 90 days to one year will save less than 1/2 inch.

Figure VIII-4 shows the lead thickness reduction for partial reference core shipment. An examination of the curve shows that even a large reduction in the number of fuel elements shipped results in only a small lead thickness reduction. This is partially due to the self shielding value of the fuel. Fuel elements in the inner rows of the cask are shielded by the elements in the outer row.

Figure VIII-5 is the dose attenuation curve of the side shield at 10 days for each full core. Also shown in Fig. VIII-6 is the attenuation curve after 2500 hr shutdown for the top and bottom of 15 reference core elements operated for 2 yr. It may be observed that the shielding required for the top and bottom of the shipping cask is approximately 2 in. less than that required for the sides.

Previous reports discussing shielding requirements for shipping the reference type fuel elements have shown that the lead requirement for the top and bottom of the shield cask are more than or equal to the sides.

The disparity is due to use of two different models for calculating shielding requirements for the end and side. The ROC code calculation for the side shielding is extremely conservative for the following reasons:

1. The code effectively uses a single energy group for calculation.

2. The average energy is assumed to be 2 Mev, well above the true effective average energy.

3. The analytical model used with ROC code is based upon conservative assumptions.

4.0 CONCLUSIONS

The optimum design of fuel transfer system for the pressurized water reactor (PWR) is a fuel transfer chute arrangement penetrating the vapor container wall. Vapor containment integrity will be maintained by use of a seal plug in the chute. Transfer handling of the core elements will be by hand tools adapted to the final design of the fuel elements and absorbers. This selection of a system was based on previous experience, simplicity of design, ease of maintenance and relatively low cost.

The optimum design of fuel transfer system for the boiling water reactor (BWR) is one in which the fuel is transferred by shielded flask. The flask is positioned over the element to be removed by indexing a vessel shield cover insert. Although more costly, the transfer flask is considered more desirable than methods which would require reactor vessel penetration with inherent hazard potential.

The optimum fuel storage arrangement is the system utilizing the shipping casks in the peripheral storage tanks. The weight saving and relative safety of this arrangement outweighs the minor problem of refined cask cooling.

Optimum shipping cask arrangements for the four cores studied are presented in Table VIII-1.

The minimum weight shield which would meet the shipping requirements could be evaluated by judicious experimentation. However, the analysis thus far performed has been sufficient to evaluate the optimum shipping cask size and decay time before shipment. An estimated 15 to 20 percent shield weight savings might result from the experimentation; however, the present budget allows only refinement of the shielding calculations on analytical basis.

5.0 RECOMMENDATIONS

It is recommended that advance studies be undertaken to obtain optimum shielding thicknesses. Any refinement in this area would result in further reduction of shield thickness and allow either lighter shipping casks or more elements per cask.

6.0 CONTINUING WORK

Further improvements will be investigated for the transfer system, the storage arrangement and the shipping cask design. Dissipation of decay heat of elements stored in shipping casks will be further studied to assure satisfactory cooling of the elements. Tooling will be studied, and designed or modified to best fit the requirements for the PL-3 plant.

TABLE VIII-1
PL-3 SHIPPING CASK DATA SHEET

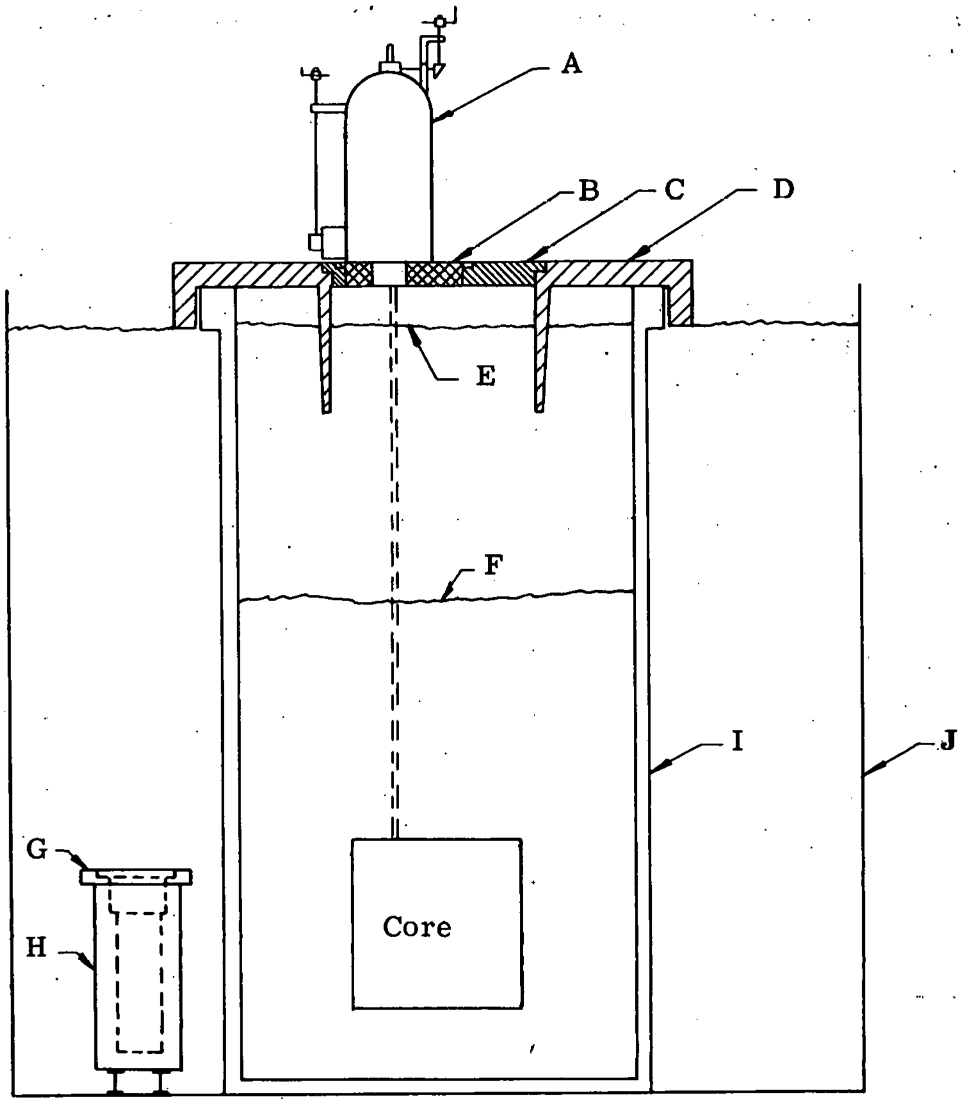
Boiling Water Core:

Rod Type	24 Elements,	9 Cruciforms
Plate Type	60 Elements,	8 or 9 Cruciforms

Pressurized Water Core:

Type 2, 7 x 7	45 Elements,	7 Absorbers
Type 3, 5 x 5	25 Elements,	5 Absorbers

Data Summary:	BWR		PWR	
	Rod	Plate	Type 2	Type 3
No. of Casks	6	5	4	2
Elements/cask	4	12	11 or 12	12 or 13
Absorbers/cask	2 or 1	2	2	3 or 2
Element length, in.	47.863	32	31-5/8	31-5/8
Absorber length, in.	49.175	37	23	23
Lead equivalent, in.	8-3/4	10.2	10	11
Bare wt/cask, lb	17,950	19,150	18,650	21,100
Loaded wt/cask, lb	19,950	20,560	20,150	22,600
Basket opening, in. sq	5.875	5.875	3	3
Transfer flask wt, lb	22,200	16,350	14,000	14,000



A - Flask
B - Element Guide
C - Section Guide
D - Shield Cover
E - Water Level, Transfer
F - Water Level, Operating
G - Locating Adapter
H - Shipping Cask
I - Reactor Vessel
J - Shield Tank

