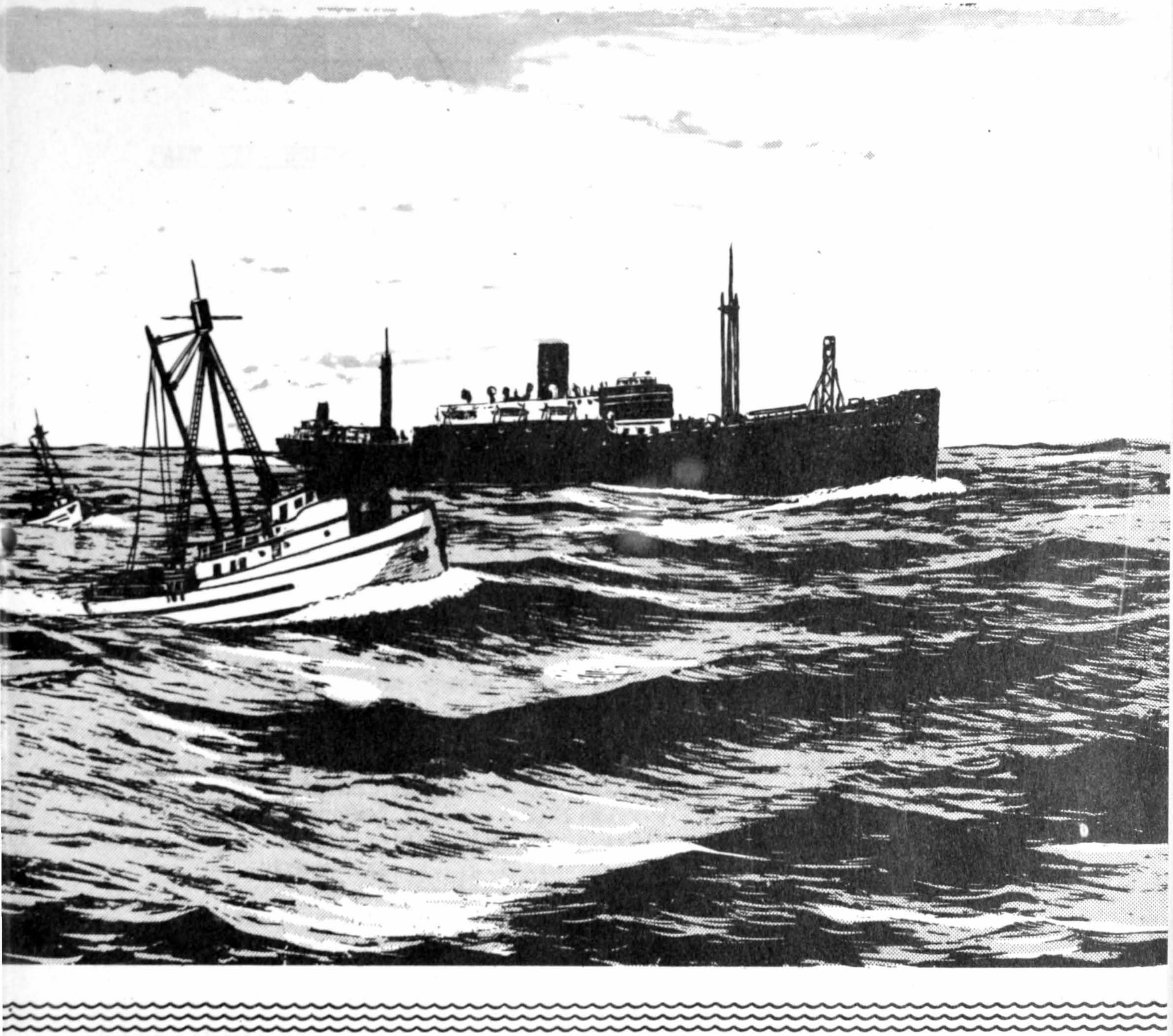
# S.S. PACIFIC EXPLORER

## ART III — BELOW DECK ARRANGEMENTS AND REFRIGERATION EQUIPMENT



FISHERY LEAFLET 316

FISH AND WILDLIFE SERVICE

UNITED STATES DEPARTMENT OF THE INTERIOR

United States Department of the Interior, J. A. Krug, Secretary
Fish and Wildlife Service, Albert M. Day, Director

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Fishery Leaflet 316

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# S.S. PACIFIC EXPLORER
## PART III--BELOW DECK ARRANGEMENTS AND REFRIGERATION EQUIPMENT [1]

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Contents



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1/ Grateful acknowledgment is extended to George Nickum of the firm of W. C. Nickum and Sons, Naval Architects; Joseph P. Lang, Chief Engineer of the Pacific Explorer; Carl A. Anderson, Refrigeration Engineer; and Leroy S. Christey, Manager for the Pacific Exploration Company, for valuable suggestions in the preparation of this report.

## INTRODUCTION

This is the third of a series of reports on the Pacific Explorer and covers the structure of the ship and the operational features of the refrigeration system. The factors considered in the conversion of the ship and a general description of the arrangement of the vessel were published in the January 1947 issue of Commercial Fisheries Review and have been reprinted as Separate No. 161. Part II on suggestions for operators of tuna receiving ships was issued as Fishery Leaflet 301. 1/

An American factory ship, the Pacific Explorer, became a reality in 1945 when the War Food Administration recommended that the Defense Plants Corporation (a subsidiary of the Reconstruction Finance Corporation) should acquire and convert an ocean-going vessel to a factory ship to further the war effort by increasing the supplies of protein food. At the cessation of hostilities the conversion of the ship was not completed but various governmental agencies decided that it would be to the advantage of the Government and the fishing industry to complete the conversion and to determine the feasibility of mother ships to expand the scope of the American fishing effort.

The Pacific Exploration Company was designated as the construction and operating agent for the Reconstruction Finance Corporation, and the firm of W. C. Nickum and Sons was selected as the naval architect. It was realized by all concerned that the Pacific Explorer was an experimental venture. Various statements are made in this paper regarding changes which, according to present belief, would improve the operation of a mother ship primarily intended for the tuna trade, or be more economical in cost of construction. These are made for the benefit of future designers or operators of similar vessels and are in no way intended to reflect on the ability or judgment of above mentioned firms. Rather it should be remembered that very little down-to-earth information was available on factory ships and none on factory ships for the products under consideration. Furthermore, the ship was converted during the latter stages of the war and the early post-war period when materials were difficult to obtain.

The market for canned tuna has been expanding and the industry now believes that it may be possible to market a pack of 5 to 6 million cases. As a result of the operations of the Pacific Explorer, a number of tuna packers are now constructing or planning to construct vessels to freeze and transport the catches of tuna fishing vessels operating off the coast of Central America. These floating receiving ships, carrying the necessary operating supplies for a fishing fleet, will greatly expand the southern tuna fishery.

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1/ Separate No. 161 and Fishery Leaflet 301 are available from the Fish and Wildlife Service, Washington 25, D. C.

The Pacific Explorer was primarily designed to prepare products from king crabs and bottom fish taken in the Bering Sea during the summer months. It was also conceived that a secondary activity would be the freezing and transporting of tuna during the winter period. When the ship was finally completed, market and supply conditions tended to discourage additional production of bottom fish, but did encourage a wider exploitation of the tuna fishery. Unfortunately, the influence of the proposed northern operations on the design of the Pacific Explorer resulted in a ship that is less efficient for handling tuna than one which could be primarily designed for the tuna trade. The spaces on the upper deck and the second deck forward (Figure 1) were respectively required for the production lines for canned and frozen products and quarters for personnel needed for the northern operations. A smaller crew is sufficient for the tuna trade and only freezer and cold storage space is needed for the cargo. Round tuna can either be frozen dry or in brine and can be quickly handled, while the northern products require extensive processing and must either be preserved in dry freezers and storages or the canned products held at normal temperatures. However, the information obtained from the operation of the Pacific Explorer will be valuable to the tuna industry and others who may plan to freeze fish at sea or in distant areas.

The ship left Astoria, Oregon, on January 4, 1947, and returned to Astoria on July 23 with a cargo of 2,250 tons of tuna.

## GENERAL ARRANGEMENTS BELOW DECK

The cargo space (Figures 1 and 2) on the ship is divided into 5 holds--numbers 1 and 2 are forward and numbers 4 and 5 are aft. Number 3 hold was formerly rigged for handling cargo but now serves only as storage space for a spare ammonia charge, machinery parts, and potable water at the second deck level. The deep tanks (bunker fuel) are located below this storage space. The engine and boiler rooms, and their casings are unchanged from their original locations and occupy the space between holds 3 and 4. Three watertight bulkheads are located between holds 1 and 2, hold 3 and the boiler room, and the engine room and hold 4.

### Upper Deck

The major portion of the space on the upper or "cannery" deck (Figure 1) is allocated for the preparation of frozen fillets and canned king crab. The processing line for fillets is on the starboard side and various tables, conveyors, and equipment are fitted on the port side for handling crabs. A trucking aisle 6 feet wide parallels the inboard side of the crab processing tables to permit the movement of materials between the production lines, freezers, or the various holds by the use of electrically driven 1-ton capacity fork lift trucks. Electric trucks were chosen because they offered less hazard from fire and fumes.

Four blast freezers are located on the cannery deck as shown in Figure 1. Each has an individual capacity of 6,000 pounds of packaged fillets on racks and trays, and has a design rating to freeze 1,250 pounds per hour. It was thought that these freezers might be used in an emergency to freeze tuna but their small individual capacity and the need for excessive handling of the fish rendered them impractical for this purpose. The cooling coils for these small capacity freezers are supplied by ammonia surge drums, or receivers, which also service 4 blast freezer coil units on the second deck. A system of conveyors is designed to transport the waste from the fillet and crab lines to a continuous process reduction plant utilizing a steam-tube drier to minimize the hazard of fire. Provision is made to sack and store the meal at the second deck level directly below the plant and to hold recovered oil in the Diesel oil tanks (Figure 2).

On the upper deck, an ammonia control room for the forward cold storage holds, a machine shop, tool storage locker and a laboratory are located directly aft of the 2 forward blast freezers. Access to the Diesel electric and compressor plants is by a passageway forward of the 2 after freezers. The forward portion of the deck is fitted with a galley, sanitary facilities, and accommodations for foremen and culinary workers for the cannery crew. Access is also provided to the forecastle for the cannery workers and to the bo's'n and chain lockers.

## Second Deck

The main freezer compartments are located on the second deck. These consist of 1 large and 2 moderate size blast freezers plus 4 shelf freezers with capacities as given in Table 1. The remaining space on the second deck forward is divided into a forecastle and mess room for 116 cannery workers, number 1 cargo hatchway, an ice making compartment, and an ice storage room. Amidships, the space is divided into storerooms and casings for the propulsion equipment. Aft, the space is divided into dry storage compartments and an after-peak fresh water or ballast tank.

The meat and vegetable storage rooms are located amidships and have respective capacities of 890 and 876 cubic feet. A Freon system, having a capacity of 3 tons of refrigeration, is used to cool the meat and vegetable rooms and the drinking water for the various fountains. In tropical waters this unit was barely sufficient for the job. The food storage compartments are accessible through the engine room casing or a door from number 4D blast freezer. The door to the blast freezer permits the use of this room for meat storage space. Substantial quantities of meat were received on three different occasions during the initial voyage of approximately 6½ months and about 40 percent of the space in the blast freezer was required for storage. Dry storage space for preserved and dry food is located on the port side of the boiler and engine room casings. The temperatures of these spaces in the tropics were too high for satisfactory storage of these items.

