DEPOT SHIP SUPPORT FOR NUCLEAR POWERED SUBMARINES

BY

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The purpose of this paper is to offer guidance in equipping depot ships with the necessary special facilities required for the maintenance and logistic support of nuclear powered submarines, during the period between normal regular dockyard refits. It must be accepted, however, that defects may occur which will be beyond depot ship resources and for these dockyard support will be needed.

This paper contains only information relative to special facilities for use in connection with nuclear plant working. It is assumed that depot ships will be equipped with light and heavy machine shops and other necessary facilities for the support of steam plant components, Diesel engines and other conventional machinery.

Pure Water Requirements

Pressurized water reactors as normally fitted in nuclear submarines use demineralized, deaerated water as the primary coolant. In *Dreadnought* for example, the primary circuit is in two loops, both loops extract heat from the one reactor and in turn each loop is cooled in one of two heat exchangers known as steam generators. Circulation is maintained over a wide range of flow requirements as necessary according to power requirements by three two-speed pumps fitted in each loop. Each loop is of seven tons capacity and in *Dreadnought* tankage is provided for the storage of sufficient water to fill one loop. This stored water is not deaerated but means are provided whereby make-up water from the tanks is deaerated by heating. Make-up requirements to meet expansion and other losses can amount to the order of 200 gallons per day. Normally, the level in the stowage tanks is maintained by filling with distilled water from the submarine's evaporating plants. However, when alongside a depot ship, submarine officers would expect to be in a position to shut down their evaporator plants and to be able to obtain all the demineralized water required from the parent ship. For submarines similar to *Dreadnought* the maximum over-the-side requirement at any one time would be of the order of seven tons, viz. sufficient to replenish the primary circuit tanks. Deaerated water will not be required. *Dreadnought* will be able to accept demineralized water into the primary circuit at a rate of 1,200 g.p.h.

Pure water will also be required for use in the depot ship for the following facilities. While it is not possible to quote precise requirements it is considered that a maximum usage of about 4 tons per day for each nuclear submarine alongside can be expected.

(*a*) Material decontamination
(*b*) Personnel decontamination
(*c*) Clean workshop
(*d*) Radio-chemistry laboratory
(*e*) Cleaning down of the above facilities.

The use of pure water for these purposes is necessary to minimize the introduction of any foreign solid or dissolved matter into the primary coolant system in order to prevent the formation of undesirable radio-active isotopes in the system and to reduce the possibility of corrosion in the system to an absolute minimum.

The purity specification of the water should be in accordance with the following :—

Specific conductivity at 25 degrees C.	—2·5 micro —mhos/cm maximum
Dissolved oxygen	—0·14 p.p.m. maximum
Total solids by evaporation	—1·0 p.p.m. maximum
Chlorides	—0·10 p.p.m. maximum
Turbidity	—None allowed—must be crystal clear.

Generally pure water for use onboard the depot ship will be required in bulk quantities during short periods in the course of a working day. It will not be practical, therefore, to restrict supply flows to the limited output flow of standard type demineralization plants. Pure water storage tanks will, therefore, be required; a total tank capacity of up to 20 tons is suggested.

The storage tanks should be of stainless steel or of medium carbon steel with a corrosion-proof, non-contaminating lining applied to prevent any contact of the water with the steel.

To prevent contamination of water during distribution stainless steel or plastic pipes and fittings should be used throughout. Pumps must be of stainless steel or plastic lined construction designed to prevent oil contamination of the water.

The pure water can be produced by a demineralizer of the ' Permutit ' type.

Electric Power

Nuclear submarines have three sources of electric power :

(i) A.C. from turbo-generators
(ii) D.C. from Diesel generators
(iii) D.C. from battery.

In addition, motor generators are installed for the conversion of A.C. to D.C., or vice-versa, as required.

All motor-driven machinery, heaters, etc., except in a few special cases, are A.C. The propulsion motor is D.C.

When alongside the parent ship with electric prime movers shut down nuclear submarines will require an over-the-side supply to maintain normal hotel services of something in the order of 350 to 500 kW. A high proportion of this load will be used to maintain the reactor plant in a stand-by condition. To avoid the use of the submarine's motor generators and consequent conversion losses, and the necessity to fit special shore supply connections in the submarine, it is preferred that this should be A.C. power. Although *Dreadnought* is being fitted with D.C. shore supply terminal boxes, it is not anticipated that such will be fitted in possible future nuclear submarines.