Figure VIII-1. Refueling Concept Using Transfer Flask

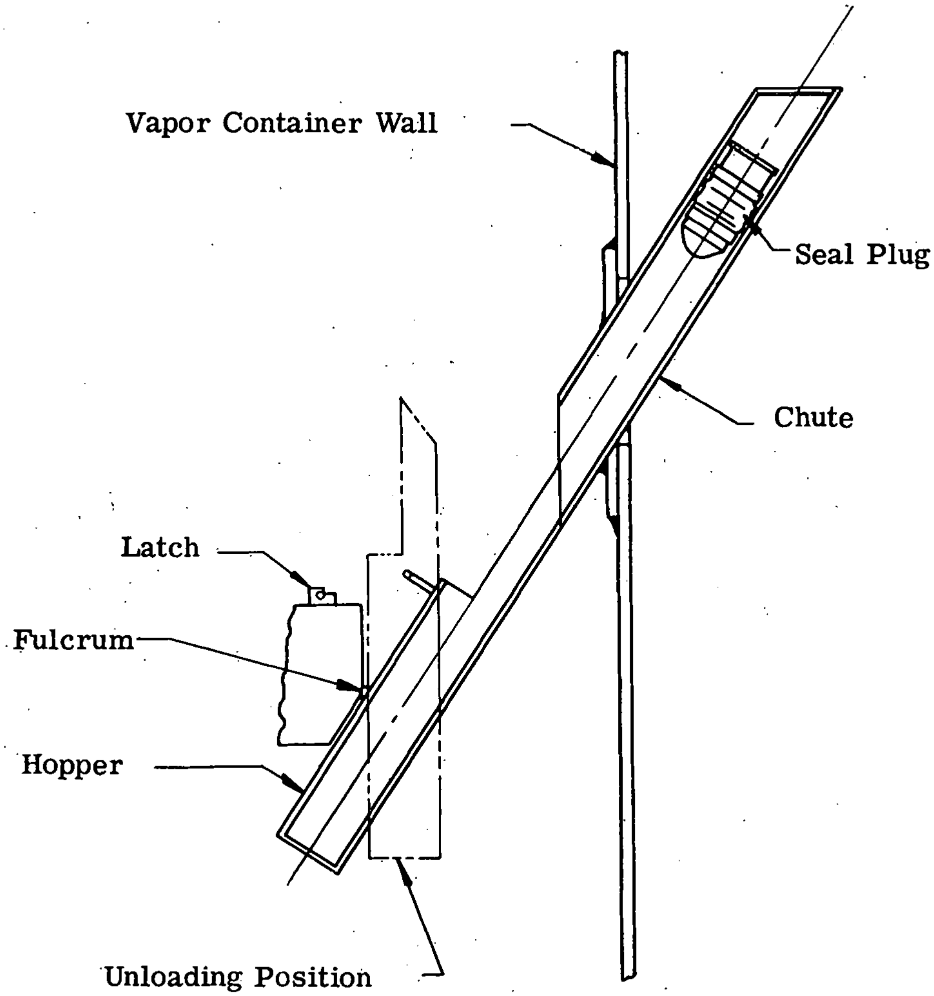


Figure VIII-2. Spent Fuel Chute Concept

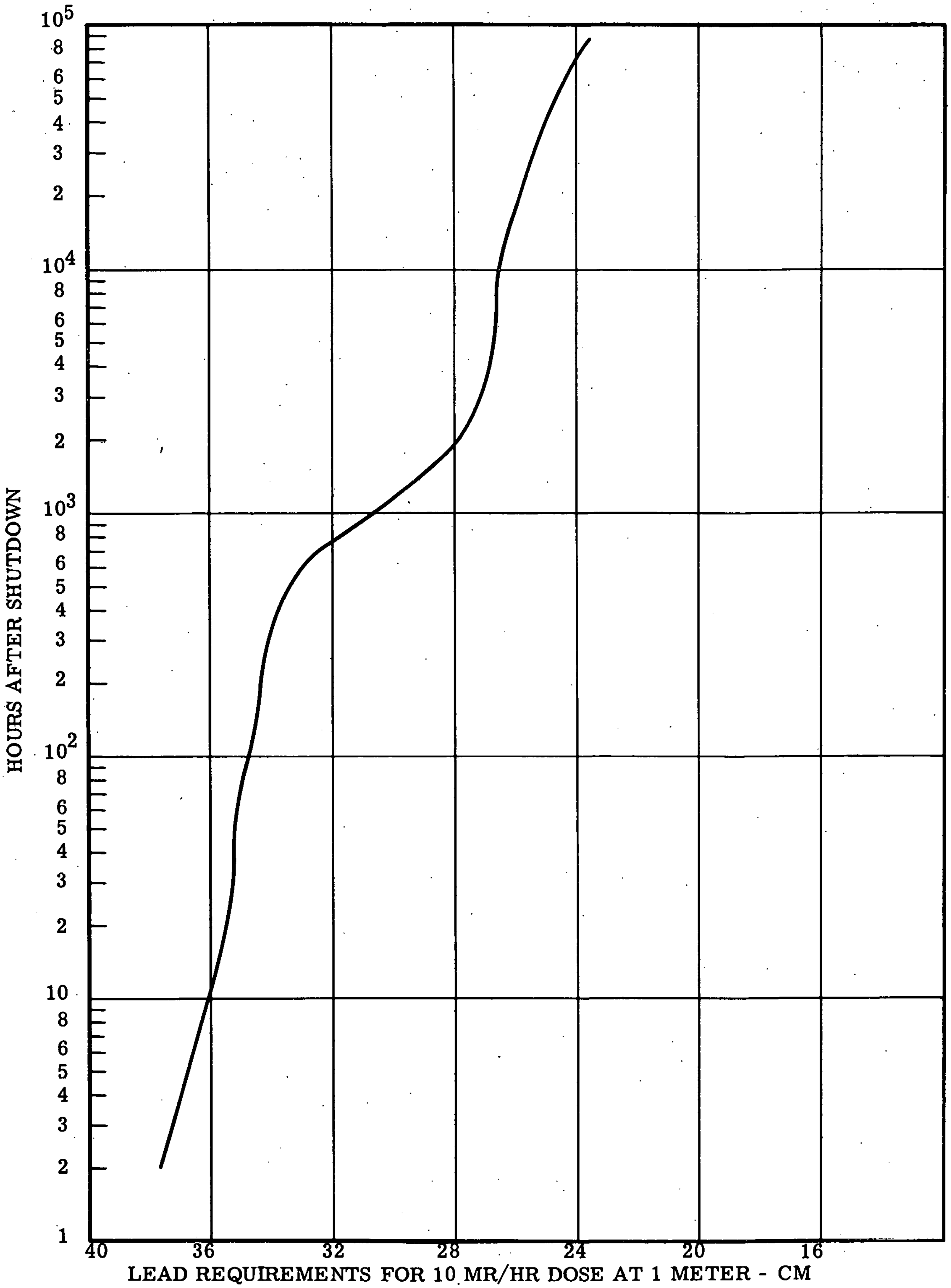


Figure VIII-3. Shielding Requirements for Shipping the Reference Core

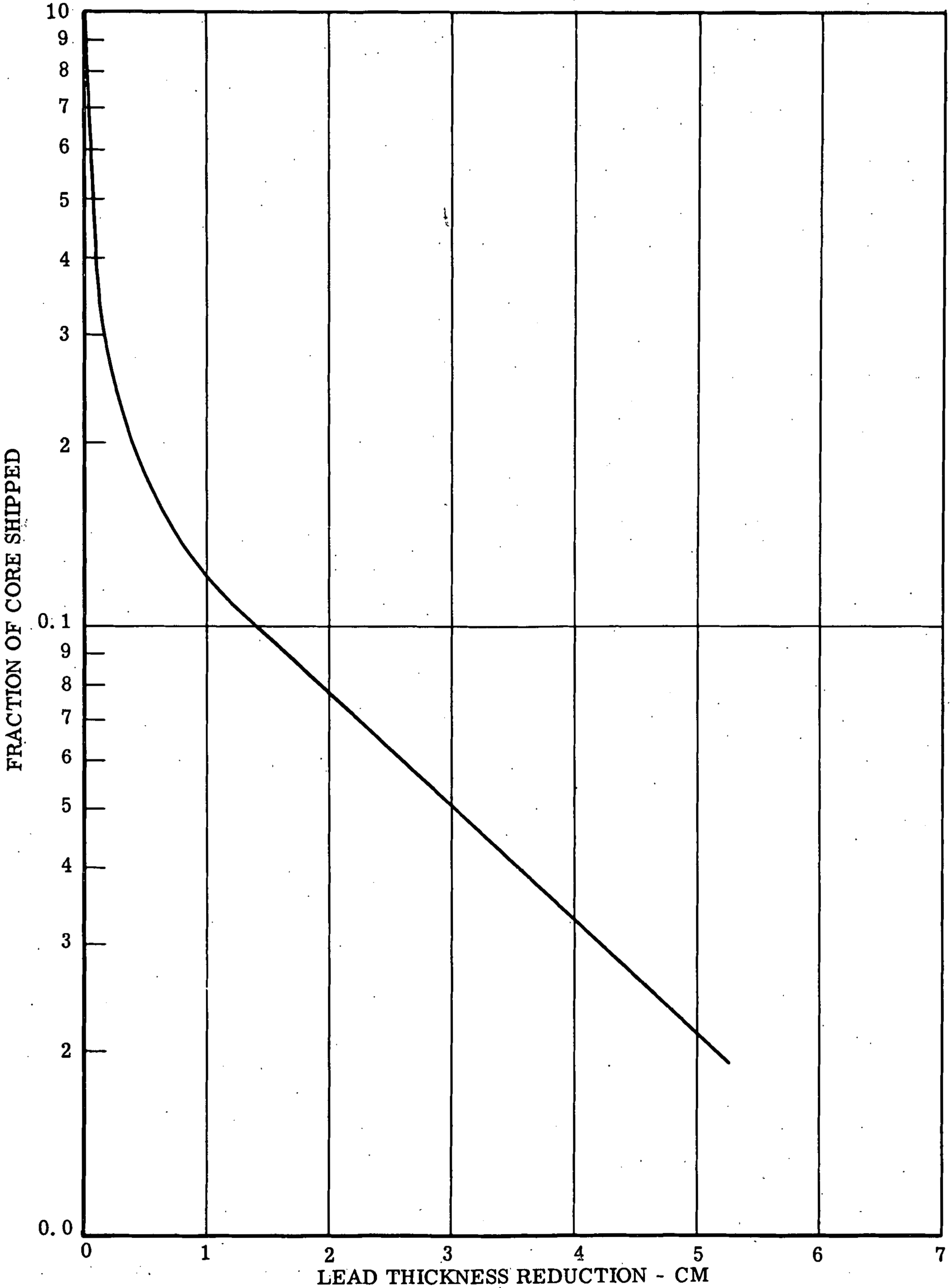


Figure VIII-4. Shipping Cask Shield Reduction for Partial Reference Core

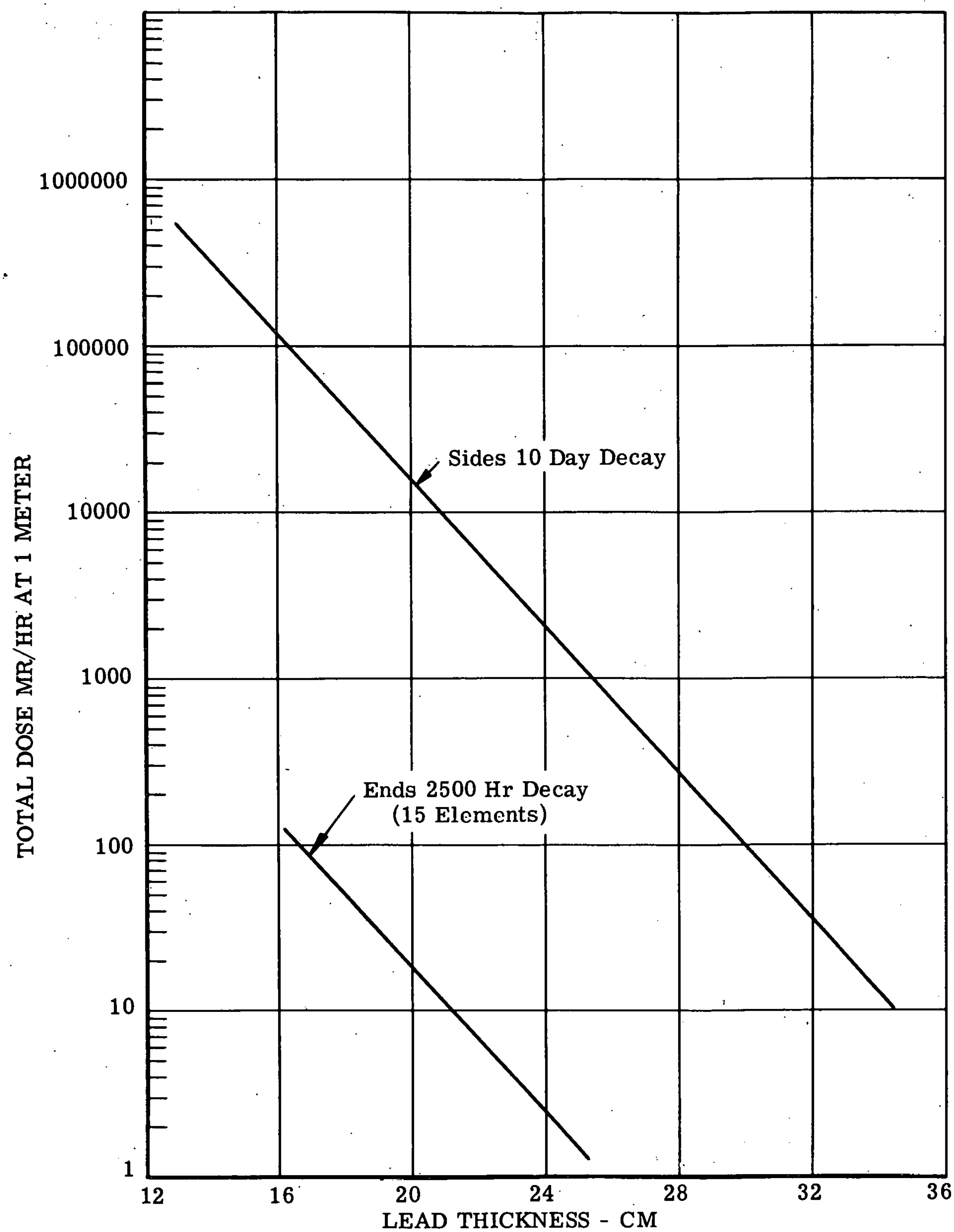
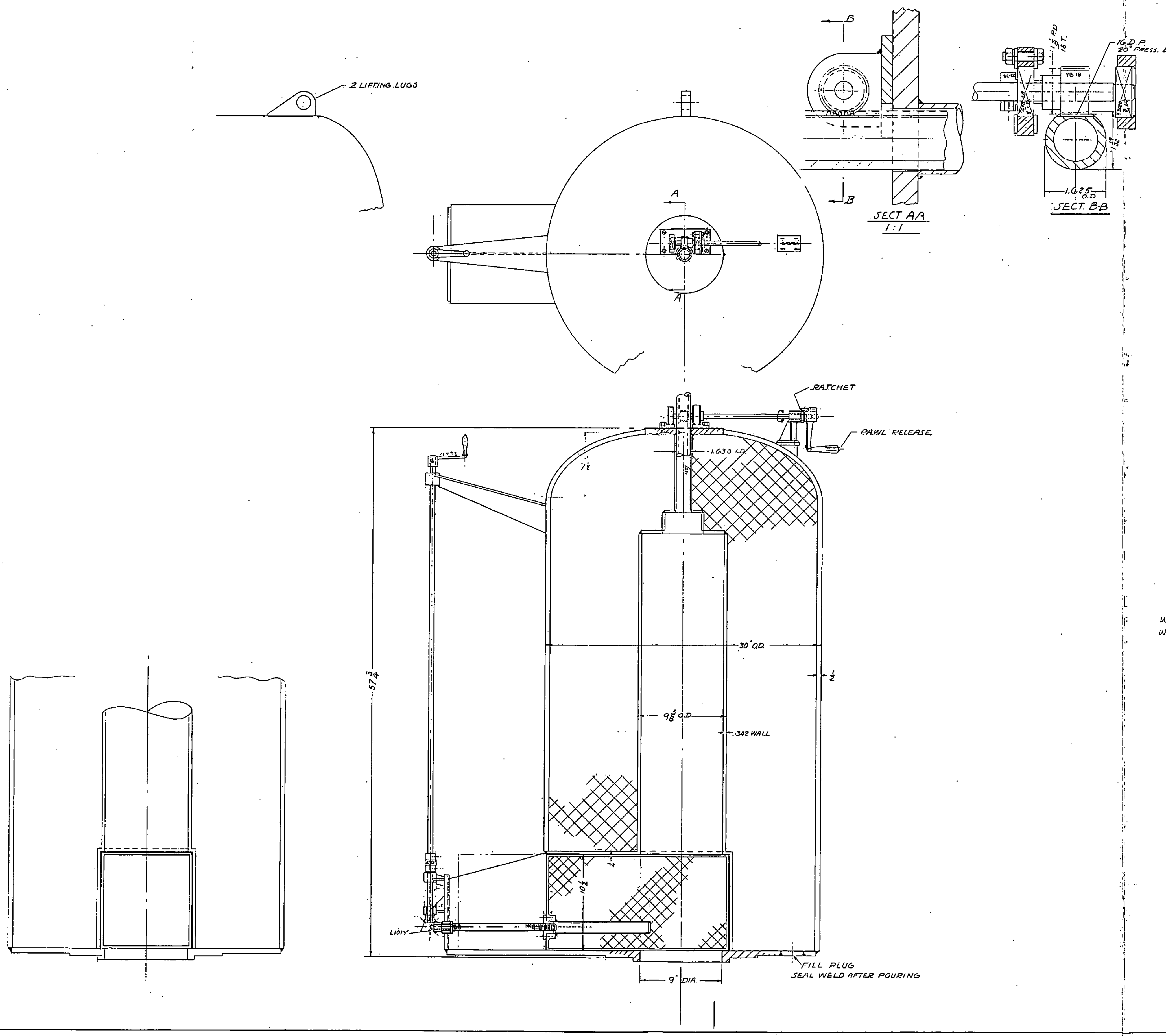