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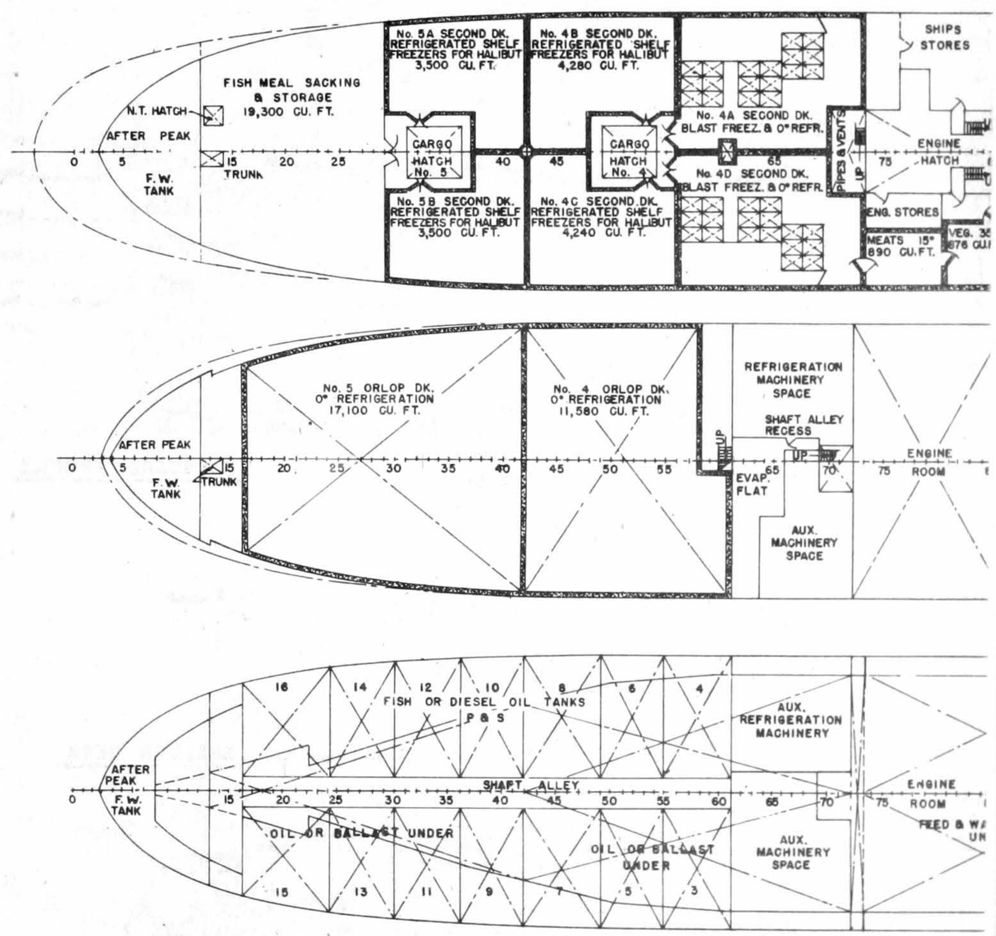


FIGURE 2.--LOWER DECKS C
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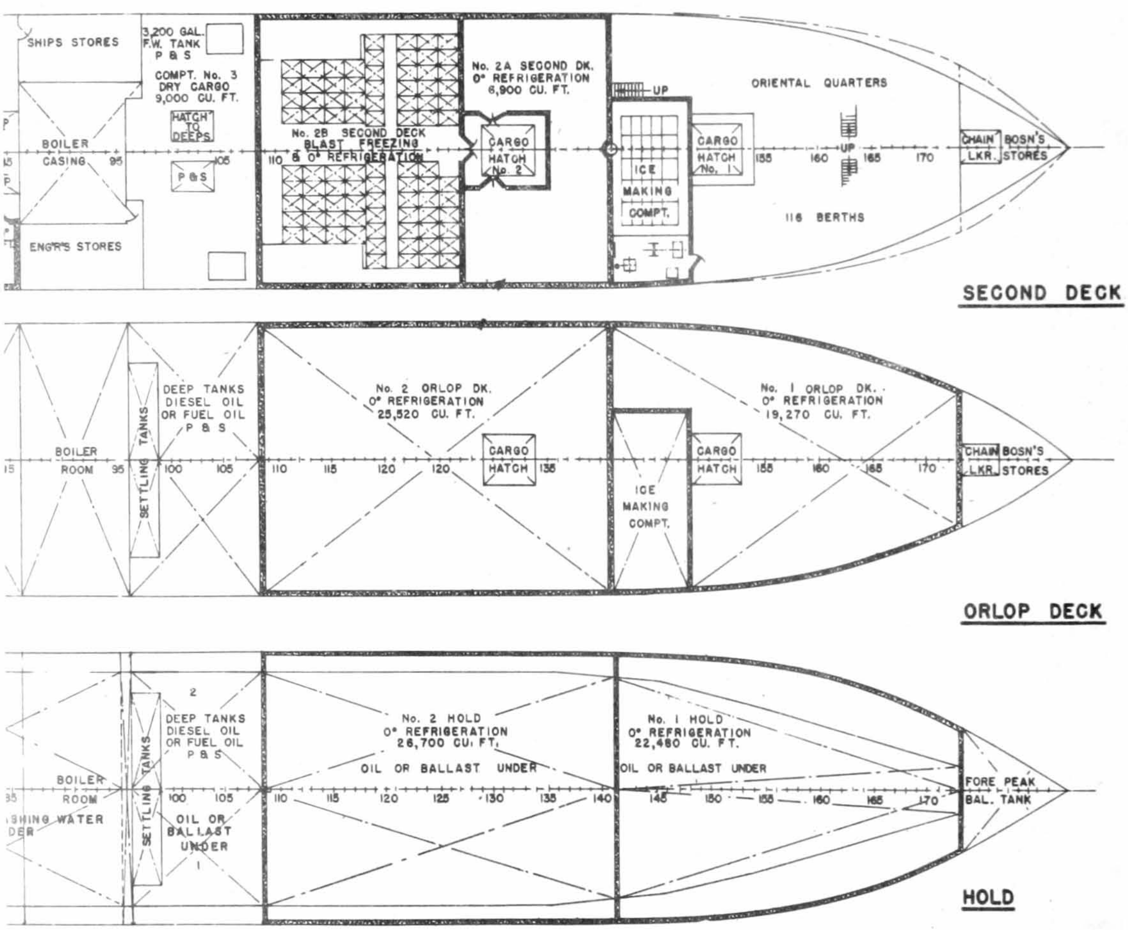


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TABLE 1.--DATA ON FREEZER AND STORAGE COMPARTMENTS

| Freezers | | | | Storage Compartments | | |
|---|---|---|---|---|---|---|
| Space | Capacity Cubic Feet | Charge in Tons | Coil Surface as Length of $1\frac{1}{4}$-inch Pipe Linear Feet | Space | Capacity Cubic Feet | Coil Surface as Length of $1\frac{1}{4}$-inch Pipe Linear Feet |
| No. 2B Blast | 12,730 | 50 | 1,860 | No. 1 Orlop | 19,270 | 5,140 |
| No. 4A Blast | 5,050 | 15 | 930 | No. 1 Hold | 22,430 | 7,380 |
| No. 4B Shelf | 4,280 | 15 | 5,800 | No. 2A Ice Storage | 6,900 | 1,760 |
| No. 4C Shelf | 4,240 | 15 | 5,800 | No. 2 Orlop | 25,520 | 5,390 |
| No. 4D Blast 1/ | 5,300 | 15 | 930 | No. 2 Hold | 26,700 | 7,270 |
| No. 5A Shelf | 3,500 | 15 | 5,900 | No. 4 Orlop | 11,580 | 3,930 |
| No. 5B Shelf | 3,500 | 15 | 5,900 | No. 5 Orlop | 17,100 | 5,080 |
| Total | 38,600 | 140 | 27,120 | Total | 129,500 | 35,950 |

1/ No. 4D blast freezer was chiefly used for storing meat products.

## Orlop and Hold Decks

A new orlop deck (Figure 2) was added to avoid excessive stacking heights for the frozen fish in the forward part of the ship and to form the tank tops for the storage of Diesel or fish oils in the after-part of the ship. These tanks have a capacity of approximately 266,000 gallons. Two fillings were required to operate the Diesel electric plant, the galley range, and the engines and other equipment on the fishing vessels for the voyage of $6\frac{1}{2}$ months. The space at the orlop level is divided primarily into 4 cold storage rooms, a continuation of the ice making compartment, boiler and engine rooms, deep tanks, and spaces for auxiliary and refrigeration machinery. At the hold level, cold storage area is provided only in the 2 forward holds. The remainder of the space is divided as shown in Figure 2. Double bottoms provide storage for fuel oil or ballast except under the engine and boiler rooms where boiler feed and washing water are held.

## FREEZER AND COLD STORAGE COMPARTMENTS

Since the Morocastle and Mohawk disasters, the governmental agencies supervising construction requirements of ships have become increasingly conscious of fire prevention and of all life saving devices for the safety of passengers and crew at sea. While the Pacific Explorer is not a passenger vessel, the exceptionally large potential complement of personnel is greater than the total number of persons on many passenger vessels. Consequently, the highest present standards for safety at sea and, in particular, for the prevention and extinguishing of fire are followed. A steam smothering system which can be controlled from the shelter deck is fitted to all the refrigerated and other storage spaces, in addition to the usual provision of fire hoses on the upper and shelter decks. The only wood entering into the construction is used in such places as wood gratings and battens in the cargo holds and hatches. The complete interior of the various refrigerated spaces is covered with non-structural steel-sheathing. This sheathing is welded to a series of angle irons hung alongside the structural framing members by bolts and spacers to minimize the metal contact surface for the conduction of heat. Protection of the insulation from water absorption depends on the moistureproof seals of the external hull and internal sheathing. The tight steel-sheathing offers advantages in cleaning but paint or oil coatings, applied by the usual shipyard techniques, have superior adherence on wood surfaces in cold storage rooms.

## Insulation

Corkboard varying from 8 to 11 inches in thickness and fibre-glass from 9 to 14 inches in thickness are used, respectively, to insulate the freezer and storage rooms. The thickness of the insulation is governed by the depth of the framing members. In all cases the projecting edges of the internal framing are covered by 2 inches of insulation. In general, the insulation appears adequate as there are no obvious external cold spots. The only pronounced cold spots are in the hatchways providing entrance to the freezer rooms where moisture condensation will occur and freeze. Under humid tropical conditions, an appreciable amount of condensation occurred on the deck of the quarters for the cannery workers. This undesirable condition might not take place under the climatic conditions of the northern latitudes for which the quarters were designed, or would be minimized in the tropics if the ventilating system was operating continously. An unsuccessful attempt of short duration was made to dry out the space with the ventilating system. This should not be considered as a fair test of the facilities since the cooling section of the ventilating system was inoperative. In any event, it is recommended that future designers should carefully consider the problem of condensation before placing living quarters adjacent to refrigerated spaces.

## Arrangements In The Freezer Compartments

The general design of the blast freezers is shown in Figure 3. Eight equivalent fin coil units consisting of approximately 930 feet of $1\frac{1}{4}$-inch

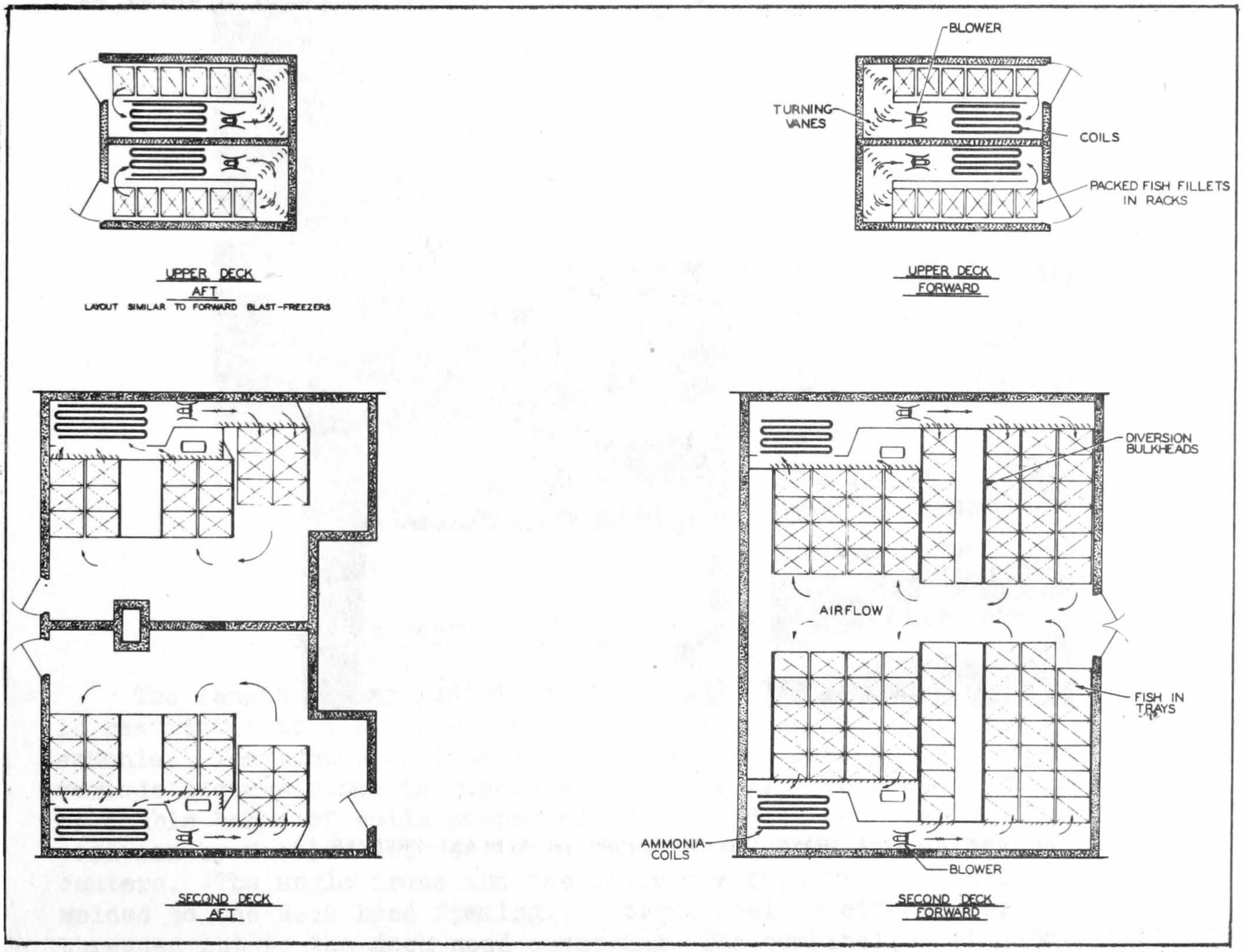


FIGURE 3.--LAYOUT OF BLAST-FREEZERS

diameter fin coils are used in the 7 blast freezers. Number 2B blast freezer is fitted with 2 units. The blast freezers have a design rating to freeze 1,250 pounds per hour per coil unit. Thus, the large blast freezer, Number 2B, is rated to freeze 2,500 pounds per hour. The cubic capacity of the second deck blast freezers was increased over that of the upper deck blast freezers to permit the freezing of a larger quantity of fish at a slower rate. Four surge drums or ammonia receivers are indicated but not labeled in the illustrations of the second deck freezers. Each of these serves the adjacent coil unit and a corresponding unit in the upper deck freezers. Forced air circulation through each coil unit and the freezer room is generated by fans driven by 15-horsepower motors. These are rated to deliver 21,000 cubic feet of air per minute. The direction of the air flow from the fans, through the plenum chamber, the distribution vanes or louvers, over the trays of fish, and return through the coils is indicated by the arrows in Figure 3. In the second deck blast freezers, the fish rest on aluminum trays (36 by 48 inches to suit the available space) supported by a fixed framework of horizontal and vertical 2-inch angle irons as shown in Figure 4. The supporting horizontal angle irons are spaced on 12-inch centers to accommodate fish up to 11 inches in diameter. The loaded trays can be readily pushed by one man along the supports. Defrosting of the freezing units is accomplished by a spray of sea water.