Further, the adoption of any alternative to a direct A.C. supply will entail the running of important units of the submarine's machinery and thus prevent or limit the opportunity of carrying out minor repairs or maintenance to these units or associated systems, besides imposing undesirable additional watch-keeping duties on the submarine's crew.

Occasionally conditions may arise such that it is necessary to shut down a reactor plant and allow it to go cold, when it will be necessary for the depot ship to supply sufficient A.C. power to make a ' cold start '. Basically, this involves heating the primary circuit water in a pressurizer to bring the circuit up to the required operating pressure. The full heat load is of the order of 300 kVA. At a predetermined pressure the primary coolant pumps are started and run to maintain coolant flow according to requirements. Also at this time power is required to the reactor fuel rod control motors in order to control the output of the reactor. These primary loads together with a number of auxiliary load requirements will total about 650 to 700 kVA to be supplied from the depot ship. After about three hours it is possible to put the turbo generators on load when the nuclear plant will become self-supporting.

It is possible for a nuclear submarine to make a ‘ cold start ’ using her Diesel generators and a fully charged battery. This is not desirable, however since it is somewhat of a strain on resources requiring the motor generators to be run on overload and resulting in a flat battery. This battery is important to the well being of the submarine since D.C. power is used to provide the essential life-saving supplies in any emergency.

Normally, it would only be expected to make a ‘ cold start ’ following a dockyard refit. The requirement for such a depot ship facility is, however, very real.

Material Decontamination Facilities

On the removal of any component, pipe length or instrument, etc., from the reactor compartment of a nuclear ship, the first step is to ensure that it is radio-actively clean. Extreme care in the use of approved shielding and protective clothing is necessary during the dismantling process and subsequent transport to a suitable decontamination area in the depot ship. During transport the component will be shielded by polyethylene sheet and/or lead shot bags. It is necessary that the access path should be planned to use the shortest possible route and to avoid all accommodation spaces. Direct lift by crane, reactor compartment access to decontamination area would be the ideal arrangement.

A spare primary coolant pump is housed in the reactor compartment of nuclear submarines and suitable handling facilities are provided to enable ships staff to replace a defective pump. These pumps will weigh about four tons and will be the largest and heaviest item expected to be handled outside of dockyard refits. In view of the provisions already made it is considered reasonable to assume that the depot ship facilities should be sized to handle a defective coolant pump, but not necessarily to decontaminate and repair. Requirements for the stowage of contaminated equipment are dealt with later in this paper.

The normal run of equipment requiring decontamination is expected to comprise tools, instruments, valves and lengths of pipe up to the order of eight feet and two inch bore, viz. equipment that will pass through a standard hatchway.

Normal decontamination measures consist of scrubbing with pure water and commercial detergent and flushing until radio-activity has been reduced to safe levels for the performance of subsequent repair work. In most cases this decontamination operation is sufficient. In order to minimize the spread of air-borne radio-active contamination which may be generated by the scrubbing operation, wet procedures should be used whenever possible.

Where radio-active contamination cannot be removed by scrubbing because of the presence of crevices or corrosion scale, shot-blasting and/or acid cleaning is necessary. If shot-blasting is necessary it must be done in a completely enclosed booth so that the resulting radio-active shot and dust can be confined, monitored for radio-activity and properly disposed of. The use of shot-blasting or acid cleaning for decontamination is of limited value as machined parts having close tolerances will be damaged beyond further use.

Because, then, of the special containment difficulties and its limited value, it is suggested that shot-blasting facilities need not be provided in a depot ship.