Figure VIII-5. Attenuation Curves for Reference Core



WEIGHT OF STEEL PARTS	1844 LBS
WEIGHT OF LEAD SHIELDING	14470 "
TOTAL WEIGHT	16314 LBS

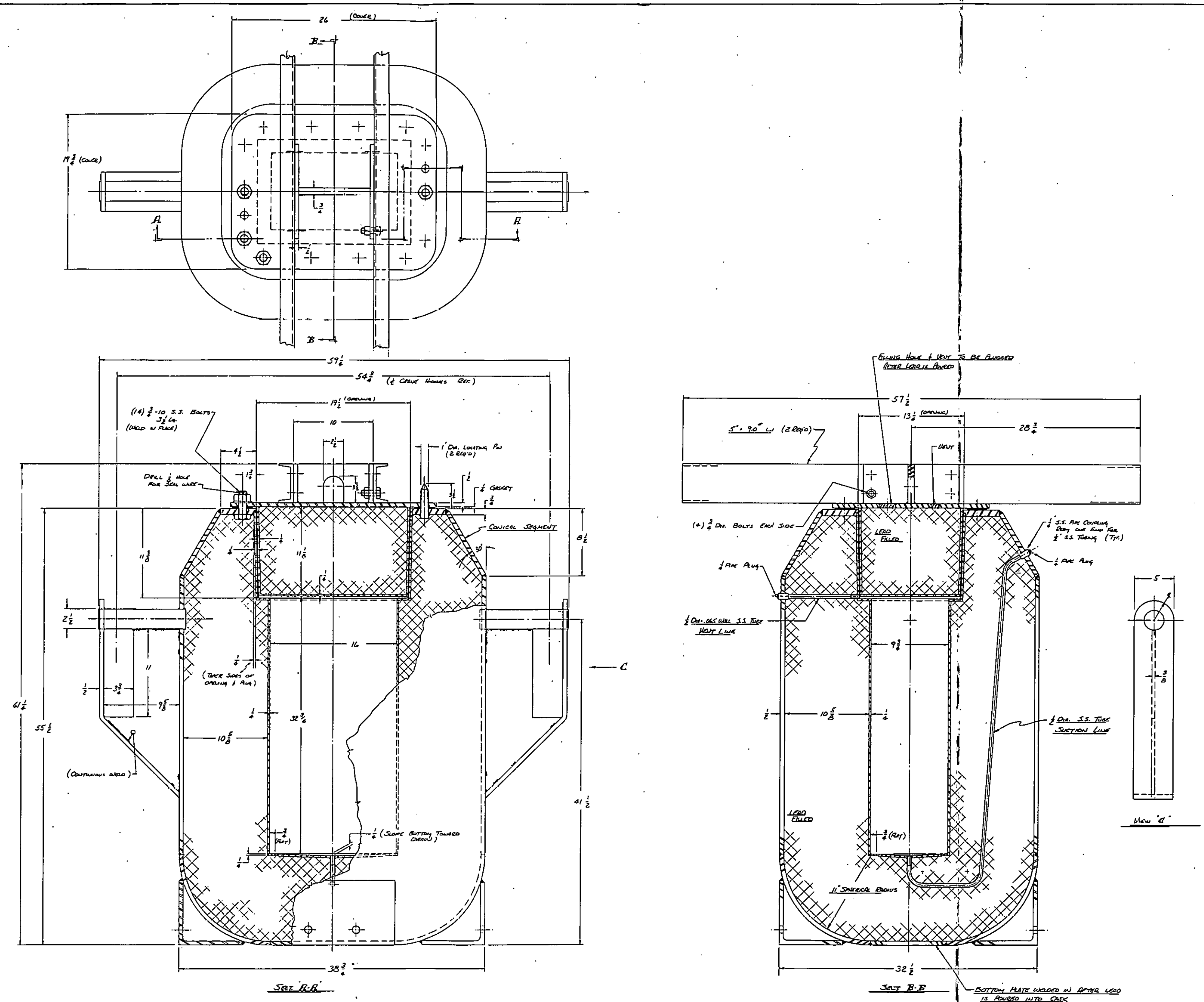
PRELIMINARY

LAYOUT
ALCO PRODUCTS INC.
SCHENECTADY, NEW YORK
ATOMIC ENERGY DEPT.

MODEL - PL-3
STARTED - FINISHED 1-5-62 - SCALE - 1/4
DRAWN BY - J. Tannenberg
DATE - 2-27-62 APPROVED - G.C. Hamilton
DATE - 2/27/62 APPROVED - R.E. Williams
DATE - APPROVED -
AUTHORITY -

TITLE - FUEL TRANSFER FLASK
BWR CONCEPT
PLATE TYPE ELEMENT

LAYOUT NO. - AEL 731



PRELIMINARY

LAYOUT
ALCO PRODUCTS INC.
SCHENECTADY, NEW YORK
ATOMIC ENERGY DEPT.

JOLL.	STARTED 1/8/62	FINISHED	SCALE ¼" = 1'
REFERENCE		DRAWN BY.	
	DATE 2-27-62	APPROVED. J.C. Hamilton	
AUTHORITY.	DATE. 2/27/62	APPROVED.	
	DATE.	APPROVED.	

TITLE- SPENT FUEL SHIPPING CASK

LAYOUT NO.- AEL-735

SHIELD OPTIMIZATION

CHAPTER IX
SHIELD OPTIMIZATION (SUBTASK 4.2.7.1)

J. F. Scoles

1.0 STATEMENT AND DISCUSSION OF TASK

Two basic reactor types were studied in the work involving shield optimization, the boiling water type (BWR) and the pressurized water type (PWR). Among these, geometrical configurations were varied as well as were dense shielding materials such as lead and iron.

It was assumed in these studies that the dense shielding material was immersed in water. Since basic criteria were minimum weight and shutdown dose, it was placed as close as possible to the reactor pressure vessel. Also, the configuration was required to be consistent with mechanical design and thermal requirements. Therefore, three cores were considered:* the highly enriched BWR, the 5 x 5 core with Type 3 elements, and the 7 x 7 core with Type 2 elements, the reference core.

2.0 OBJECTIVES OF THE TASK

The radiation level at the surface of the primary shield is restricted to 100 mr/hr at 2 hr after shutdown. The neutron flux at one mile from the PL-3 is restricted to 1 neutron per meter^2 per minute. Restrictions are also imposed on radiation levels during reactor operation in the plant and camp areas, thus limiting the air scatter dose. An outside shield radius of about 7.5 ft is dictated by the neutron limit. Operating dose limitations do not appear at this time to be limiting criteria. The basic remaining objective is the shutdown dose rate.

Since minimum shipping weight, ease of construction and reliability are required, a study of material combinations which will perform the required shielding is required. This dictated a parametric shield optimization study.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

The calculational method used to obtain required dose rates for the shielding study was a machine code for primary shielding written at Alco Products and

* Humphries, G. E. (Proj. Eng.), "PL-3 Concept Selection," Alco Products, Inc., AP Note-408, January 31, 1962.

known as the ROC Code.* The code obtains dose rates for both operating and shutdown reactor conditions. It differentiates between the dose contributed by the core as a source and that contribution considering neutron reactions in the materials of the shield as a source, the shield here being defined as that portion of the configuration exterior to the core. Basic input information consists of material and geometrical data as well as normalized two-group neutron flux values. Output consists of dose rates due to five different source energy groups.

Shielding materials investigated were lead, iron and water. The thickness of lead was varied from 0 to 4 in., the iron investigated varied from one 2 in. ring to four 2 in. rings with a 1 in. water annulus between each ring.

The reference configuration was taken as one with a 7 x 7, Type 2 PWR employing a stainless steel pressure vessel of 40 in. ID.

A detailed description of all configurations studied will soon be published, but a table of configurations and reactor conditions is given here in summary form.

TABLE IX-1
REACTOR CONFIGURATIONS AND CONDITIONS OF OPERATION

Reactor Type	Core	Pressure Vessel Material	Gamma Shielding	Operating Conditions
BWR	High enriched	Clad carbon steel	0" Pb	Shutdown/
		59.5" ID	1.5" Pb	Shutdown
			4" Pb	Shutdown
PWR	5 x 5 Type 3	Clad carbon steel	0" Pb	Shutdown
		3" steel reflector	1.5" Pb	Shutdown
			4"	Shutdown
PWR	7 x 7 Type 2	Clad carbon steel	0" Pb	Shutdown
		1.125" wall	1.5" Pb	Shutdown
		0.25" stainless clad	4" Pb	Shutdown
		51.5" ID	0" Pb	Operating
			1.5" Pb	Operating
			4" Pb	Operating
PWR	7 x 7 Type 2	Clad carbon steel	2" Fe	Shutdown
			6" Fe	Shutdown
			8" Fe	Shutdown
PWR	7 x 7 Type 2	Stainless steel	2.5" Pb	Shutdown
		2.5" wall		Operating
		40" ID		

/ All shutdown runs made 0.1 day after operation.

* Rosen, S.S., Oby, P.V., Caton, R.L., "Preliminary Shield Calculations on the IBM-650 (ROC Codes)," Alco Products, Inc., APAE Memo-143, October, 1958.

Neutron flux distributions were normalized to true flux values for each reactor. From the neutron distribution, it was possible to obtain flux values thru the shield region to be used as part of the input to obtain gamma doses due to neutron interactions in the shield materials.

4.0 CONCLUSIONS

Conclusions are presented here in the form of two typical plots. Figure IX-1 shows the gamma dose rate from the core centerline for the reference configuration. Figure IX-2 shows the thickness of lead as a function of shield radius both to meet the neutron flux limit and the gamma shutdown dose rate limit.

5.0 CONTINUING WORK

The development item proposed for continuation of this effort, Primary Shielding Development Studies will complete this effort and includes also experimental evaluation of the performance of the primary shielding for configurations near those indicated optimum in this study.