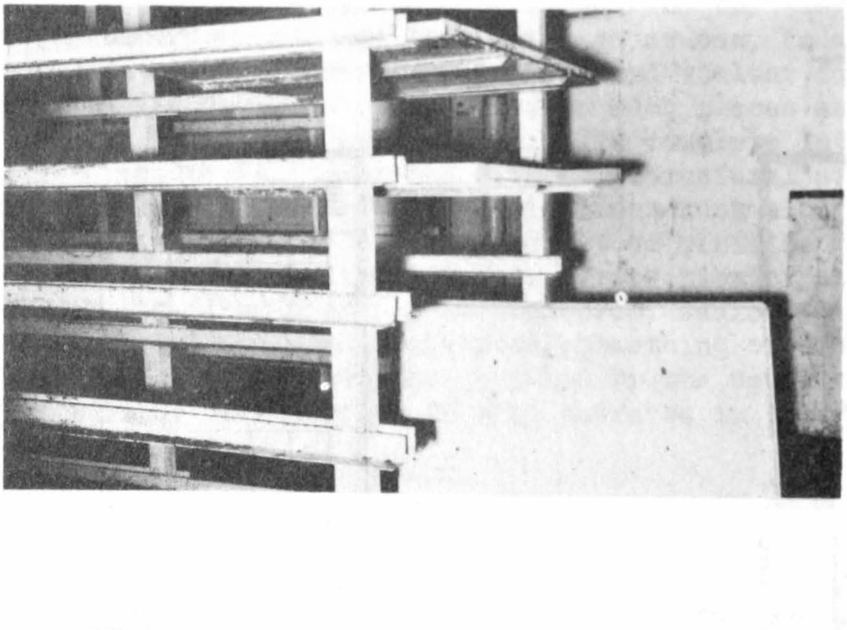

FIGURE 4.--THE TRAYS AND FRAMEWORK IN A BLAST-FREEZER

The shelf freezer rooms are fitted with 4 sets of shelf coils spaced on 12-inch vertical centers to permit freezing tuna up to $10\frac{1}{2}$ inches in diameter. As indicated in Table 1, approximately 5,800 feet of $1\frac{1}{4}$-inch diameter ammonia coils are used in each shelf freezer room. These are attached by U-bolts to a fixed angle iron framework. Removable galvanized metal plates of heavy gauge are fitted over the coils to increase the area of contact with the fish. Increased heat transfer by conduction is obtained by using coils with a square cross-section area rather than the conventional round cross-section pipe. Two ammonia receivers are provided to service the 4 shelf freeze rooms. Hot gas is used for defrosting the coils. Figure 5 presents a view of the tuna being frozen on the shelf coils.

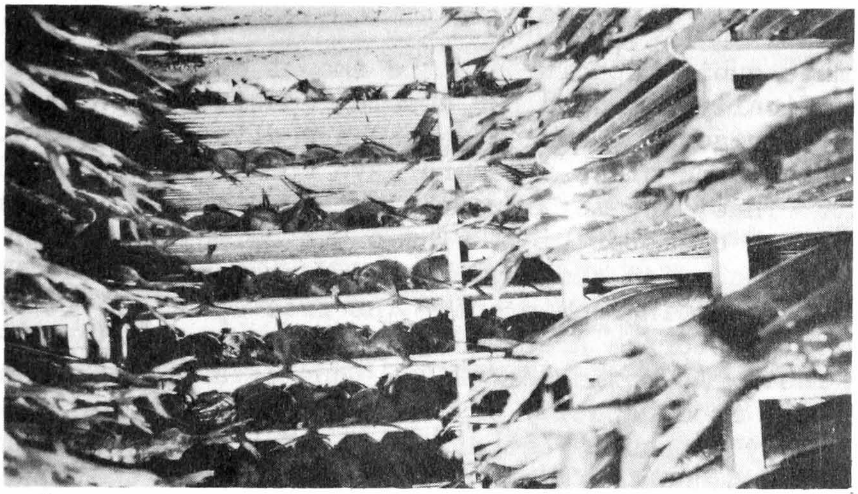

FIGURE 5.--FISH BEING FROZEN ON SHELF COILS

## Arrangements In The Storage Compartments

The length of any individual cooling coil circuit in the storage rooms is restricted to 1,200 feet because of the practical limitations of pumping ammonia. The number of linear feet of $1\frac{1}{4}$-inch diameter coil used in the various storage rooms is presented in Table 1. The cooling coils consist of double banks of coils suspended from the deck head. These are fixed in position by U-bolts and rest on superimposed angle irons located on 6-foot centers. The angle irons and the coils are supported by threaded iron rods welded to the deck head framing. A tight seal is effected by welding a threaded nut to the deck head sheathing. The combination of U-bolt fastenings and threaded suspension rods affords flexibility between the ship and the coils to minimize the possibility of rupture which might result from distortion of the ship in a heavy sea.

Air circulation by natural convection is accomplished in the various storage rooms by utilizing the warmth of the walls and the cooling of the coils. Horizontal wooden battens of 2 by 6 inch material are attached to the sides of the rooms to allow 6 inches of free space between the fish and the walls. The fish are stacked on wood gratings made of 2 by 4 inch material, with about ½-inch of open space. The gratings rest on 2-inch stringers but the use of 3 or 4 inch stringers would insure better circulation since bits of broken tuna collected under the gratings and caused local interference with the air currents. The air warmed by the walls of the room can rise, circulate over the coils, descend through the fish and return to the sides by passing under the gratings. Mr. Otto Young of the Pacific Fisheries Experimental Station at Vancouver, British Columbia, has suggested an improved method of air circulation for the existing coil type of cold storage rooms by placing 2 baffles between the walls of the room and the fish. This permits a rising column of air between the outer baffle and the wall and a falling column of air between the 2 baffles. This should minimize the movement of air through the fish with a consequent protection of the glaze.

The approximate cubic capacity and the amount of ammonia-refrigerated coil surface specifically intended for cooling (exclusive of inter-connecting piping in the refrigerated compartments) are given in Table 1. In addition, the 4 upper deck blast freezers have cooling units totaling about 3,720 linear feet. Thus, the total refrigerated coil area is approximately 66,790 feet of 1¼-inch diameter pipe. The cubic capacities shown are calculated as the free space for storing cargo and are exclusive of the area occupied by the refrigerating equipment. The free space on the shelf coils is available for cargo storage area. Hence the total capacity for cargo is 168,100 cubic feet. Approximately 2,200 tons of dry frozen tuna were stowed in the storage room capacity of 129,550 cubic feet, or a ton of fish required approximately 59 cubic feet of space. The space requirement per ton varied from 57 to 61 cubic feet depending on whether the tuna were small or large. Data on the possible freezing charges in the shelf freezers are also presented in Table 1. A full freezing charge in the shelf freezers varied from 15 to 17 tons and the maximum charge in number 4A blast freezer was about 16 tons. Number 2B blast freezer has tray space for a charge of about 50 tons of tuna. Maximum charges could be successfully frozen in this freezer if good fortune prevailed. If difficulties were encountered through improper defrosting or inadequate operation of the freezer, charges in excess of 30 tons are apt to require an unduly long period for freezing.

Access to the freezers on the second deck is provided by pairs of overlap-type steel-covered insulated freezer doors in the bulkheads isolating the freezer rooms from the hatchways. Even with a rubber seal, an excessive amount of ice was formed around the doors during operations in the tropics. This is due to the high moisture content of the air and the good heat conductivity of steel door surfaces and casings. A double, rather than a single, rubber seal might have minimized icing. Wooden doors and casings might also minimize this condition but a water-moistureproof seal would be required between the casing and the bulkhead to avoid distortion. The after freezer rooms are necessarily of odd shape and the fish must be handled several times before they can be placed in position in the intermediate and remote sections of the freezer. In these instances the tuna could be more efficiently directed into position through a system of small hatches in the deck head. Such an arrangement would, however, interfere with the operations in the northern fisheries. The layout and elevations of number 2B blast freezer and the hatch on the upper deck permits a straight line flow of tuna to position for loading on the trays. This results in a considerable saving of effort.

Access to the cold storage rooms is provided by the removal of one or both of a pair of insulated hatch plugs. Isolation of the hatchways in the storage rooms, by a system of bulkheads and doors, is avoided thereby increasing the storage space and facilitating the admittance of frozen fish. It requires 6 men and a tackle-fall or the use of the ship's rigging to remove the 5 by 12 foot hatch plugs. Plugs of one quarter the present size or hatch boards and a fiber cover to avoid air currents would be more convenient by being easier to remove and by allowing openings of variable size for admitting fish. Fixed pipe ladders with removable top sections at each deck level in the way of the hatches are provided for the movement of the personnel. A passage space about 3 feet wide between the hatch openings and the bulkheads is provided at the second, or freezer deck level, for safety.

## Movement Of Fish

The fish are removed from the holds of the fishing vessels, placed in wooden boxes, hoisted by the ship's rigging and lowered to the upper deck. The boxes are reinforced with angle iron and have a hinged end to facilitate dumping. They measure 56 by 39 by 31 inches in size and have a capacity of about 1 ton of fish. Figures 6 and 7 show the boxes being raised to the ship and dumped on the partially opened hatch of the upper deck. The weights were established by a dynamometer scale (see Figure 6) which had a capacity of 5,000 pounds. A scale of 3,000 to 4,000 pounds capacity would be adequate to weigh 1 ton and would provide larger graduations. Scales of this type should be periodically checked by test loading with weights established on a platform scale. With this precaution, the discrepancy between the weight of tuna purchased on the ship and sold at the cannery was only about ½ of 1 percent which is not excessive and can, in a large part, be attributed to dehydration of the tuna.

Figure 8 shows the tuna being placed on an inclined chute and allowed to slide into a freezer where they were manually placed in position for freezing. After the fish are frozen they are again placed on inclined chutes and directed toward the storage rooms. Figure 9 shows the tuna falling from the chute to an orlop deck storage room. Figure 10 shows the tuna being stacked in number 1 orlop room. After a portion of the fish is stacked, they are glazed by a spray of water delivered by a common garden hose and a spray nozzle. The fish must be thoroughly sprayed from the side and top of the pile to form a satisfactory glaze. Both fresh and sea water were used for glazing, with good results. Fresh water is expensive and salt water is usually considered to produce a better glaze because of a greater resistance to cracking. A glaze was also applied with water delivered by a 2-inch fire

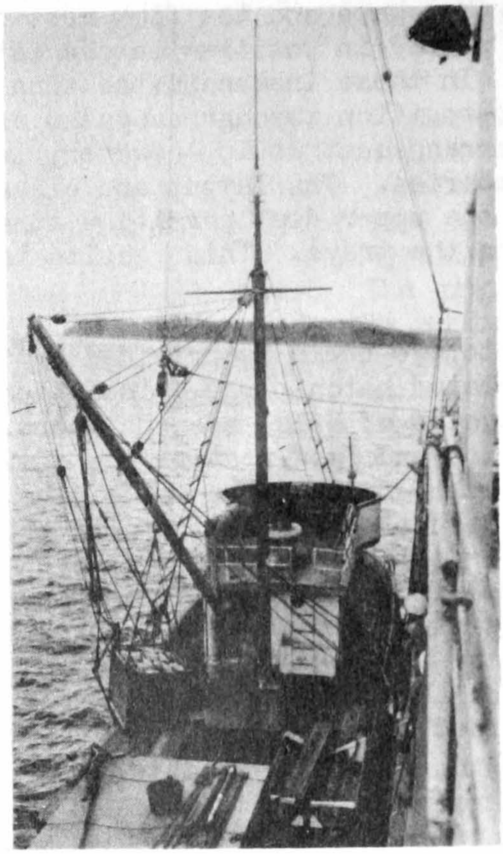

FIGURE 6.--FISH BOX BEING RAISED FROM FISHING VESSEL
(NOTE THE DYNAMOMETER SCALE)