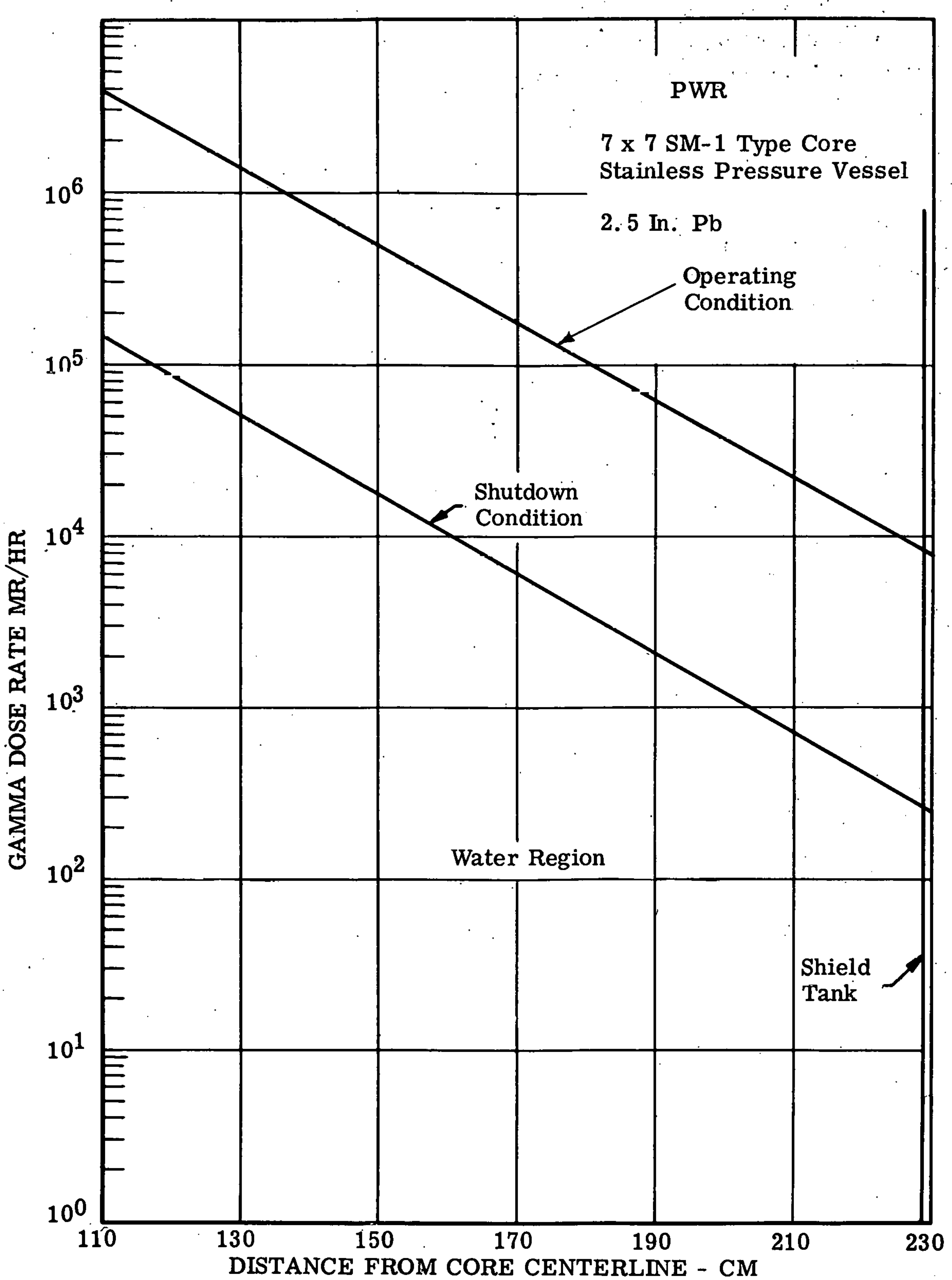


Figure IX-1. Gamma Dose Rate Vs. Distance from Centerline of Core

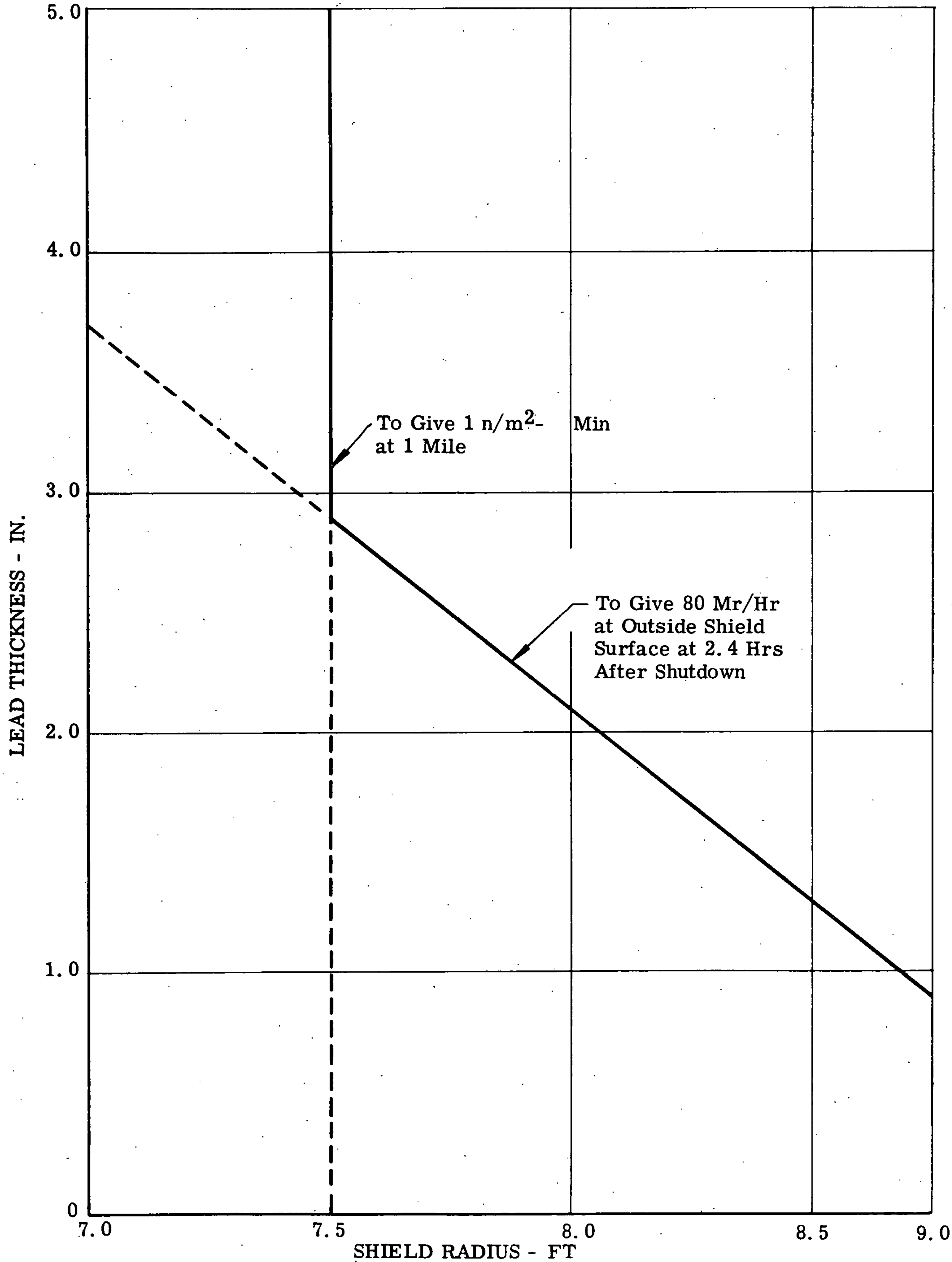


Figure IX-2. Lead Thickness Vs. Primary Shield Radius

SHIELD
EFFECTIVENESS

CHAPTER X
SHIELDING EFFECTIVENESS (SUBTASK 4.2.7.2)

J. F. Scoles

1.0 STATEMENT AND DISCUSSION OF THE TASK

Minimum shipping weight consistent with ease of construction and safety have dictated that the primary shield be of optimum design. Water is available on-site and need not be shipped in. This suggests its extensive use for shielding. The neutron leakage from the shield and to a radius of one mile is also limited.

This optimization problem may be approached by utilization of advanced shielding codes and experimental data. The shielding codes will provide analytical evaluation of the shielding. Experimental data available or specially performed will provide empirical evaluation of the shielding configurations.

2.0 OBJECTIVES OF TASK

Early objectives of this effort were to perform literature surveys to gather information available on shielding experiments and shielding codes which might be of use in the PL-3 shield design effort. It soon became evident that more experimental data are needed than are now available. This leads to an additional objective, that of identifying facilities which could provide additional needed experimentation.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

A literature survey of computer codes was made from published lists, Nuclear Science Abstracts and unpublished material. Information sought for each code of potential interest included code identification, computer and programming system, nature of the problem solved, method of solution, restrictions on the code, options available, machine running time, references, author (s) and issuing facility. This information will be published in a topical report to be issued shortly.*

* Scoles, J. F., et al, "Studies of Shielding Optimization and Effectiveness for PL-3," Alco Products, Inc., APAE Memo-315, to be issued.

The search for experimental shielding data revealed the following of interest to the PL-3.

ORNL-2518* summarizes all of the pure water data for the BSR. These data were taken along an axis from one face of the BSR in its pool. No intervening materials were between the reactor and detectors. Measurements were made to 175 cm from the reactor face for fast neutrons, 765 cm for gamma radiation, and 460 cm for thermal neutrons. The lack of independance between gamma radiation and thermal neutrons is evidenced in these curves. Near the reactor, captures of thermal neutrons and accompanying production of 2.2 Mev gamma radiation contributes significantly to the gamma dose (0 to 50 cm). At large distances form the reactor, practically all of the thermal neutron flux is due to photoneutron production (beyond 180 cm).

NARF-55-85T describes the lead shadow shield experiment performed by Convair.** In the experiment, lead slabs up to 9 in. in thickness were placed between the GTR and detector locations along an axis perpendicular to the reactor face. Fast neutrons and gamma dose measurements were taken to as far as 175 cm from the reactor face in one configuration with many measurements to 125 cm. No thermal neutron measurements were reported.

Similar measurements were made at the BSR with lead slabs in water. However, these are reported in classified documents, access to which is not permitted under the contract.

In all of these configurations, an aluminum structure reactor in an open pool with only lead slabs is used. Since the PL-3 will have a stainless steel structure core, stainless steel pressure vessel (and perhaps stainless steel thermal shielding), steel shield tank walls, steel jacketing on the lead shielding, and high neutron cross section vessel insulation, the experimental data available cannot be expected to provide the empirical shield evaluation needed. With this in mind, an effort was made to identify a facility which could mock-up the reactor leakage incident upon the shielding and test the effectiveness of several shield configurations near that to be used on the PL-3.

A literature survey was conducted to locate suitable research reactor facilities with the capabilities to perform an experimental shielding effectiveness program. This survey included university research reactor facilities, AEC-owned facilities, other government owned and privately operated facilities, and privately owned and operated facilities. Out of 35 facilities tabulated during the search, 12 were eliminated because of insufficient reactor power ratings (below 100 kw (t)). The remaining 23 facilities were mailed a letter of inquiry in an

* "Attenuation in Water of Radiation from the Bulk Shielding Reactor," Oak Ridge National Laboratory, ORNL-2518, undated.

** Harris, J. W., "An Investigation of Shadow Shielding in Water," Convair, NARF-55-85T, 1956.

attempt to gather additional information about these facilities and their capabilities. The replies were tabulated with respect to pertinent information: availability and presently scheduled experimentation, adequacy of reactor power level, equipment available for use during the experimental program, manpower capability and background in similar types of slab shielding experiments and manpower available to perform an experimental program for the PL-3 shielding effectiveness study. Based on this tabulation, the university facilities were eliminated because of lack of manpower and, to some extent, lack of equipment required to perform the experiment adequately. The privately owned and operated facilities did not lend themselves to a slab shielding experiment. The AEC-owned facilities, in general, had prior experimental commitments and were not available for use for this program; other government-owned and privately operated facilities, with the exception of General Dynamics/Fort Worth, were not equipped to perform the slab shielding experiments proposed for the PL-3. As a carryover from the ANP program, General Dynamics/Fort Worth had available a slab shielding facility(outside ASTR Tank Facility), an adequate number and size of lead, steel and borated material slabs for the experimental program, more than adequate dosimetry equipment and a shielding staff with an average of approximately 6 years' experience per engineer in experimental and theoretical shield design experience. After a visit by two Alco engineers to personally evaluate this facility and the firms capabilities, the decision to select it was made. This selection was justified on the basis of available equipment, slabs and capabilities.