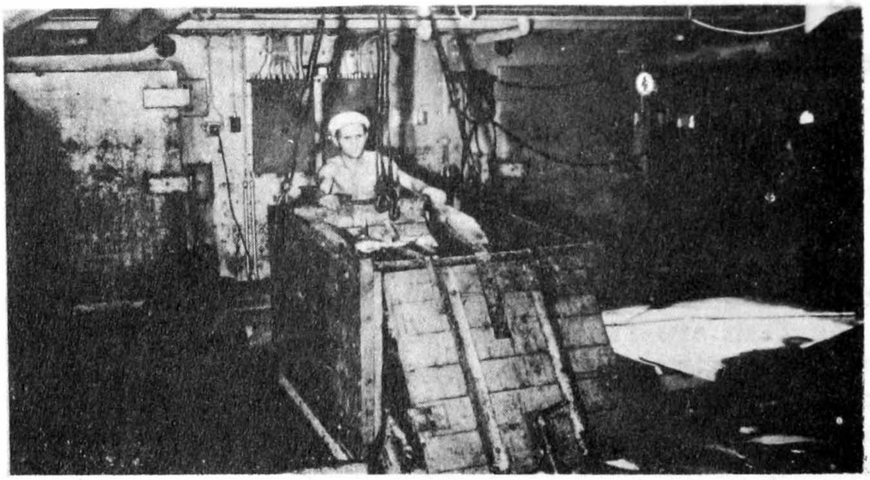

FIGURE 7.--FISH BOX BEING DUMPED ON UPPER DECK

FIGURE 8.--FISH BEING PLACED ON AN INCLINED CHUTE FOR MOVEMENT INTO A FREEZER

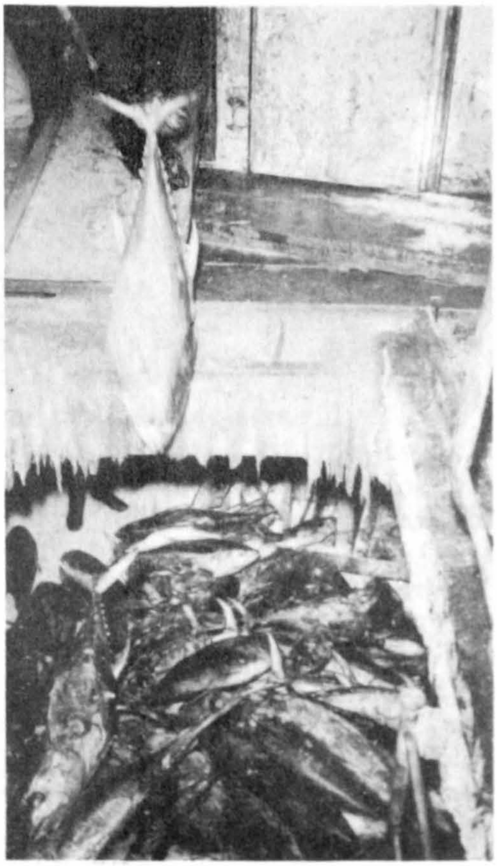

FIGURE 9.--A TUNA FALLING FROM A CHUTE IN A FREEZER ROOM TO A STORAGE HOLD

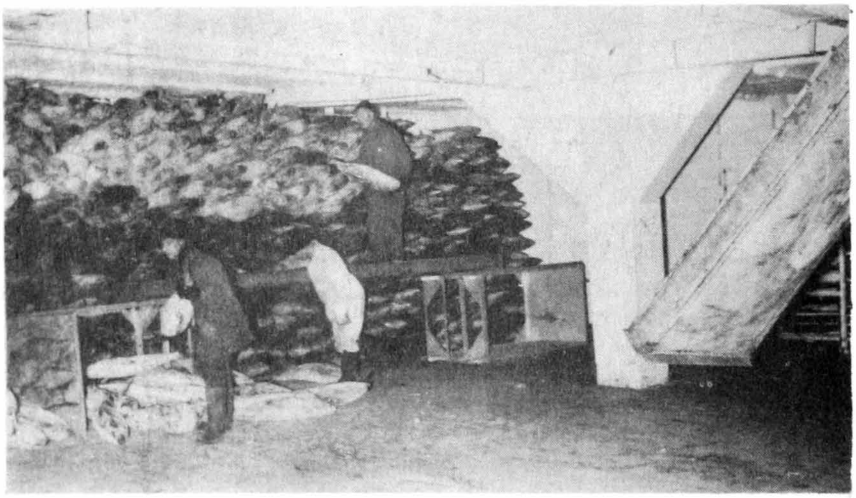

FIGURE 10.--STACKING TUNA

(NOTE THE OVERHEAD COILS, SIDE WALL BATTENS AND FISH DELIVERY CHUTE) hose, which required much less time, but the large volume of water resulted in a glaze of pronounced variation in thickness. It is estimated that the glaze applied by a garden hose varied from the thickness of paper to about 1/8 inch but the average was probably in excess of 1/16 of an inch in thickness.

Unfortunately, the need of quarters for the cannery crew and the use of number 2A storage room for ice did not permit the installation of a freezer at number 1 hatch. Tuna destined for these storage spaces must be conveyed from number 2B blast freezer to the upper deck or trucked from the after freezers and conveyed to number 1 hatch, as shown in Figures 11 and 12.

Fresh or frozen tuna slide very well on smooth surface chutes but a type of inclined roller chute commonly used for transporting cased goods is unsatisfactory, probably because of the irregular and rigid form of the tuna. Tuna dropped from one deck to that below (10 to 12 feet) on smooth wood or sheet iron chutes at an angle of about 30 degrees attain sufficient velocity to be projected for distances from 30 to over 40 feet inside the storage room from the starting point. Tuna preserved in ice aboard the fishing vessels and subsequently frozen to 0° F. aboard the ship can be dropped from the upper deck to number 1 orlop deck, a distance of more than 20 feet without any excessive external injury. But the use of chutes even at a steep incline is preferable to a free fall as the fish strike the deck with a glancing blow. They also become deflected along a horizontal plane toward the stack, which aids in handling. Dropping even thoroughly frozen tuna from the upper deck to the hold level causes excessive external damage. Brine frozen tuna even at 0° F. are softer, probably because of salt penetration, than fish preserved in ice and subsequently frozen to the same temperature. Consequently, fish from brine boats must be handled less roughly than those from ice boats.

## ICE PLANT

Ice is required by the tuna vessels not equipped with brine freezing systems. The storage of the necessarily large quantities of ice presents several problems. Space occupied by ice is not available for the storage of tuna. Concentrating the ice in a single hold will delay loading the area and require perhaps unnecessary movement of tuna between the freezers and the storage rooms. Distribution of ice in the several holds will require an equally objectional movement of ice or the provision for space and duplicate equipment for crushing and delivering ice to the fishing vessels. An excess quantity of ice must be carried to meet the possible eventualities if reliance must be placed on obtaining ice from a shore installation at the home port. An analysis of these conditions during the planning stage of the Pacific Explorer indicated that a supply of ice from shore, supplemented by ice produced on the ship, would be most desirable.

A cake type of ice plant quite similar to the conventional shore installation is located, as shown in Figure 2, on the second and orlop decks and is rated to have a capacity of 10 tons per day. The gross volume of the ice tank is about 1,640 cubic feet and 122 ice cans of 300 pounds capacity each are used. An ice freezing rate of 36 hours is anticipated, so over half of the ice cans may be removed each day. The unique features of the ice tank are a series of baffles extending about 3 feet below the

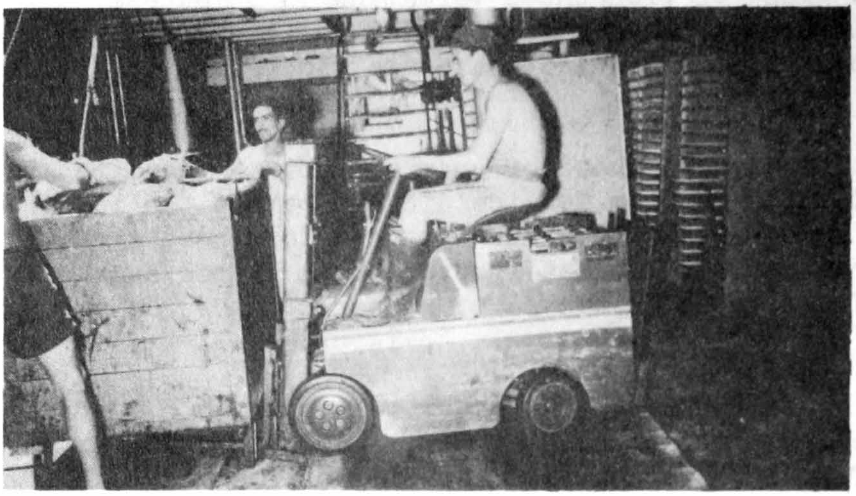

FIGURE 11.--TRUCKING TUNA WITH ONE-TON CAPACITY FORK LIFT TRUCKS

FIGURE 12.--CONVEYING TUNA

surface of the cooling brine, and an equalizing or overflow line to minimize the sloshing and intermixing of the fresh water in cans and the brine. A foul weather tank of 260 cubic feet capacity is located under the ice-making tank as part of the equalizing system and it also serves as a brine reservoir when the roll or list of the ship prevents the making of ice. The equalizing line terminates at each end of the brine tank and is T-connected to, but can be isolated from, the foul weather tank. A 2-horsepower circulating pump controlled by an automatic float in the foul weather tank returns the brine to the ice-making tank when a surplus collects. The circulation of the cooling brine from the tank and through the refrigeration coils is accomplished by a 2-horsepower impeller type of agitator.

Even with these precautions, difficulties are experienced in making ice if the ship has more than a perceptible roll or list. The design of the type of common brine agitator that was available required that it be placed within the tank and that the intake be near the surface of the brine. As a consequence, the flow of brine is interrupted with the rolling or an unfavorable list of the vessel. Ice could be made under less favorable conditions if a positive type of external pump which had an intake near the bottom of the ice-making tank was used to agitate the brine. This would permit further lowering of the levels of both the brine and the water in the cans and allow a greater degree of sloshing without intermixing of the liquids. Dilution of the brine by the water to be frozen raises the freezing point and increases the probability of frosting on the refrigerant coils, and also causes the foul weather tank to become full and ineffective. When the vessel is reasonably steady, good quality ice can be made in the anticipated quantities.

After the ice is frozen, the cans are removed from the tank by an overhead crane and deposited in a thaw tank fitted with both steam jacket and sea water thawing systems. The excessive use of steam for thawing tends to fracture the ice cakes, while thawing with sea water is somewhat slow. A combination of the two systems proved advantageous but thawing is still the bottleneck in production and several more thaw tanks would be advantageous. Figures 13 and 14 show the ice cans being removed from the freezing tank and also thawing preparatory to dumping the cake. Finally the cakes are passed through a sliding watertight bulkhead door (required by U. S. Coast Guard regulations) and held in number 2A storage for aging until needed. The reserve supply of shore-produced ice is raised from the number 2 orlop deck to the 2A storage by portable vertical lift elevators as needed to supplement the ice produced on the ship.

When the ice is to be delivered, as shown in Figures 15, 16, and 17, it is withdrawn through the watertight door and deposited in a horizontal rotary type crusher powered by a 20-horsepower motor. The crushed ice is then conveyed horizontally to a 5-horsepower driven vertical roto-lift conveyor and discharged into an ice flinger on the shelter deck. The roto-lift is insulated and fitted with a jacket of steam coils to facilitate thawing if the ice should become solidly frozen. The ice flinger, driven by a 15-horsepower motor, can be used to service the fishing vessels or to distribute the ice to the fish bins in northern operations. The ice crushing and delivery system has a maximum capacity of about 20 tons per hour. A total of 1,076 tons of ice comprised of 642 tons produced on shore

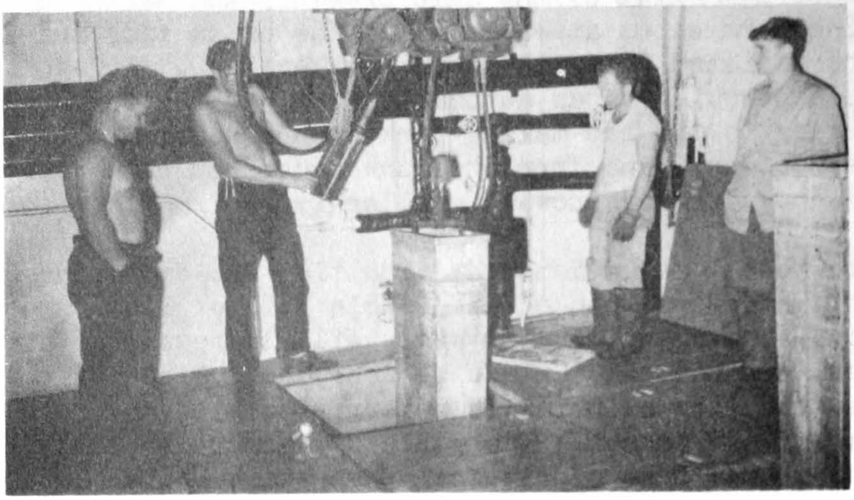

FIGURE 13.-- REMOVING AN ICE CAN FROM THE ICE FREEZE TANK
(NOTE THE ICE TANK AMMONIA SURGE DRUM OR RECEIVER DIRECTLY BEHIND THE ICE CAN)

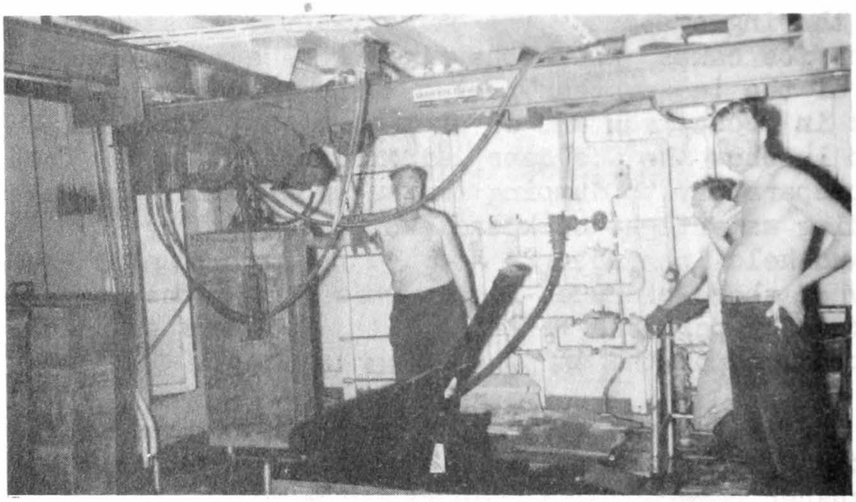

FIGURE 14.--REMOVING AN ICE CAN FROM THE STEAM AND SALT WATER THAWING TANK PREPARATORY TO DUMPING

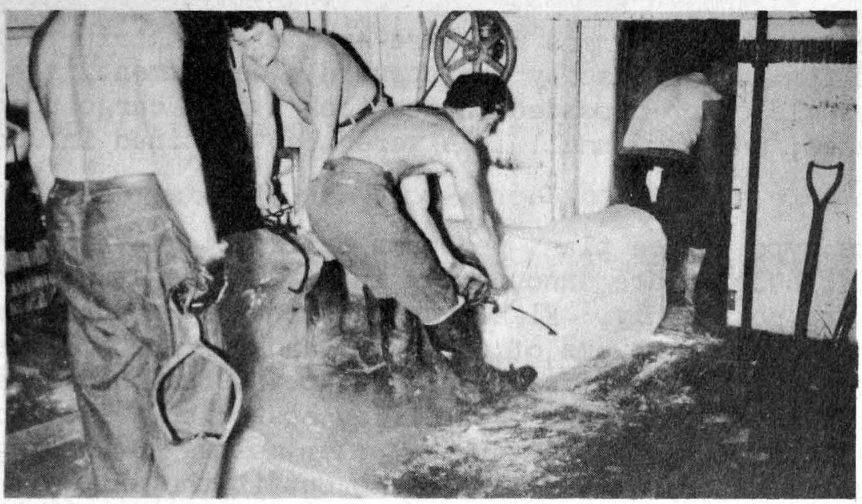

FIGURE 15.--REMOVING ICE FROM THE STORAGE ROOM AND CRUSHING IT FOR CONVEYING TO THE SHELTER DECK

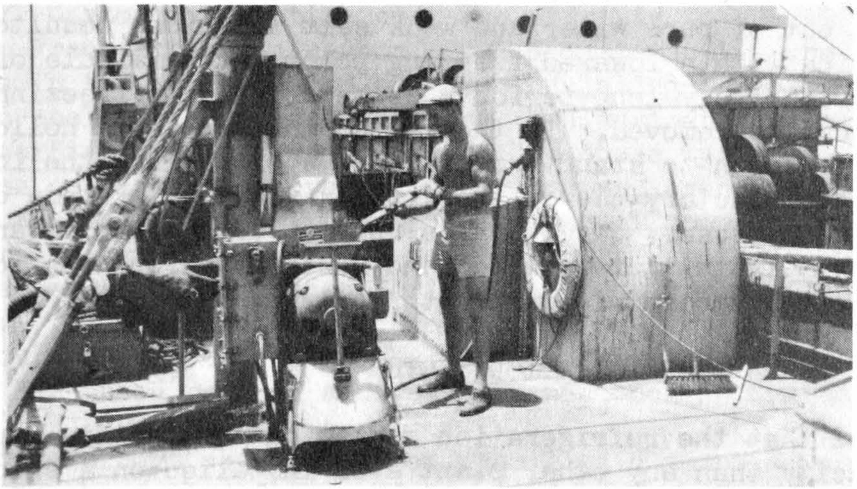

FIGURE 16.--ICE FLINGER FOR DELIVERING CRUSHED ICE TO THE FISHING VESSELS

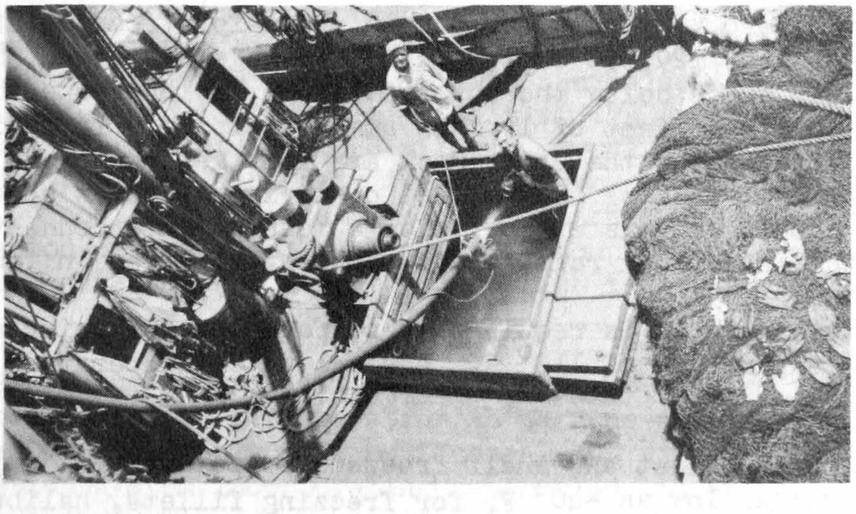

FIGURE 17.--A FISHING VESSEL TAKING ON A LOAD OF CRUSHED ICE

and 434 tons frozen on the ship were required on the first trip to preserve the tuna and for general use by the steward's department. In addition all the fishing vessels which depended on ice took a full cargo upon leaving the United States, and some small lots were also obtained in Central American ports.

While the cake type of ice plant performs satisfactorily in Central American ports, difficulties are encountered in making ice at sea or if the vessel is listing noticeably. Flake ice machines may produce satisfactorily at sea but added problems of conveying and storage will be encountered. Furthermore, the manufacture of ice aboard the ship is an added complication to an already large and diversified operation. It also imposes a substantial additional load on the potable water making and storage facilities. The most satisfactory alternative is to outfit the ship with sufficient ice for the trip, particularly since it can be obtained from shore installations at a price of $5.00 or less per ton. It is estimated that the cost of potable water evaporated from sea water is between $5.00 and $6.00 per ton and the additional labor costs and expense involved in making ice on the ship probably equals or exceeds the stevedoring costs of loading ice in port. Attempts were made to make ice from sea water but the selective freezing out of pure water and weak salt solutions resulted in a large core of brine with a lowered freezing point in the middle of the cake. Either an excessively long period must be devoted to freezing the core or the core must be removed. In the latter instance, the hollow cakes lacked sufficient strength to stand handling and storage, and the ice tended to be too wet for satisfactory use on the fishing vessels. Future operators planning to load the necessary cargo of ice in port could plan advantageously to distribute the supply in various holds and route it through an ice house on deck to minimize the amount of equipment required.

## REFRIGERATION SYSTEM

It is believed that the refrigeration system on the Pacific Explorer has a greater capacity than any other plant ever installed on a ship of United States registry. Although there are refrigerator ships having far greater cubic storage capacity, these are designed for transporting meat, fruit or produce and few, if any, are expected to refrigerate the cargo space to a temperature less than 15° F. The Pacific Explorer is designed to hold cargo at sub-zero temperatures and has space for freezing about 120 tons of tuna. A total of 129,550 cubic feet of storage space and 38,600 cubic feet of freezer space below the upper deck are cooled respectively by 35,950 and 27,120 linear feet of $1\frac{1}{4}$ inch ammonia piping. In addition, the 4 small blast freezers on the upper deck are refrigerated by 3,720 feet of pipe. The total coil area of 66,790 feet of $1\frac{1}{4}$ inch pipe is specifically intended for cooling and is exclusive of a mass of interconnecting piping. Data on the individual refrigerated spaces are given in Table 1.

The refrigeration system is required to perform the following services in an outside air temperature of 110° F. and sea water temperature of 85° F.:

1. Refrigerate the blast and shelf freezers to potential temperatures as low as -40° F. for freezing fillets, halibut, crabs and tuna.

2. Freeze 120 tons of tuna in 24 hours.

3. Keep the storage rooms at sub-zero temperatures.

4. Freeze water to ice at the rate of 10 tons per day.

5. Cool the heat exchanger water for the ventilating system when operating in the tropics.

6. Hold the ship's stores at 15° F. for meat and 38° for fresh produce, and cool the potable water delivered to the fountains. An independent Freon system is used for this purpose.

When the initial design of the vessel was being considered, a considerable amount of correspondence and discussion was carried on with the manufacturers of refrigeration equipment and ship construction approval authorities concerning the refrigeration system. A careful analysis was required in view of the large load to ascertain which would be the most advantageous refrigerant and system of refrigeration which would meet with approval. Customary practice on cargo ships is to use either a direct expansion Freon system, a carbon dioxide system utilizing brine coolers and coils in the holds cooled by the circulating brine, or an ammonia system to cool the circulating brine. The estimated refrigeration load on the Pacific Explorer was so large that these types would have been too cumbersome or very expensive. A Freon system, even using some of the low temperature Freon gases with high speed radial compressors was calculated to require 40 percent more horsepower than the system finally adopted. The space requirements needed for the compressor plant, the large heat exchangers, pumping equipment, and piping inherent to a circulating brine system would be nearly double that of the compressor room in the selected system. For these reasons a direct ammonia cooling system was adopted.

In the direct cooling system, the liquid ammonia is evaporated directly in the coils of the refrigerated areas. No additional heat exchangers are required and the size of the mains can be reduced to require less space, lower construction costs, and considerably less power to operate. The objections to the direct cooling system are the absence of the "cold reserve" of the brine in the event of a short term breakdown, the hazard to personnel from fumes, and the danger of fire or explosion if a major leakage of ammonia should occur. Since the vessel is constructed in so far as practical of non-inflammable materials, the probability of a fire getting out of control is minimized. Similarly, by careful design, the refrigeration mains and piping are kept away from machinery spaces and living quarters in order to confine possible leakages to areas which are not required for the operation of the vessel. The entire compressor plant is located in a compartment which can be isolated and which is provided with an emergency exit.

The bidding specifications for the plant were of the functional type describing the job of refrigeration to be done and the successful bidder was to design and supply equipment capable of doing the job. A compound refrigeration system incorporating sub-cooled liquor and a flooded system in the refrigerated areas was selected as being the most economical to supply, install, and operate from the standpoint of power requirements. In a flooded system, a large reserve of liquid ammonia is maintained in the refrigerated areas to provide more stable temperatures. The refrigerant is delivered to various surge drums or receivers, at strategic locations to service the various freezers and storage rooms. In the freezers, the supply of ammonia at the surge drums is regulated by float controls and delivered to the coils by liquor circulators. Ammonia for the storage rooms is pumped from the cold storage surge drum to liquid supply headers and distributed to the coils. Adjustment of the liquid feed and suction control valves in the control rooms regulates the flow of ammonia to the various banks of storage room coils to maintain the different temperatures. On the return suction side, the surge drums act as traps to separate excess liquor which may be drawn back from the coils.

## Power Plant

The ship was equipped originally with two 15 KW steam-driven direct current generators. These were adequate for lighting and small load service of the ship in her former general cargo duty but were entirely inadequate for a refrigerated ship. These generators are still in use for emergency lighting and for running the gyro-compass.

After an analysis of comparative costs, it was decided to use alternating current generators producing 3 phase, 60 cycle current at 440 volts for the additional electrical loads. Alternating current is particularly adaptable to the ship since it is possible to increase the overall efficiency by using synchronous motors on the refrigeration plant and to use smaller leads and motors with the higher voltages. Also, the large synchronous motors have an appreciable effect on the power factor for the whole system. Motors of 220 volts can be used in damp locations or where the power requirements are small, and 110 volts are available for lighting and other miscellaneous services.

Electric power is furnished by 3 Diesel-electric units of 450 horsepower each, rated at 300 KW and 440 volts. Two of these are adequate to carry the electrical load. Switchboard voltages of 440, 220, and 110 are provided for the various services. All the motors for the refrigeration and ventilation system are either 440 or 220 volts. Two motor generators of 7.5 KW are provided for the regular excitation service on the synchronous compressor motors in addition to a possible emergency excitation from the steam-driven generators. All the remaining AC motors on the ship are of the induction type.