4.0 CONCLUSIONS REACHED

Sophisticated machine codes are available for the IBM-7090 and should be obtained for use in PL-3 shielding design analysis. Two such codes are the G. E. Flexible Monte Carlo Code and the General Dynamics Shield Penetration Code.

No experimental shielding data are available sufficiently near the PL-3 configuration to permit it to be used as experimental verification. An experiment is needed if the shield activation (for shutdown dose) and shield neutron capture reactions (for operating gamma dose) are to be adequately evaluated.

5.0 CONTINUING WORK

As a part of the engineering effort toward shield design, it is planned to make operational and use one or more advanced shielding codes for PL-3 design analysis.

As a part of the primary shielding development studies proposed for PL-3 Phase II development effort, a comprehensive slab shielding experiment is planned.

CRIT. EXPER. ON 5 x 5
ARRAY (TYPE 3 FE)

CHAPTER XI
CRITICAL EXPERIMENTS ON A 5 x 5 ARRAY OF TYPE 3 FUEL ELEMENTS (SUBTASK 4.2.8)

S.N. Kemp

1.0 STATEMENT AND DISCUSSION OF THE TASK

Critical experiments performed at the Alco criticality facility investigated the feasibility of utilizing a small diameter, advanced high performance, pressurized water reactor core to satisfy the design objectives of the PL-3. The core selected for experimentation consisted of a 5 x 5 lattice array of Type 3 mockup fuel elements, controlled with either four or five control rods of the absorber-fuel element follower type (Fig. XI-1). The fuel cell was a square, 2.94 in. on a side, yielding a small equivalent core diameter of 16.6 inches. The metal/water ratio was approximately 0.352 and the overall fuel height was 22 inches.

Experiments performed included five and four rod bank calibrations, reactivity effect of a water reflector versus a laminated steel reflector of various thickness, stuck rod configurations, and temperature coefficient measurements.

2.0 OBJECTIVES OF THE TASK

These experiments were needed to support the analysis made upon this core, because extrapolation of experimental data obtained on larger cores results in uncertainties difficult to access. These data were then utilized as backup information during the concept selection.

3.0 DESCRIPTION OF WORK ACCOMPLISHED

The initial core loading contained 20 Kg of U-235 and approximately 33.6 grams of B-10 in the form of uniformly distributed boron-impregnated Mylar tape. The stationary fuel elements contained 18 fuel plates, each loaded with 46.3 grams of U-235. The control rod fuel elements contained 16 similar fuel plates, each loaded with 42.2 grams of U-235. The boron was removed in approximately 6 gram increments to drive the critical bank position in and obtain the differential worth curves for both the four and five rod banks.

During removal of the boron-impregnated Mylar tape, the B-10 worth was evaluated by following the reactivity change with the calibrated control rod bank.

Immersion heaters and a mixer were used in the reactor tank to increase the moderator temperature from room temperature (68°F) to 115°F. The change in reactivity associated with the change in temperature was determined by the change in critical position of calibrated control rod A.

The relative worth of three solid stainless steel reflectors approximately 1/2, 1, and 2.5 in. thick with an essentially infinite water reflector were evaluated by observing the change in reactivity for the four and five rod configurations on a calibrated control rod bank.

Since all four rod bank measurements were made with the central control rod fully withdrawn, and there exists a difference in U-235 loading between a stationary element and a control rod element. The difference in reactivity was measured for a central stationary element and the central rod element. The four rod critical bank position was established with the center control rod fully withdrawn and a four rod critical bank position was again established with a stationary element substituted for the central control rod. The difference in reactivity attributed to the two different calibrated bank positions determined the reactivity difference.

Stuck rod configurations were evaluated for both the four and five rodded cores. These were made in order to determine whether these cores would meet the stuck rod criteria set forth for the PL-3.

4.0 CONCLUSIONS REACHED

Based on the results of this experimental program, the following conclusions can be drawn.

1. The cold, clean, critical bank positions and K_{ex} with no burnable poison in the core for the four and five control rod combinations were 4.00 in. and 4.75 in., and 26.3 dollars and 26.4 dollars, respectively. Calculations based upon the experimental data indicated an expected core life of approximately 15 MWYR, adequate for the PL-3 design criteria.

2. In the five control rod configuration, with the 9.5 grams of B-10 loading, all control rods exhibited a reversal of worth; i.e., the rod at or near the fully withdrawn position had a positive worth over the upper 3 in. of travel during insertion, when the remaining four rods were banked. However, in the same core with the four rod configuration, there was no worth reversal indicated.

3. The following relative worths were determined for three solid stainless steel reflectors when compared to an infinite water reflector: +110.8 cents for a 2.6 in. thickness; -126.0 cents for a 1.0 in. thickness; -183.2 cents for a 0.5 in. thickness. This indicates a gain of approximately 1.11 dollars in reactivity if a steel reflector of greater than 2.5 in. in thickness is used in conjunction with this core.

4. A negative temperature coefficient determined for the core surrounded by a 2.575 in. thick stainless steel reflector was approximately 1.05 cents/^{o}F at 115^{o}F.

5. The core would be subcritical with any one rod stuck in the out position and the remaining control rods fully inserted, thus satisfying a PL-3 design criteria.

5.0 RECOMMENDATIONS

Based on results of this experimental program, the 5 x 5 array of Type 3 fuel elements with a four control rod configuration shows promise for use as a core for a small, portable power plant. However, future experimentation should be conducted to investigate power distributions, power spikes and the use of flux suppressors to avoid abnormal power spikes, and to determine the optimum (B-10) burnable poison loading to allow the best performance throughout core life.

6.0 HIGHLIGHTS OF WORK

All reactivity measurements were taken by measuring the difference in control rod position to achieve criticality between some reference condition and the condition under investigation. The reactivity worth of moving the single rod or bank was established by a series of control rod calibrations obtained using the period method at various control rod or bank locations. The total worth of a reactivity measurement was obtained from the difference in the critical positions of a calibrated control rod or bank.

The initial core loading contained 20 Kg of U-235 and approximately 33.6 grams of B-10 in the form of uniformly distributed Mylar tape impregnated with boron, which was removed in approximately 6 gram increments to drive the control rod bank and obtain the differential worth curves for both the four and five rod systems. All control rod calibrations were made by period measurements. After a critical position was established, the rod or rods to be calibrated were raised above the critical position to put the reactor on about a 30 second period. The period was related to the reactivity change divided by the change in rod positions, which yields the differential rod worth at a point midway between the critical position and the period position. The differential rod worth curves of the four and five control rod bank are given in Fig. XI-2 and XI-3 respectively. The four control rod bank calibration was made with the central control rod C fully withdrawn. These measurements were taken as a function of grams B-10 in the core, Fig. XI-4 and XI-5.

The differential rod worth curve for control rod A is given as Fig. XI-6. These measurements were taken with 9.526 grams of B-10 in the core and a 2.575 in. thick stainless steel reflector. The data and calculation sheets for these measurements are given as Tables XI-1, XI-2 and XI-3.

The average core temperature is plotted as a function of the critical position of calibrated control Rod A in Fig. XI-7. These measurements were made with a B-10 loading of 9.526 grams and a 2.575 in. thick stainless steel reflector. Table XI-4 shows the temperature coefficient of this core configuration in cents reactivity per degrees F at temperatures from 61°F to 115°F and Table XI-5 is the data and calculation sheet.

Table XI-6 shows the results of the relative stainless steel reflector worths for an essentially infinite water reflector. It can be seen that by replacing the water by a solid 2.575 in. stainless steel reflector, a positive reactivity gain of 110.82 cents was achieved. However, the thinner stainless steel reflectors decreased the core reactivity compared to the water-reflected core. The data and calculation sheet is given as Table XI-7.

With 9.526 gram B-10 core loading, an essentially infinite water reflector and a room temperature of 68°F, criticality was determined for the configurations given in Table XI-8. Included in the same table are the results of the measurements, given as the measured critical position.

The reactivity of the center stationary fuel element, position #33, is greater then the central control rod fuel element by 141.46 cents. This measurement was made with a 9.526 gram B-10 Loaded core and an essentially infinite water reflector. The data and calculation sheet is given as Table VI-10.

TABLE XI-1
5 ROD BANK CALIBRATION

Boron-Loading (gms)	Critical Bank Positions					Supercritical Bank Positions					X_1 5 Rod Average Critical Position	X_2 5 Rod Average Super-critical Position	$\Delta X = X_2 - X_1$	$\bar{X} = X_1 + \frac{\Delta X}{2}$	Slope of Log N	$\Delta \rho$	$\frac{\Delta \rho}{\Delta x}$
	A	B	C	D	E	A	B	C	D	E							
33.584	14.050	14.048	14.050	14.044	14.042	14.150	14.159	14.153	14.158	14.160	14.047	14.156	.109	14.102	37.0	11.37	104.31
	14.045	14.046	14.050	14.048	14.042	14.254	14.262	14.261	14.261	14.258	14.046	14.259	.213	14.152	15.6	22.33	104.84
27.480	10.813	10.820	10.816	10.819	10.819	10.923	10.938	10.939	10.938	10.928	10.818	10.923	.105	10.870	14.51	23.4	174.62
						10.945	10.958	10.953	10.952	10.953		10.952	.134	10.885	18.75	19.78	172.0
21.377	8.757	8.759	8.750	8.762	8.753	8.811	8.803	8.821	8.811	8.808	8.755	8.811	.056	8.783	32.4	12.9	230.36
						8.841	8.861	8.846	8.842	8.849		8.848	.093	8.801	16.3	21.7	233.33
15.274	7.489	7.494	7.497	7.494	7.490	7.532	7.550	7.547	7.553	7.544	7.493	7.545	.052	7.519	29.3	14.08	270.77
						7.576	7.574	7.587	7.576	7.570		7.577	.084	7.535	13.8	24.17	287.74
9.526	6.226	6.228	6.229	6.226	6.231	6.279	6.283	6.283	6.282	6.293	6.228	6.284	.056	6.256	18.6	19.88	355.00
						6.302	6.298	6.310	6.300	6.314		6.305	.077	6.267	11.1	27.46	356.60
5.360	5.725	5.723	5.724	5.720	5.720	5.770	5.780	5.780	5.770	5.776	5.722	5.775	.053	5.748	17.0	21.05	397.17
0	4.740	4.752	4.750	4.753	4.755	4.788	4.790	4.789	4.789	4.785	4.750	4.788	.038	4.769	22.0	17.7	467.00
						4.812	4.790	4.820	4.795	4.794		4.802	.052	4.776	13.2	24.8	477.00

TABLE XI-2
4 ROD BANK CALIBRATION

Boron Loading (gms)	Critical Bank Positions A	Critical Bank Positions B	Critical Bank Positions D	Critical Bank Positions E	Supercritical Bank Positions A	Supercritical Bank Positions B	Supercritical Bank Positions D	Supercritical Bank Positions E	X_1 4 Rod Average Critical Position	X_2 4 Rod Average Supercritical Position	$\Delta X = X_2 - X_1$	$\bar{X} = X_1 + \frac{\Delta X}{2}$	Scope of Log N	$\Delta \rho$ cents	$\frac{\Delta \rho}{\Delta x}$ $\frac{\text{cents}}{\text{inch}}$
33.584	13.672	13.658	13.668	13.672	13.861	13.849	13.850	13.850	13.657	13.872	.195	13.755	19.1	19.57	100.4
					13.899	13.898	13.900	13.900		13.899	.242	13.778	14.0	23.97	99.1
27.480	10.394	10.393	10.386	10.391	10.487	10.481	10.498	10.500	10.391	10.492	.101	10.441	25.0	16.05	158.9
					10.538	10.538	10.531	10.530		10.534	.143	10.463	14.4	23.48	164.2
21.377	8.290	8.287	8.288	8.269	8.339	8.341	8.348	8.347	8.283	8.344	.061	8.313	29.5	14.05	230.3
					8.387	8.387	8.399	8.380		8.388	.105	8.335	13.1	24.9	237.1
15.274	6.988	6.987	6.989	6.984	7.055	7.057	7.041	7.057	6.987	7.052	.065	7.019	20.3	18.70	287.7
					7.090	7.089	7.085	7.094		7.089	.102	7.038	11.0	27.5	269.6
9.526	5.669	5.670	5.672	5.668	5.716	5.718	5.719	5.720	5.670	5.718	.048	5.694	23.25	16.97	353.5
					5.739	5.745	5.744	5.747		5.744	.074	5.707	12.2	25.96	350.8
5.360	5.093	5.091	5.092	5.092	5.139	5.141	5.131	5.141	5.092	5.138	.046	5.115	24.1	16.52	359.1
0	4.001	4.00	3.999	4.000	4.029	4.033	4.034	4.040	4.000	4.034	.034	4.017	30.1	13.75	405
					4.055	4.058	4.058	4.057		4.057	.057	4.029	16.9	21.15	372

TABLE XI-3
CALIBRATION OF ROD A

	Critical Position					X_2 Supercritical Position of Rod A	$\Delta X = X_2 - X_1$	$\bar{X} = X_1 + \frac{\Delta X}{2}$	Slope of Log N	$\Delta\rho$	$\frac{\Delta\rho}{\Delta X}$ $\frac{\text{Cents}}{\text{Inch}}$
	X_1 A	B	C	D	E						
1	10.008	4.000	21.600	4.000	4.000	10.244	.236	10.126	27	15.12	64.07
2	9.829	4.052	21.600	4.050	4.052	10.120	.291	9.974	20.7	18.48	63.51
3	9.550	4.127	21.600	4.122	4.129	9.788	.238	9.669	26.5	15.33	64.41
4	9.292	4.195	21.600	4.198	4.198	9.596	.304	9.444	17.9	20.35	66.94
5	8.888	4.302	21.600	4.306	4.305	9.232	.344	9.060	14.5	23.48	68.25
6	10.541	3.856	21.600	3.854	3.854	10.847	.306	10.694	21.1	18.25	59.64

TABLE XI-4
TEMPERATURE COEFFICIENT MEASUREMENTS - 2.575 INCHES
STAINLESS STEEL REFLECTOR - 9.526 GRAMS B-10

Temperature °F	Reactivity Cents/°F
61.3	0.000
70.0	-0.261
79.6	-0.414
81.8	-0.259
83.5	-0.261
86.9	-0.536
89.1	-0.500
91.8	-0.614
93.2	-0.833
95.0	-1.02
97.8	-0.892
100.5	-1.15
102.4	-0.939
104.3	-1.07
107.2	-0.856
110.3	-0.978
113.0	-0.970
115.0	-0.928

TABLE XI-5

TEMPERATURE COEFFICIENT MEASUREMENTS - 2.575 STAINLESS STEEL REFLECTOR

Temperature ^{o}F	Rod Positions					Temperature Change ^{o}F	Rod A Change Inches	Rod A Worth Per Inches	Reactivity Change	Cents / ^{o}F
	A	B	C	D	E					
61.25	9.683	4.000	21.600	4.000	4.000	-	-	-	-	-
70.0	9.718	4.000	21.600	4.000	4.000	8.75	.035	65.15	2.28	.261
77.7	9.809	4.000	21.600	4.000	4.000	7.7	.091	-	-	-
79.56	9.821	4.000	21.600	4.000	4.000	1.86	.012	64.52	0.77	.414
81.8	9.830	4.000	21.600	4.000	4.000	2.24	.009	64.48	0.58	.259
83.52	9.841	4.000	21.600	4.000	4.000	2.72	.011	64.45	0.71	.261
86.88	9.869	4.000	21.600	4.000	4.000	3.36	.028	64.28	1.80	.536
89.06	9.886	4.000	21.600	4.000	4.000	2.18	.017	64.20	1.09	.500
91.78	9.912	4.000	21.600	4.000	4.000	2.72	.026	64.18	1.67	.614
93.16	9.930	4.000	21.600	4.000	4.000	1.38	.018	63.95	1.15	.833
95.04	9.960	4.000	21.600	4.000	4.000	1.88	.030	63.88	1.92	1.02
97.82	9.999	4.000	21.600	4.000	4.000	2.78	.039	63.69	2.48	.892
100.48	10.029	4.000	21.600	4.000	4.000	1.66	.030	63.55	1.91	1.15
102.44	10.058	4.000	21.600	4.000	4.000	1.96	.029	63.35	1.84	.939
104.32	10.090	4.000	21.600	4.000	4.000	1.88	.032	63.17	2.02	1.07
107.18	10.129	4.000	21.600	4.000	4.000	2.86	.039	62.96	2.45	.856
110.32	10.180	4.000	21.600	4.000	4.000	3.14	.049	62.73	3.07	.978
112.96	10.221	4.000	21.600	4.000	4.000	2.64	.041	62.50	2.56	.970
115.04	10.252	4.000	21.600	4.000	4.000	2.08	.031	62.34	1.93	.928

TABLE XI-6
REFLECTOR WORTH MEASUREMENTS

Reflector	Reactivity Change Cents
Water	
2.575 inch	+ 110.82
Stainless Steel	
1.030 inch	- 125.97
Stainless Steel	
0.515 inch	- 183.25
Stainless Steel	

TABLE XI-7
REFLECTOR WORTH MEASUREMENTS

Reflector	5 Rod Critical Bank Positions					5 Rod Supercritical Bank Positions					X_1 5 Rod Average Critical Position	X_2 5 Rod Average Super-critical Position	$\Delta X = X_2 - X_1$	Bank Worth Cents/Inch	Differ-ance Inches	Average Value of Worth Cents/Inch	Worth Change Cents
	A	B	C	D	E	A	B	C	D	E							
Water	6.224	6.224	6.226	6.227	6.223	6.280	6.288	6.278	6.279	6.274	6.225	6.280	.055	358.18	-	-	-
2.575 Stainless Steel	5.910	5.919	5.919	5.921	5.928	5.971	5.966	5.970	5.973	5.974	5.919	5.971	.052	366.11	.306	362.15	+ 110.82
1.030 Stainless Steel	6.591	6.589	6.588	6.589	6.588	6.659	6.660	6.660	6.651	6.656	6.589	6.657	.068	353.53	.364	355.85	- 125.97
Water	6.257	6.255	6.259	6.256	6.252	6.293	6.293	6.298	6.296	6.298	6.256	6.296	.040	357.00	-	-	-
.515 Stainless Steel	6.790	6.794	6.793	6.793	6.790	6.849	6.850	6.853	6.857	6.856	6.792	6.853	.061	353.28	.516	355.14	- 183.25

TABLE XI-8
STUCK ROD MEASUREMENTS - 9.526 GM B-10

Configuration #	Rod(s) Fully Inserted	Rod(s) Fully Withdrawn	Critical Rod(s)	Critical Position
1	ABCD		E	Subcritical
2	ABDF		C	Subcritical
3	ABD	F	C	Subcritical
4	ABC	F	D	Subcritical
5	ACD	F	B	Subcritical
6	AD	CE	B	5.251 in.
7	AB	CE	D	3.873 in.
8	ABD	C	E	Subcritical
9	E	C	ABD	7.115 in.
10	E		ABCD	7.742 in.
11	C		ABDE	9.477 in.
12*	DE	A	B	1.240 in.
13*		A	BDE	0.340 in.

* Stationary element in center core position, #33.

Table XI-9 illustrates the configuration and results of the same core arrangement with no B-10 loading.

TABLE XI-9
STUCK ROD MEASUREMENTS - NO B-10

Configuration #	Rod(s) Fully Inserted	Rod(s) Fully Withdrawn	Critical Rod(s)	Critical Position
1	ABCD		E	Subcritical
2	ABDE		C	Subcritical
3	ABD	E	C	6.990 in.
4	ABC	E	B	7.258 in.
5	ACD	E	B	12.463 in.
6	AD	CE	B	Supercritical
7	AB	CE	D	Supercritical
8	ABD	C	E	10.570 in.
9	E	C	ABD	5.911 in.
10	E		ABCD	5.745 in.
11	C		ABDE	6.710 in.

TABLE XI-10

REACTIVITY DIFFERANCE (STATIONARY ELEMENT - CONTROL ROD ELEMENT)

	4 Rod Critical Bank Positions				4 Rod Supercritical Bank Positions				X_1 4 Rod Bank Average Critical Position	X_2 4 Rod Bank Average Super-critical Position	$\Delta X = X_2 - X_1$	$\bar{X} - X_1 + \frac{\Delta X}{2}$	Slope of Log N	$\Delta \rho$	$\frac{\Delta \rho}{\Delta X}$ $\frac{\text{Cents}}{\text{Inch}}$
	A	B	D	E	A	B	D	E							
Central Control Rod Element	5.669	5.670	5.672	5.668	5.739	5.745	5.744	5.747	5.760	5.744	.074	5.707	12.3°	25.96	350.81
					5.716	5.718	5.719	5.720		5.718	.048	5.694	23.25°	16.97	353.54
Central Stationary Element	5.354	5.357	5.354	5.352	5.413	5.416	5.420	5.425	5.354	5.418	.064	5.386	15.9°	22.06	344.69

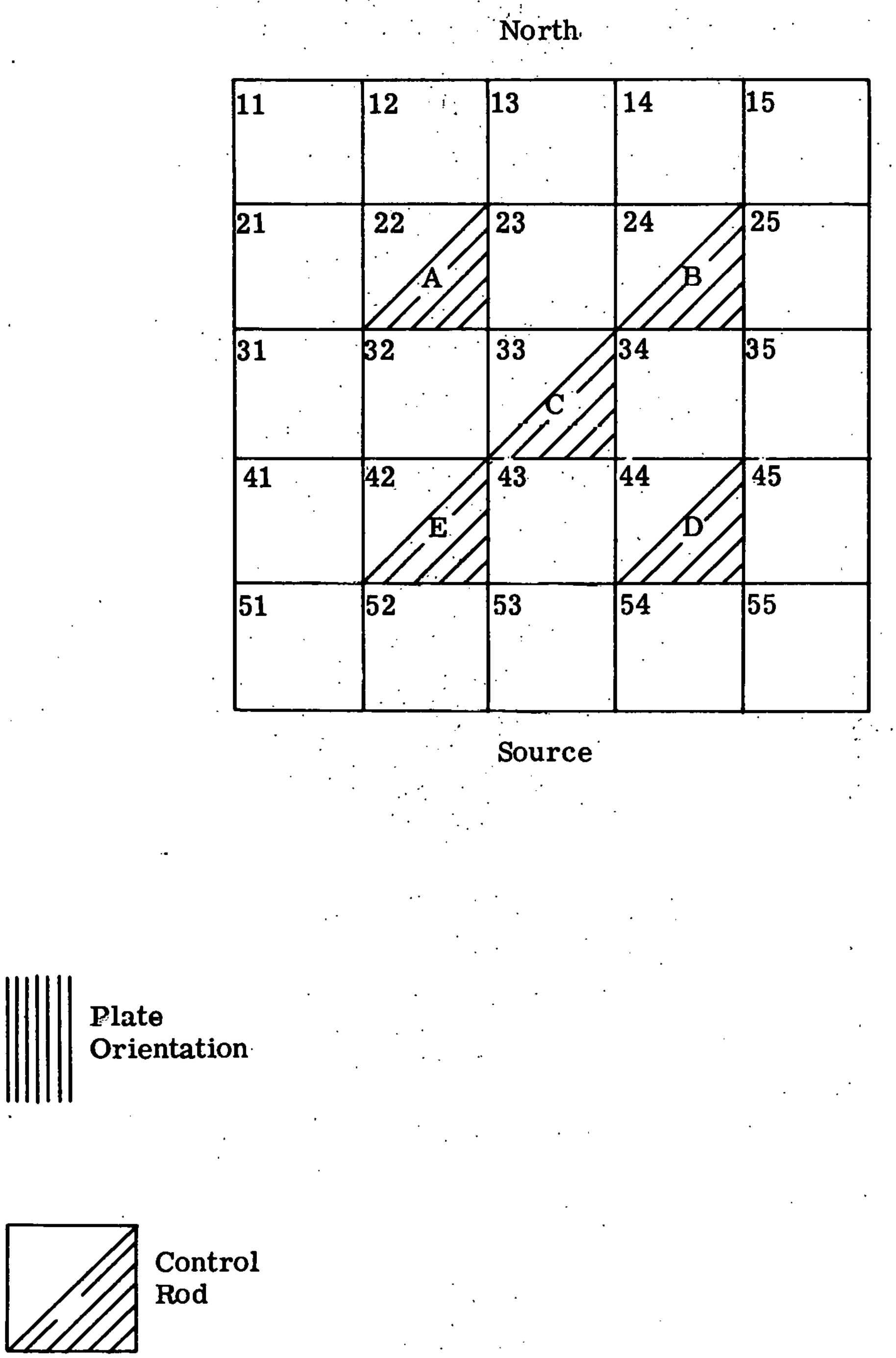


Figure XI-1. Positioning of a 5 x 5 Array of Type III Elements; 5 Control Rod Core for PL-3 Mock-up.