## Compressor Room

An ammonia flow diagram of the compressor room is shown in Figure 18. The compressors consist of 2 large and 1 small high-stage machines and 2 boosters. The boosters are a 4-cylinder, 15 by 10 inch machine and a twin cylinder, 13 by 9 inch machine driven by 125 and 50 horsepower synchronous motors, respectively. The booster compressors have rated capacities

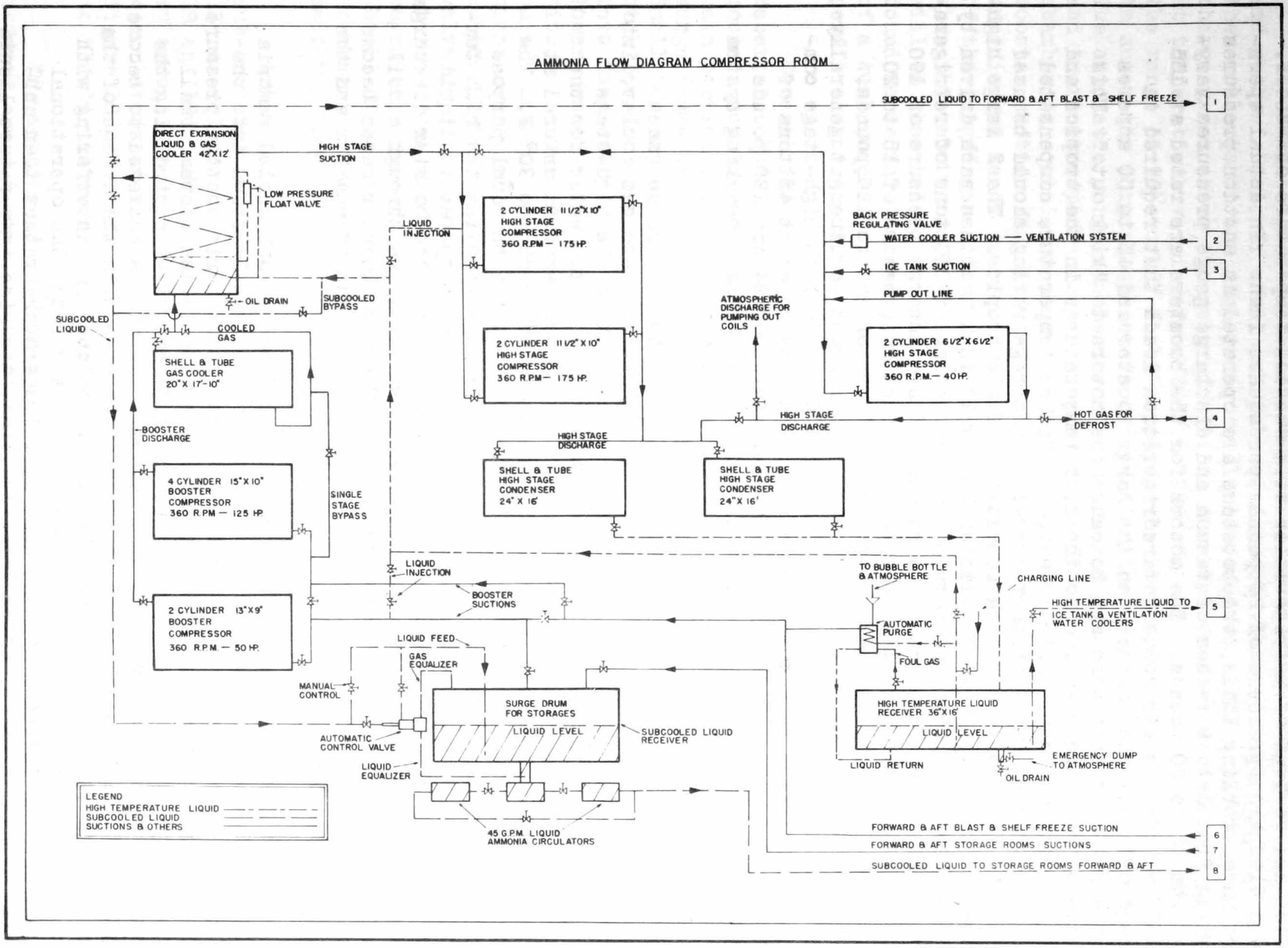


FIGURE 18.--AMMONIA FLOW DIAGRAM IN THE COMPRESSOR ROOM

of 134 and 65 tons of refrigeration at a suction temperature of -25° F. and a discharge pressure of 24 pounds per square inch. In actual operation under working loads, the boosters are operated at suction pressures varying from 5 to 9 inches of vacuum and discharge gauge pressures varying from 15 to 20 pounds. The motors for the boosters are rated at 135 and 55 amperes at 440 volts but refrigeration loads that required in excess of 115 to 120 amperes on the large booster and 45 to 50 amperes on the small booster were apt to cause the motors to "kick out." This condition may have been due to the high temperatures in the tropics and their effect on motor control devices. Either temperature compensated controls or elements of higher over-load amperage rating should be used under the extreme temperature conditions of the tropics. The 2 large high-stage compressors are twin cylinder $11\frac{1}{2}$ by 10 inch machines each driven by a 175-horsepower motor and have a combined rating of 230 tons of refrigeration at a suction pressure of 24 pounds and a discharge pressure of 190 pounds. These are normally operated at a suction pressure of 15 to 20 pounds per square inch and a discharge pressure of 180 to 190 pounds. The motors are rated at 185 amperes but the current requirement generally varies from 140 to 150 amperes. The small $6\frac{1}{2}$ by $6\frac{1}{2}$ inch high-stage compressor is driven by a 40-horsepower motor and is rated at 45 tons of refrigeration at suction and discharge pressures of 24 and 190 pounds. This small compressor may be directly connected to the ice-making system or may be run in parallel with the larger machines.

The plant is designed to circulate the booster discharge gases through a 20-inch diameter by 17-foot long shell-and-tube gas cooler, into a direct expansion liquid-and-gas cooler, and then to the high-stage machines (see Figure 18). The temperature of the supply water for the gas cooler varied from 82° to 84° F. and the gaseous ammonia entered at temperatures between 150° and 195° F. to be cooled to 85° to 90° F. The direct expansion liquid-and-gas cooler is designed for the dual purpose of further cooling the booster discharge gas and sub-cooling the high temperature liquid. A float controls the flow of high temperature liquid into the "DE" chamber to maintain a level for cooling the booster discharge and cooling the major portion of the liquid which passes through a coil inside the DE cooler to become sub-cooled. The warm booster gases become cooled by the evaporation of the liquid ammonia in the DE chamber and the gas phase is drawn into the high stage compressor.

In actual operation, it is found that the use of sub-cooled ammonia presents certain difficulties. A quantity of oil may be drawn into the system by the boosters which operate at a sub-atmospheric suction pressure. While several provisions for oil removal are made in the system, small amounts apparently collect in the automatic float valves controlling the flow of ammonia to the various surge drums. The oil is believed to become gummy in the sub-cooled liquid and then interferes with the action of the control floats, thus disrupting the overall balance and interfering with the operation of portions of the system. At any rate, the operational problems are noticeably reduced when high temperature rather than sub-cooled liquid is used. Under this condition, the high temperature liquid bypasses the DE cooler, as shown in Figure 18, and goes directly to the freezers or through the storage room receiver to the storage compartments. The chamber of the DE cooler then merely acts as a surge drum in the booster discharge line.

The ammonia gas is further compressed in the high-stage machines and enters a pair of shell and tube condensers where it liquifies and then collects in the high pressure liquid receiver. The high-stage discharge gases enter the pair of 24-inch diameter by 16-foot long condensers at temperatures varying from 260° to 290° F. and the liquid is cooled to the range of 90° to 99° F. by supply water at a temperature of 82° to 84° F. An automatic purging system is provided on the high temperature receiver. The automatic purge can be opened and the gas phase consisting of ammonia and inert atmospheric gases is passed into the purging chamber. The purge chamber is cooled, as shown in Figure 18, by a coil hooked directly to the booster suction line and is supplied with high temperature liquid. The ammonia gas tends to condense and be returned to the receiver but a portion of the purged gases is forced through a water bottle. The bubbling ceases when the receiver is purged of inert gases since the ammonia coming through will be absorbed by the water. The automatic feature of the system was found to be unreliable so manual purging was adopted. The incorporation of a dual purging system would afford a standby arrangement which would permit cleaning and adjustment of the spare.

Several divisions of the liquid are made at the high temperature receiver. The liquid can be diverted to the ice-making tank and the water coolers for the ventilation system, line 5, or the purging system, but the main portion passes through, or is bypassed around, the DE cooler to the surge drums servicing the various freezing units or the cold storage rooms. Small take-off lines, or liquid injection lines, are shown from the main high temperature liquid line. These permit the bleeding of liquid ammonia into the suction side of the compressors to enable them to be operated at lower temperatures and to reduce the degree of superheating. The distribution of ammonia between the various surge drums (see Figure 21) depends on the natural temperature-pressure relation of the ammonia, on a sufficient supply of ammonia to satisfy the flooded condition, and the throttling action of the float control valves. The float which controls the admission valve is activated by the gas-and-liquid equalizing lines, as illustrated, at the surge drum for the storages. A parallel manual-control system for regulating the ammonia level is provided for use if the automatic system should fail. The surge drums have the dual purpose of acting as a receiver or ammonia storage for the area to be refrigerated and of serving as a settling trap to prevent the return of wet gas to the boosters.

After leaving the DE cooler, or the bypass, the liquid enters the sub-cooled line and is divided between the surge drum for storages (Figure 18) or follows line 1 to the various surge drums for the freezers (Figures 18 and 19). Positive flow from the surge drums to the coils is effected by ammonia circulating pumps of 45 gallons per minute capacity. Two liquid circulators at the low pressure storage receiver (surge drum for storages, Figure 18) are used, either jointly or individually to pump liquor, line 8, to the liquid ammonia headers which in turn supply the storage rooms.

The suction lines from the four freezer surge drums aft and the two forward are all eventually joined to become a common suction line in the compressor room as indicated by line 6. The suction lines from the forward and aft storage rooms become a common line 7 to enter the surge drum, or

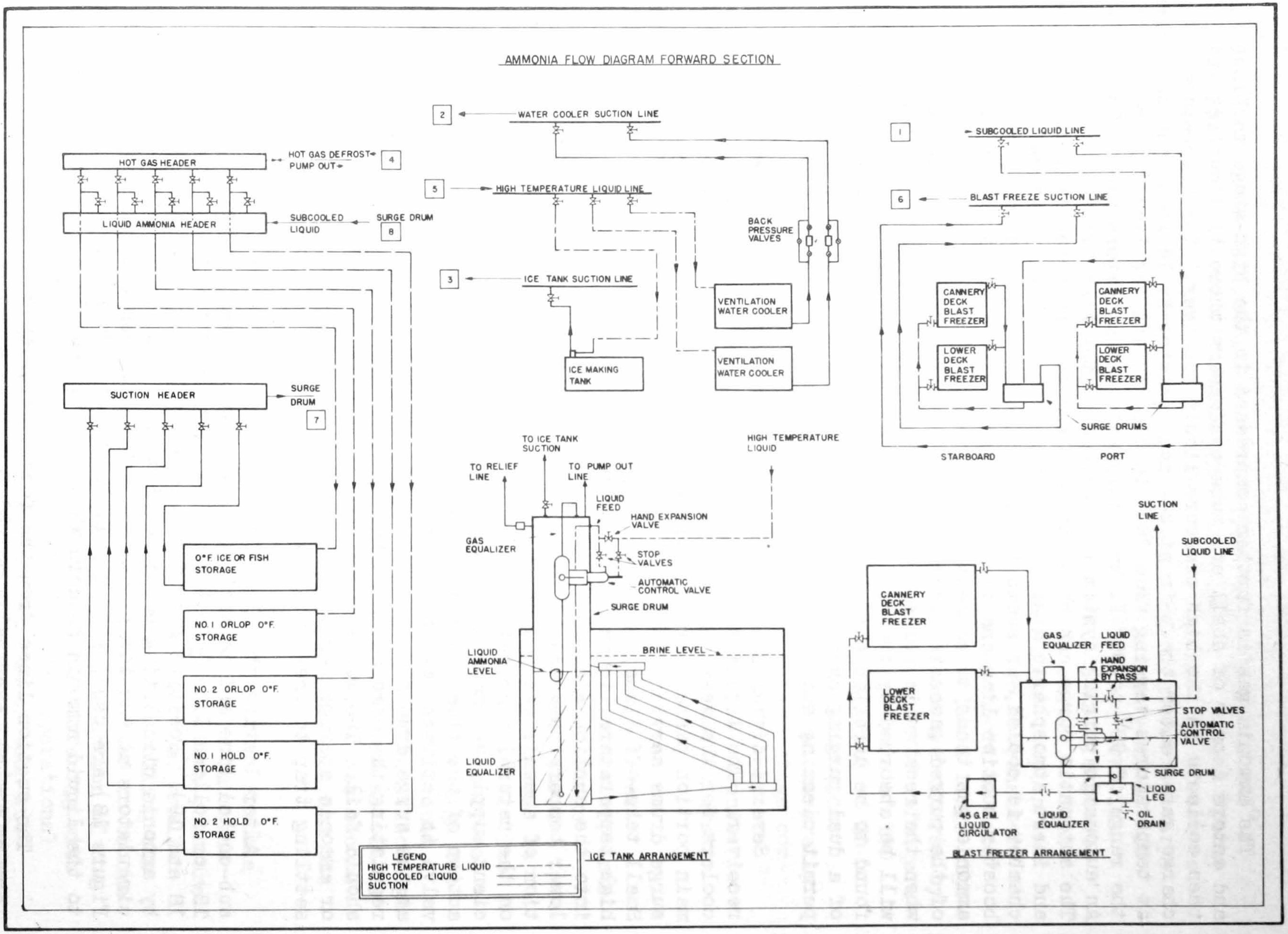


FIGURE 19.--AMMONIA FLOW DIAGRAM IN THE FORWARD SECTION OF THE SHIP

trap, for the storages. In the compressor room the freezer suction and the storage suction lines may be joined or paralleled to the boosters. When operating the plant at full capacity, it is found necessary to use the common suction line between the storages and freezers to maintain desired temperatures. Throttling of the suction valve at the storage surge drum controls the general temperature in the storage rooms, and the suction valves in the control rooms govern the temperatures of the individual storage compartments. Opening the single stage bypass permits the suction gas to avoid the boosters if single stage operation is desired for light loads or to start the plant. The plant is started on single stage operation and the boosters may be cut in when the suction pressure has been reduced to 5 pounds. An operating charge of 35,000 pounds of ammonia appears to be necessary to assure an adequate distribution and to fully satisfy the flooded operating condition of the plant.