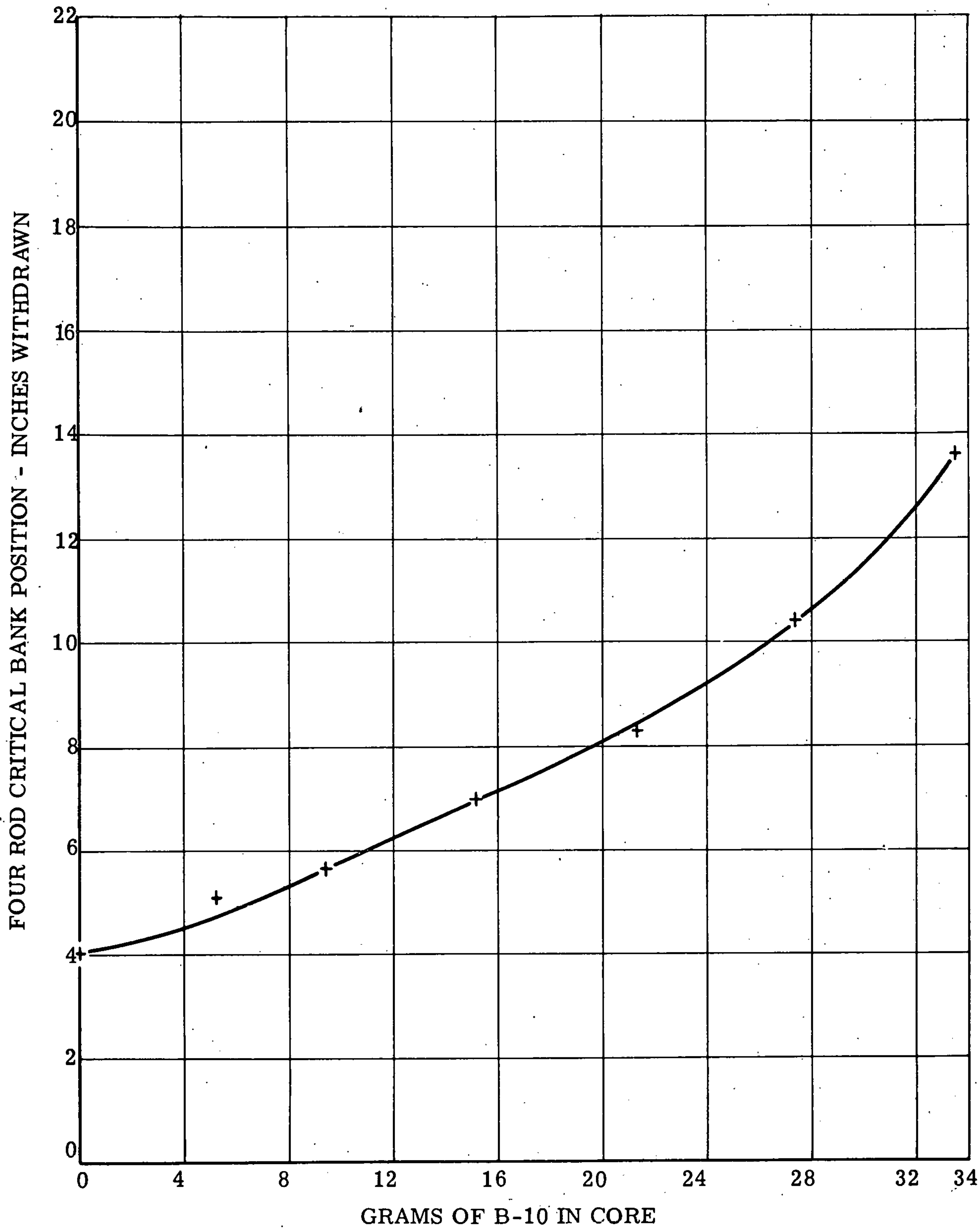


Figure XI-2. Four Rod Critical Bank Position Versus Grams B-10 in a 5 x 5 Array of Type III Elements

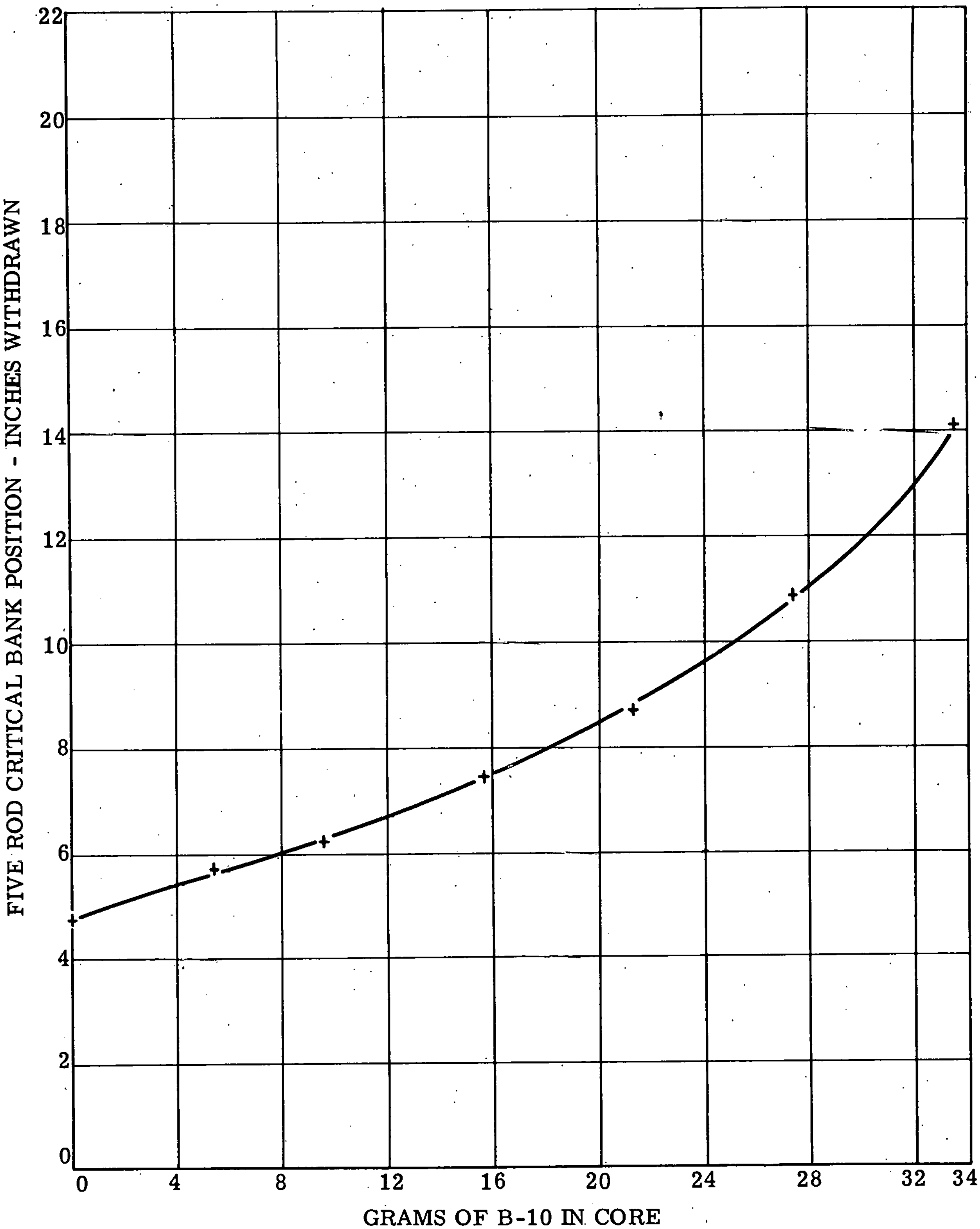


Figure XI-3. Five Rod Critical Bank Position Versus Grams B-10 in a 5 x 5 Array of Type 3 Elements

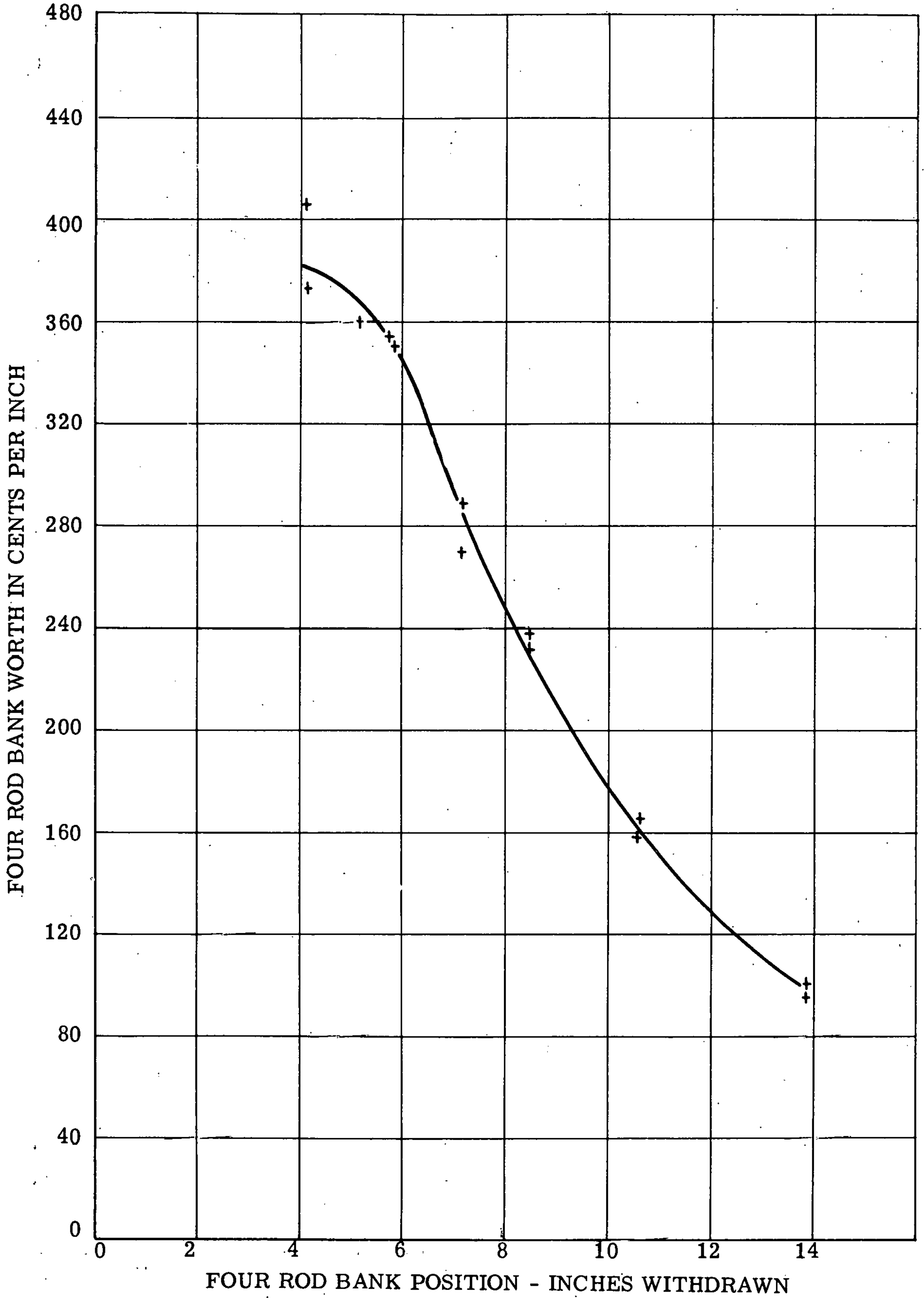


Figure XI-4. Four Rod Bank Worth Versus Four Rod Bank Position in a 5 x 5 Array of Type 3 Elements