The $6\frac{1}{2}$ by $6\frac{1}{2}$ inch compressor has several possible functions. It may be hooked into parallel operation with the 2 large high-stage machines by taking suction from the DE cooler and discharging it to the high-stage condensers. The compressor may be operated independently on the suction lines from the ventilation coolers or the ice tank, lines 2 and 3, or finally it may be used to pump out or defrost the shelf freezer and storage room coils, line 4. The shelf coils are on a direct pump-out defrost line but a header system in the control room must be cut into the liquid supply side of the desired storage room coils for these purposes. The ventilation water coolers and the ice tank are supplied with high temperature liquid direct from the receiver, line 5. Two automatic back pressure valves in series are fitted to the ventilation water coolers to maintain the desired ammonia temperature of $35^{o}$ F. in the cooler. Unfortunately, the temperatures in the coolers were not properly controlled on the second day of operation, and this caused the cooler to freeze and burst.

## Storage and Freezer Compartments

The methods of ammonia circulation in the storage and freezer rooms and in the ice-making tank are shown in Figure 19, and a view of the ammonia control room is presented in Figure 20. Ammonia is delivered to the liquid headers, line 8, from the storage surge drum and may be divided among the various sections of coils as indicated. The refrigerant is returned through the suction header to the surge drum, line 7. Each bank of coils has an individual set of supply and suction valves to permit regulation of the temperature in the storages. The dual purpose hot-gas-defrost pump-out header is connected to the supply side of the coils and may be brought into service by opening the isolation valves. Two separate header systems, or ammonia control rooms, are provided for the forward and after groups of storage holds.

The surge drum and freezer coil layout shown in Figure 19 is a typical flow arrangement of either the blast or shelf freezers. The liquid ammonia is delivered to the surge drum, passes through the liquid leg, and is forced to either or both of two freezer units by a liquid circulator. Manually operated feed-and-suction valves control the distribution of the refrigerant

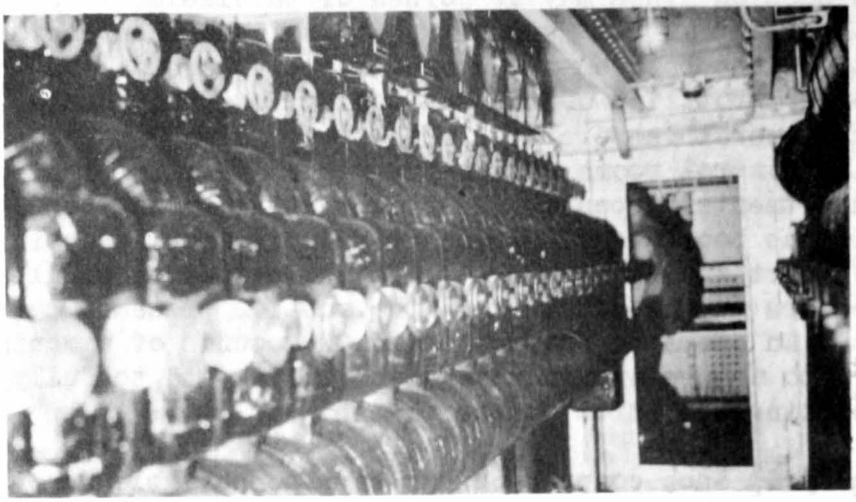

FIGURE 20.--THE AMMONIA CONTROL ROOM FOR THE FORWARD STORAGE HOLDS (NOTE THE RECORDING THERMOMETERS, THE HOT GAS DEFROST HEADER AND THE LIQUID FEED HEADER ON THE LEFT, AND THE SUCTION HEADER ON THE RIGHT)

FIGURE 21.--A SURGE DRUM SERVICING TWO SHELF FREEZER COMPARTMENTS. THE LARGE PIPES ARE THE SUCTION LINES, THOSE OF INTERMEDIATE SIZE ARE FOR LIQUID SUPPLY AND THE SMALL ONES CONTROL THE FLOAT. NOTE THE MOTOR AND LIQUID CIRCULATOR

between the freezers. The return suction line from the freezers terminates at the surge drum and the dried gas returns to the compressors via a surge drum suction line.

A common high temperature liquid line feeds both the ventilation water coolers and the ice-making system. Separate suction lines are required, however, since the cooler is on direct expansion, and back pressure valves are needed to maintain safe temperatures while a surge drum and flooded system are used for making ice. In the ice-making system, a float control or a parallel manual control system maintains the refrigerant at a level slightly below the high side of the cooling coil suction header. The refrigerant flows by gravity to the lower supply header and into the coils where it absorbs heat from the brine, evaporates, passes through the surge drum, and is returned to the suction side of the high-stage compressor. The brine level is maintained at a height above the cooling coils and is circulated around the coils and the ice cans by a brine agitator, neither of which are shown.

## OPERATIONAL PROBLEMS

In actual practice the refrigeration system of the Pacific Explorer was found to be quite complex and sensitive to operate at the anticipated performance levels under tropical conditions.

### Personnel

Since working agreements with the maritime unions require the hiring of men in rotational order from their lists, it is difficult to "hand pick" or engage outside personnel having the necessary experience to operate a complex refrigeration system. Most marine "reefer" men are familiar with only the relatively simple direct expansion systems commonly used for holding ship's stores or for those on combination general cargo and refrigerated storage ships. Consequently, the refrigeration system on the Pacific Explorer is beyond the experience of the usual run of "watch" engineers, and extensive training and supervision by the engineer in charge is required. Unfortunately, this person cannot be on duty 24 hours per day and operational errors are bound to occur. After a period of 3 months, the ability of the operating personnel to manipulate the system improved considerably. Had the plant been a shore installation, the personnel would normally consider its operation to be a long-term job, but many maritime workers are transients by nature and nearly a complete turnover was experienced during the single voyage of approximately 6½ months. Therefore, a complex refrigeration system becomes a further burden as constant training of personnel may be necessary. Also, regulations of foreign governments may prove embarrassing. On the first trip, two competent replacements were hired in the United States, but the government of Costa Rica would not grant visas to the men and tried to insist that their citizens be hired.

An additional factor which contributed to the turnover of personnel was the length of the voyage and the consequent exposure of the crew to the ailments common to prolonged service in the tropics. In normal commmercial voyages most cargo ships remain in tropical latitudes or touch tropical ports for only relatively short periods, whereas the Pacific Explorer spent more than five months in the tropics and chiefly in one port. Further, the crew and the management anticipated a voyage of only three to four months' duration. If the voyage had extended for only the anticipated period, the turnover of personnel would have been at a reasonable minimum. The desired load of tuna could not be obtained within the anticipated time because the project was new, and it was difficult to attract an adequate and highly-skilled fishing fleet.

## Refrigeration Plant

The operation of the refrigeration plant is complicated by several series of joining and parallel flows of the refrigerant. Changes in the setting of control valves for one part of the system generally causes secondary effects in other parts; thus, a complete understanding of these combined effects is required to maintain a balanced operating condition. Each refrigeration plant has its individual operating peculiarities and trial-and-error methods of operation were necessary to master these problems. One division of flow is at the high temperature receiver where a common line (contrary to the illustration in Figure 19 for purposes of simplicity) supplies the ice tank, DE cooler and the purging system. A joining flow was experienced if suction for the ice tank was taken by the large high-stage machines rather than by the 6½ by 6½ compressor. Even if the small compressor was used, some difficulty was experienced in regulating the flow of the refrigerant in the ice-making system possibly because of its remote position.

After leaving the DE cooler, the liquid must be supplied to seven receivers consisting of four in the blast freezer, two in the shelf freezers, and one for the storages, or a total of eight receivers including that for the ice tank. This distribution is effected by the natural temperature-pressure properties of ammonia, and if any of the eight float controlled valves function improperly, the system becomes unbalanced by the presence of too little or too much liquid. A local surplus may result in the return of unusually wet gas which causes frosting or "slugging" of the boosters and necessitates shutting off the supply of the refrigerant until the trouble can be located. Isolation and pumping out of the various surge drums, because of their location in cold areas, usually required considerable time. Meanwhile the freezing process is interrupted, at least in the area under investigation, and the refrigeration capacity of the boosters may be temporarily unavailable if the slugging is serious. Fortunately, fouling of the floats is an infrequent occurrence when high temperature rather than sub-cooled liquid is used. On the return side, the suction lines from the four freezer surge drums aft become a common line to join the suction line from the two forward blast units and finally to join the suction line from the storage receiver. The provision of some visual aid on the surge drums to indicate the liquid level would be of great assistance when attempting to determine the source of the slugging.

For proper flooded operation, an adequate and distributed supply of the refrigerant is essential. The operators believed that the presence of oil in the system combined with sub-cooled liquid caused a gumming deposit in the floats which might result in a disruption for short or moderately long periods. Further, the ammonia seemed to accumulate in the coldest areas and was difficult to remove from these places because of its temperature and vapor-pressure properties. Thus, if the storage rooms were cold, it was difficult to start refrigeration in freezers which had become warm during periods of prolonged idleness or even during unloading and loading. The common suction line construction from the freezers and the storages caused trouble in this respect. Shortly before the last month of fishing operations, the shortage of ammonia became a pressing problem and since the storage rooms had to be robbed of ammonia to freeze fish, a constant juggling was required. It is thought that the improper functioning of the automatic purging system or manual purging by less experienced operators, when other factors might have been responsible for the high head pressures, caused the excessive loss of ammonia. In time, marine growth accumulated in the sea chests and probably to some extent in the supply and discharge lines for the condensers. Initially the pressure of the supply water was 80 pounds per square inch. This was gradually reduced to 30 pounds at the end of approximately 4 months but, upon cleaning the sea chests, the pressure rose nearly to its original level. This difficulty, coupled with condenser water temperatures in excess of 84° F. and the presence of non-condensible gases, tended to raise the head pressures.

Even short-term failures of the electrical supply caused a considerable loss of time and difficulty in returning the plant to normal operating conditions and temperatures. Electrical failures, in addition to interrupting the compressors, caused all the supply water pumps, ammonia circulators, and freezer fans to be stopped, resulting in a disruption of the ammonia flow, temperatures, and pressures throughout the entire system. Pressures in excess of normal operating levels may cause failures of the packing on the liquid circulators. This necessitates a long period of forced air circulation before the affected area can be worked. At best, every electric motor on the ship must be reset and started to resume operation, and usually the plant must be run on single stage operation for a time before the boosters can be placed into service. Failure of the electrical supply for only 15 minutes may require the operation of the plant for many hours before pre-existing conditions can be re-established.

## Freezers

Tuna when placed in the freezers normally have an appreciable amount of surface moisture that deposits on the coils during the freezing operation. Also, there is some desiccation of the fish which adds to the deposits of frost. In the shelf freezers, a maximum amount of 17, but usually only 15 tons of tuna were in direct contact, through gauge metal plate, with approximately 5,800 feet of pipe. In the various blast freezers, a shelf space for 15 or 25 tons of tuna is available per freezing unit of 930 feet of coils. Thus, a relatively minor amount of moisture deposited on the large shelf coil area becomes a problem of major concern on the smaller blast freezer coil area.

The operation of the shelf freezers presented only relatively minor and infrequent difficulties from such causes as leakage through the ammonia circulator packings and the resumption of refrigeration if the rooms were allowed to become unusually warm during periods of idleness. The rates at which tuna could be frozen were somewhat better than might be expected in this type of freezer. As a general statement, tuna up to 25 pounds in weight could be frozen to 0° F. in 9 to 18 hours, while those from 25 to 50 pounds required 18 to 24 hours and fish in the 50 to 100 pound range required from 24 to 36 hours. The shelf coils are fitted with an effective hot gas defrosting system and nearly a week of operation is permissible between defrosting periods. The freezing of fish in shelf freezers is thought to depend mainly on the transfer of heat by comparatively gentle convection currents, by conduction through direct contact, and to some extent by radiation. The greater contact area effected by the use of square cross-section area coils as contrasted to the line contact area with the older type of round coils, probably results in a significant increase in the amount of heat transferred by conduction. After the freezing is started, the air temperature in the shelf rooms quickly drops to low levels and the temperature differential between the air and the refrigerant is considerably less than in the blast freezers. These conditions together with the large shelf coil areas probably cause a minimum of dehumidification of the air at the surface of the coils and minimizes the need for defrosting.

The blast freezers are defrosted by a spray of sea water which collects in pans under the coil units and is discharged to the bilges by gravity. If the charges of tuna to be frozen are more than 10 to 15 tons per coil unit, an excessive number of defrosting periods may be required. If defrosting is required only at the start of the run and not more than once during the freezing period, the blast freezers usually perform satisfactorily. Complications may be expected if additional defrosting is necessary. Residual water may freeze in the supply or removal lines resulting in inadequate defrosting or water may accumulate on the floor of the freezers to further aggravate the frosting condition when freezing is resumed. If there is unusually heavy frost, a supplemental source of water will be required for defrosting. Unfortunately, access to the coils is difficult and defrosting is held to be an overtime task by the "reefer" crew. Improvement in the performance of the freezers resulted when a definite responsibility and a fixed routine of inspecting the coils was initiated. Even with all precautions, irksome situations developed but at least they were known and corrective measures could be taken within a shorter period of time.

The leakage of ammonia through the packings of the circulator pumps in the blast freezers was a frequent and annoying occurrence. Unfortunately, the leakage might progress for several hours before it was noticed. Ventilation of the freezers below deck is more difficult than in a shore installation and many hours of air circulation may be necessary before the ammonia concentration can be reduced sufficiently to permit working in the area. This may result in thawing and damage to the fish or at least cause a considerable interference with the production schedule. It is the opinion of the operating personnel that a positive shaft-seal type of circulator would be more desirable than the present packing seal. Residual defrost water on the coils or from other sources is apt to be drawn into fan motors of the blast freezers and cause an electrical failure. These must have the highest waterproof and insulation ratings if sea water is to be used for defrosting.

A 15 to 20 ton charge per coil unit in any of the freezers generally required in excess of 24 to 36 hours for freezing to $0^{\circ}$ F. A charge of 50 tons in number 2B blast freezer might require from 36 hours to 3 days for freezing, depending on the operational difficulties encountered.

Unfortunately, more effort is required to load the shelf freezers than the blast freezers. In the shelf freezers the major part of the fish must be handled individually and placed in position on the coils. This could be alleviated by the use of conveniently located loading hatches in the deck-head to facilitate the distribution of the fish about the freezer by using a chute. The blast freezers have a decided advantage over the shelf freezers in loading, as the fish can be delivered by a straight line flow through an aisle and placed on the trays. The loaded trays can readily be pushed along the supporting frame by one man.

## Storage Compartments

Little difficulty was experienced in maintaining temperatures of zero or below in the storage rooms with the exception of number 1 orlop room and number 2A room used for ice storage. In the latter room the successive additions of fresh ice may be expected to raise the temperature. Perhaps significantly, these two storages are under a deck-head having no refrigerated space above. A considerable amount of condensation was generally noticeable on the floor of the cannery workers' quarters, but the thickness of the insulation between it and number 1 orlop room should be adequate under normal conditions.

## RECOMMENDATIONS FOR THE REFRIGERATION PLANT

The refrigeration plant performed reasonably well when an adequate supply of ammonia was at hand, skilled operators were in charge of the plant, no ammonia leakages or power failures occurred, and defrosting was not a particularly difficult problem. The location of the surge drums and ammonia circulators outside rather than inside the blast freezer rooms would be more desirable since a leakage of ammonia would soon be detected and the equipment would be more readily accessible. Ammonia leakage in the shelf freeze rooms was not frequent, possibly because of the more constant operating temperatures and the infrequent need for defrosting. In addition, the equipment in these areas is readily accessible and is not enclosed by the air ducts which are necessary in the blast freezers. In the shelf freezers, either of the two rooms served by a common surge drum and circulator may be isolated and can be used if leakage should occur in the other. The ammonia circulators for the storage rooms are located in the compressor room. A leakage of ammonia from these was infrequent, possibly because of the more constant operating temperatures, and could be readily detected by the watch operator. In addition, the compressor room has an adequate system of forced draft ventilation and the operating temperatures are nearly constant.

Refrigeration systems on shipboard should be of the simplest possible structural and operational design. A compound and flooded system of refrigeration may be more economical from the point of power requirements, but the saving in this respect may be partially nullified by the added expense of personnel for overtime if difficulties are encountered. Basically sound equipment which may give trouble when under the care of less experienced personnel should be avoided. The use of a completely separate system of piping and refrigeration equipment for the functions of freezing and storing the tuna would have many operational advantages.

The shelf freezers operated more satisfactorily than the blast freezers, but the blast freezers had the advantage of straight line flow for charging and removing fish. If the tuna are to be dry frozen, a combination of the large coil area characteristic of shelf freezers and the high degree of air turbulence characteristic of the blast freezers appears to be the most desirable combination for maximum capacity and freedom from operational problems. The freezers should be designed and located so that the fish can be delivered readily to their position in the freezer and later to the storage holds. The relationship between the capacity of the freezers and cubic capacity of the storages should be balanced to avoid or minimize the necessity of transporting fish between various hatches. If shelf freezers are used, long banks of coils with suitable doors for admitting or removing fish at each end of the freezer are worthy of consideration. If these freezers are located below deck, convenient loading hatches should be provided. The use in the aisles of the freezers of hinged-end-section, reversible-travel conveyors which are capable of being extended beyond the doors when they are in a working position may offer advantages in the movement of materials. If the freezers are located between two hatches, they might well serve two holds. The use of blast fans in shelf freezers should provide a marked increase in their capacity since convection currents are important in shelf freezing and the sole means of heat transfer in blast freezers. The large coil area and the closeness of the fish to the coils might be expected to provide smaller temperature differentials between the surface of the fish, the air and coils in a shorter time than in the conventional blast freezers. This would minimize the dehydration of the surface and flesh of the fish.

If blast freezers are to be used, they should also be designed and located to expedite the flow of material. Blast freezers are normally used to freeze packaged fish or those materials which can be frozen very rapidly and resist loss of moisture. A far different problem is encountered in freezing tuna which normally have relatively large amounts of surface moisture. Consequently, such units should have a far greater coil area than is common in other installations. On the Pacific Explorer, a maximum quantity of only 15 tons of tuna could be readily frozen per cooling unit of approximately 930 feet of coils, but even with this limitation, defrosting might require unusual care. Doubling or tripling the amount of coil area should greatly diminish the freezing time and provide better performance.

It should be emphasized that all units of the blast freezers which may be a source of operational difficulties should be readily available for inspection and repair, and should be located outside the freezer if possible. Doors at opposite ends, or some system of available forced ventilation for the emergency removal of ammonia fumes should be incorporated in any type of dry freezer.

## RECOMMENDATIONS FOR DESIGN OF RECEIVING VESSELS FOR TUNA

As a result of the first trip of the Pacific Explorer several persons and companies are building or are considering building ships for freezing and transporting tuna. Since these vessels are intended only for the tuna trade, consideration is being given to modifications of the direct-brine-freezing system that is used on modern tuna clippers. Brine freezing has been reported to have an adverse effect on the quality of certain fish which are to be ultimately distributed in fresh fish markets, but fortunately the freezing of tuna in brine does not have an apparent adverse effect when it is to be canned. On the modern tuna clippers, the fish are dropped into the brine wells, chilled in sea water brine, and partially frozen in a strong sodium chloride brine to a temperature ranging from $15^{\circ}$ to $20^{\circ}$ F. The brine is then removed and the fish are held in subsequent dry storage in the same well. Depending on the length of time they are in storage, the tuna may eventually be lowered in temperature to the range of $0^{\circ}$ to $10^{\circ}$ F. This system of preservation is the most satisfactory of those which have been developed to date on the clippers. The advantages are that it requires less labor and reasonably maintains the general quality of the cargo, although the storage temperatures are not ideal. Persons interested in the operation of receiving ships should devote extensive thought and research to applications and refinements of the direct-brine-freezing technique before adopting it on larger ships.

It may be too expensive to construct a large receiving vessel with a complete cargo space of refrigerated brine wells which is standard practice on the small, by comparison, modern tuna clippers. Consequently, it would appear to be more feasible when construction costs are considered to use a system of brine freezing and subsequent dry storage in a conventional type of cold storage compartment. One serious disadvantage of the brine system used on the tuna clippers is that the fish become frozen into a solid mass and are difficult to remove without thawing. Removal of the fish in this condition from the freezing tanks for subsequent dry storage will be impractical on receiving ships. One factor contributing to this solidly frozen condition is the practice of cramming as many fish as possible into a well to increase the pay load. Salt penetration into the flesh of the fish, and surface films of brine, slime and scales are also believed to be significant factors in the tendency for the tuna to freeze together. Unfortunately, the penetration of salt appears to create a softer condition of the surface layers of the tuna frozen in brine as contrasted to dry frozen fish at the same temperature within the range of temperatures in common use. The presence of salt films and salt penetration lowers the freezing range at the surface and should tend to facilitate heat removal from the interior of the fish. As the temperature of the tuna is lowered in dry storage, the salt-containing films and surface layers become more thoroughly frozen. These conditions may entirely explain the solidly frozen mass of fish on the tuna clippers. However, the factors inherent to direct-brine freezing may also be responsible and it may be necessary to take certain precautions.

The dense brines have a buoyant effect on the tuna and may cause them to jam and freeze together at the top of the tank or other receptacle which may be used. The surface layer of slime, scales and moisture on the fresh, unfrozen tuna will have a high freezing point and the sudden exposure to cold brine may cause them to freeze into a solid mass. If the brine is circulated during the freezing cycle, the conditions of heat exchange should counteract this initial effect of jamming the fish into a solid mass. The individual fish could also be plunged into the brine which should have the same effect in avoiding the initial formation of a frozen mass. The effect of salt on the surface and in the flesh will lower the freezing point locally. This together with the buoyancy of the tuna and the falling temperature of the brine may cause the tuna to freeze together as the freezing progresses. If this condition should prevail and be serious, variations in the amount of fish in a given volume of brine or an adjustment of the temperature to which the fish are cooled may eliminate the problem.

It is theorectically possible to freeze tuna in a eutectic concentration of sodium chloride brine which has a minimum freezing point at -6° F. but eutectic solutions are difficult and impractical to maintain. When making ice in blocks, it is not considered good practice to attempt to maintain a sodium chloride brine temperature of less than 5° to 10° F. to avoid freezing the brine at the surface of the refrigerating coils. Since a temperature differential must exist between the tuna and the brine in order to obtain a practical rate of heat transfer, it may not be feasible to bring the temperature of the fish below the range of 12° to 18° F. If the minimum temperature is appreciably above 10°, a cooling period of indeterminate duration in dry storage will be necessary to lower the temperature of the fish to zero. The low temperature is necessary to maintain quality for prolonged storage life. A sufficient degree of cooling may be effected by the cooling action of the conventional type of cold storage room coils, but it may be advisable to have a special cooling room with a large coil area. The successive addition of comparatively large quantities of warm fish will elevate the temperatures of ordinary cold storage rooms and may cause excessive dehydration of the fish.

The system of freezing tuna in brine has an important advantage in that a large reserve of "cold" may be established during periods of low fish production. Another partial advantage of brine freezing is that a higher rate of heat transfer can be obtained between solids and a liquid, than in the gas and solids combination of dry freezing methods. Hence, other factors being equal, there is an initial advantage in using the brine system at the start of the freezing cycle, but when the temperature of the fish reaches 12° to 15° F. there is a definite limitation of the differential of temperature which can be obtained with sodium chloride brine. The need to produce low temperatures of the fish may serve as a bottleneck in using the brine system as compared to dry freezing. The rate at which fish deteriorates in the range of 22° to 30° F. is many times greater than in the range of 0° to 15° F. Consequently, the rapid decrease of the temperature of the fish to 15° F. or lower is a pronounced advantage. On a test freezing run aboard the ship, 3 thermocouples (one just under the skin, another at a distance of about 1 inch into the flesh, and a third at the backbone about $2\frac{1}{4}$ inches into the flesh) were inserted in a 30 pound tuna which was frozen in a blast freezer. The results indicated that a 5 degree or greater temperature differential can be expected between the underside of the skin and the backbone of such a fish during the cooling period. Persons freezing tuna should consider that the brine temperature will be substantially lower than the surface and particularly the internal temperatures of the fish unless time is allowed for the system to reach equilibrium.

Only tests under practical operating conditions will determine whether or not the initial quick cooling effect of cold sodium chloride brines will provide a method superior to dry freezing for installation on tuna receiving ships.