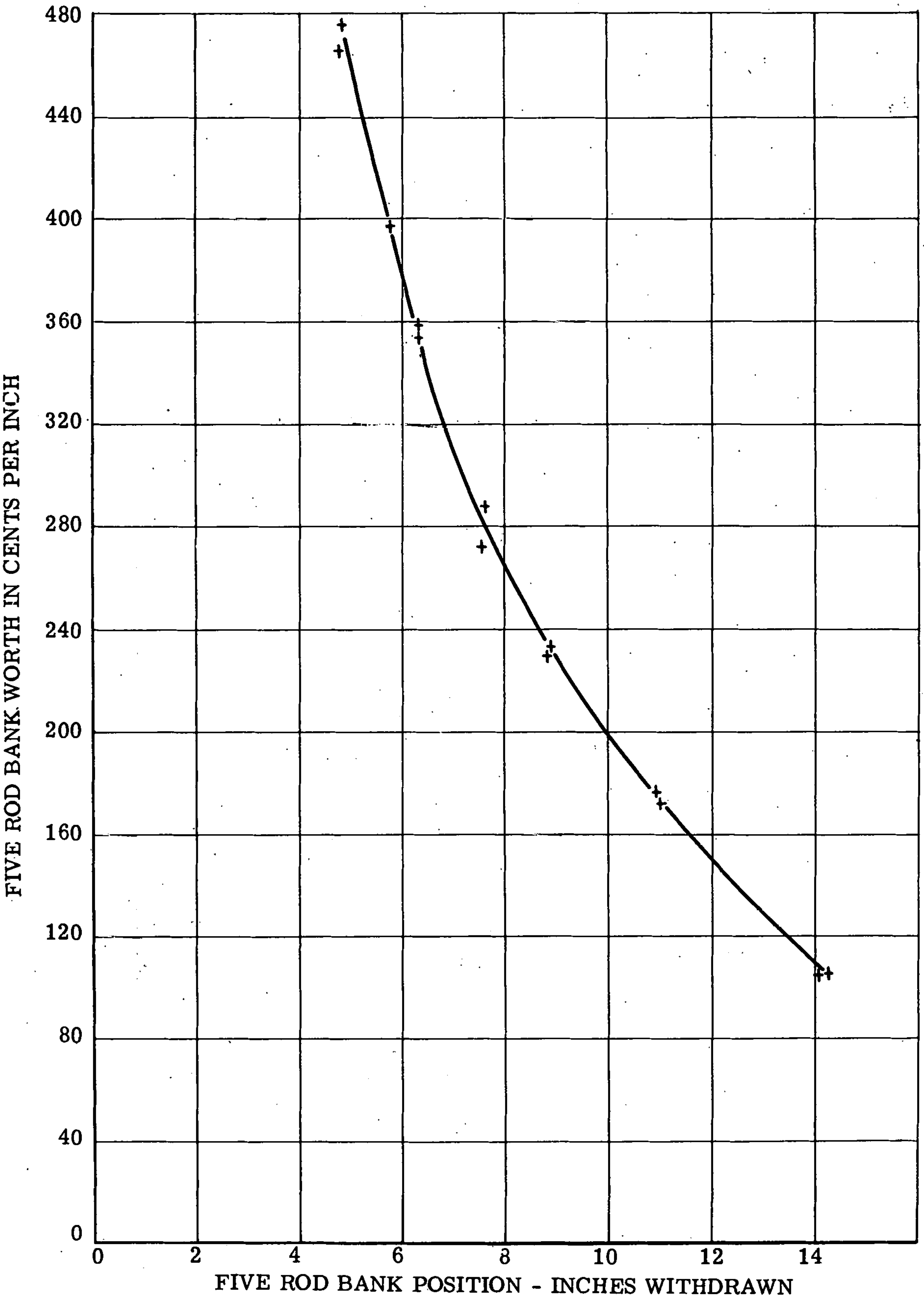


Figure XI-5. Five Rod Bank Worth Versus Five Rod Bank Position in a 5 x 5 Array at Type 3 Elements

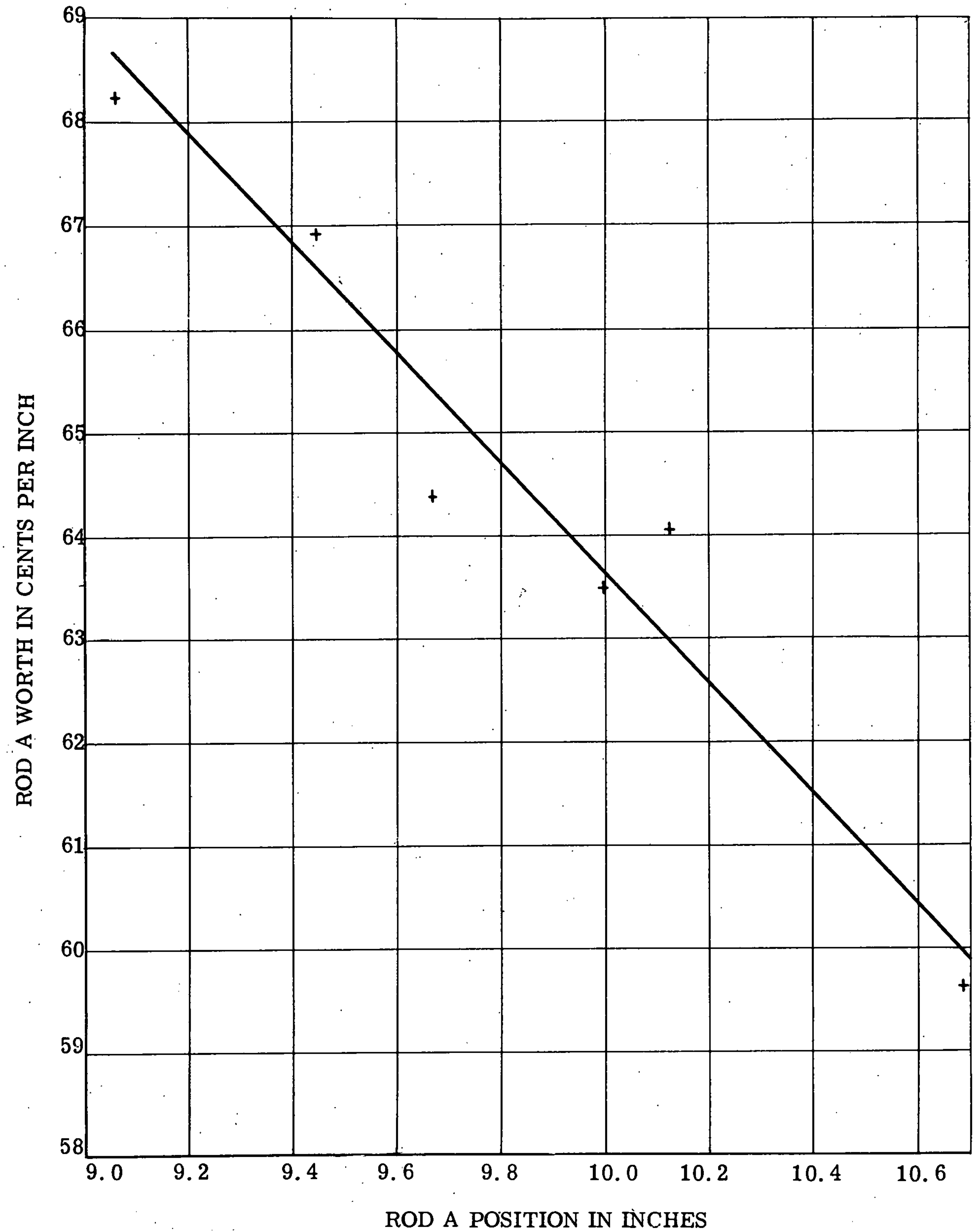


Figure XI-6. Rod A Worth Versus Rod A Position In a 5 x 5 Array of Type 3 Elements, 9.526 Grams of B-10 Loading, 2.575 Inch Thick Stainless Steel Reflected Core

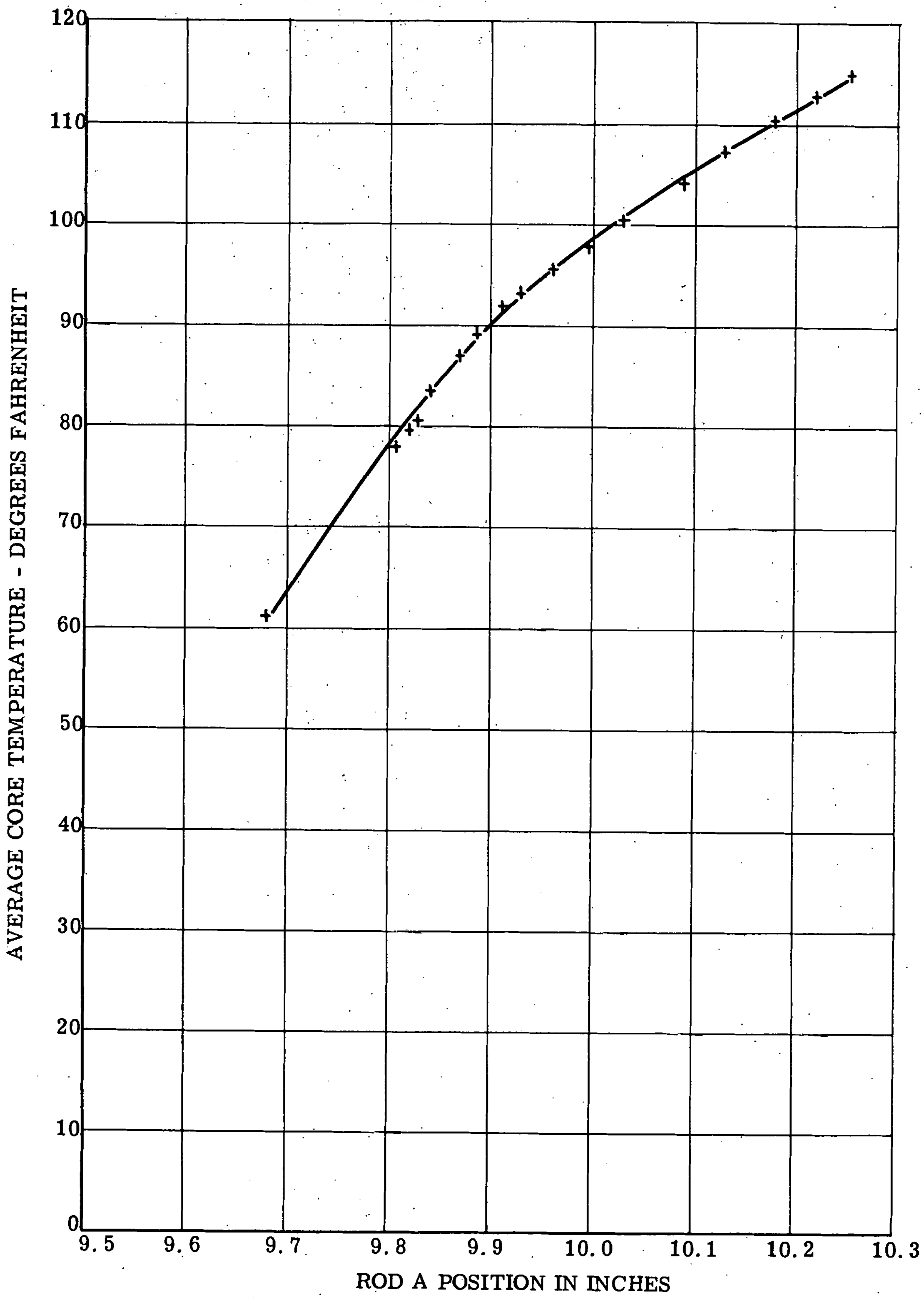


Figure XI-7. Average Core Temperature Versus the Position of Rod A in a 5 x 5 Array of Type 3 Elements, 9.526 Grams of B-10 Loading, 2.575 Inch Thick Stainless Steel Reflected Core