To meet requirements it is considered that a compartment with direct crane access and a floor area of about 100 to 200 sq ft should be provided, fitted out as shown in FIG. 1 with the following facilities :—

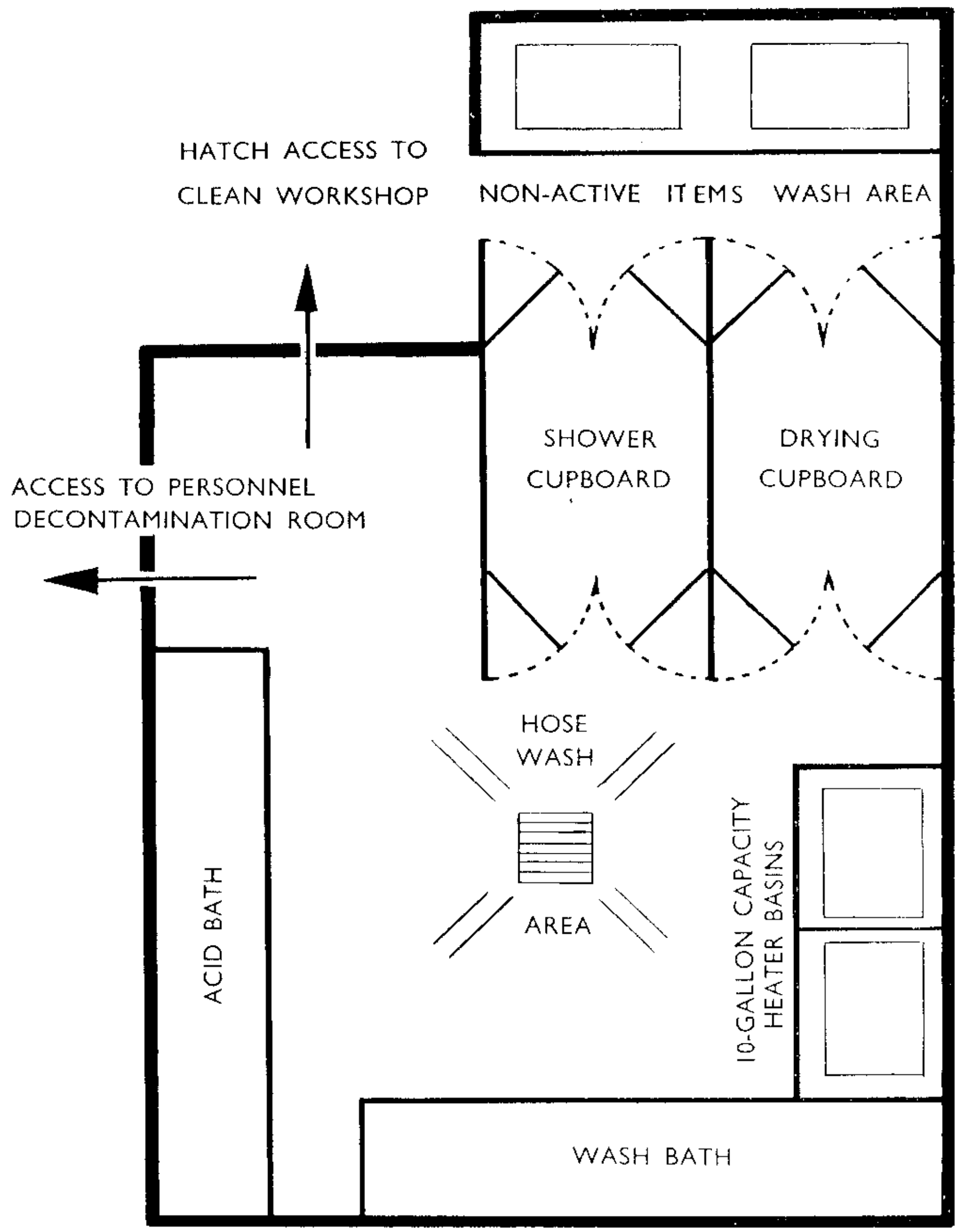

FIG. 1 MATERIAL DECONTAMINATION AREA

(i) Drying cupboard, electrically heated
(ii) Shower cupboard with fitted water sprays
(iii) 2 in. No. 10-gallon capacity electric heated stainless steel wash basins in the active wash area
(iv) 2 in. No. 10-gallon capacity electric heated stainless steel wash basins in the non-active wash area
(v) Acid wash bath, 8 ft × 1 ft 6 in. × 2 ft 6 in. deep of stainless steel
(vi) 1 or 2 in. No. wash baths, 8 ft × 1 ft 6 in. × 2 ft 6 in. deep of stainless steel
(vii) Pure water supply to basins, shower cupboard, and for hosing down large items on the floor.

All drains should be arranged for gravity disposal to the radio-active waste disposal system.

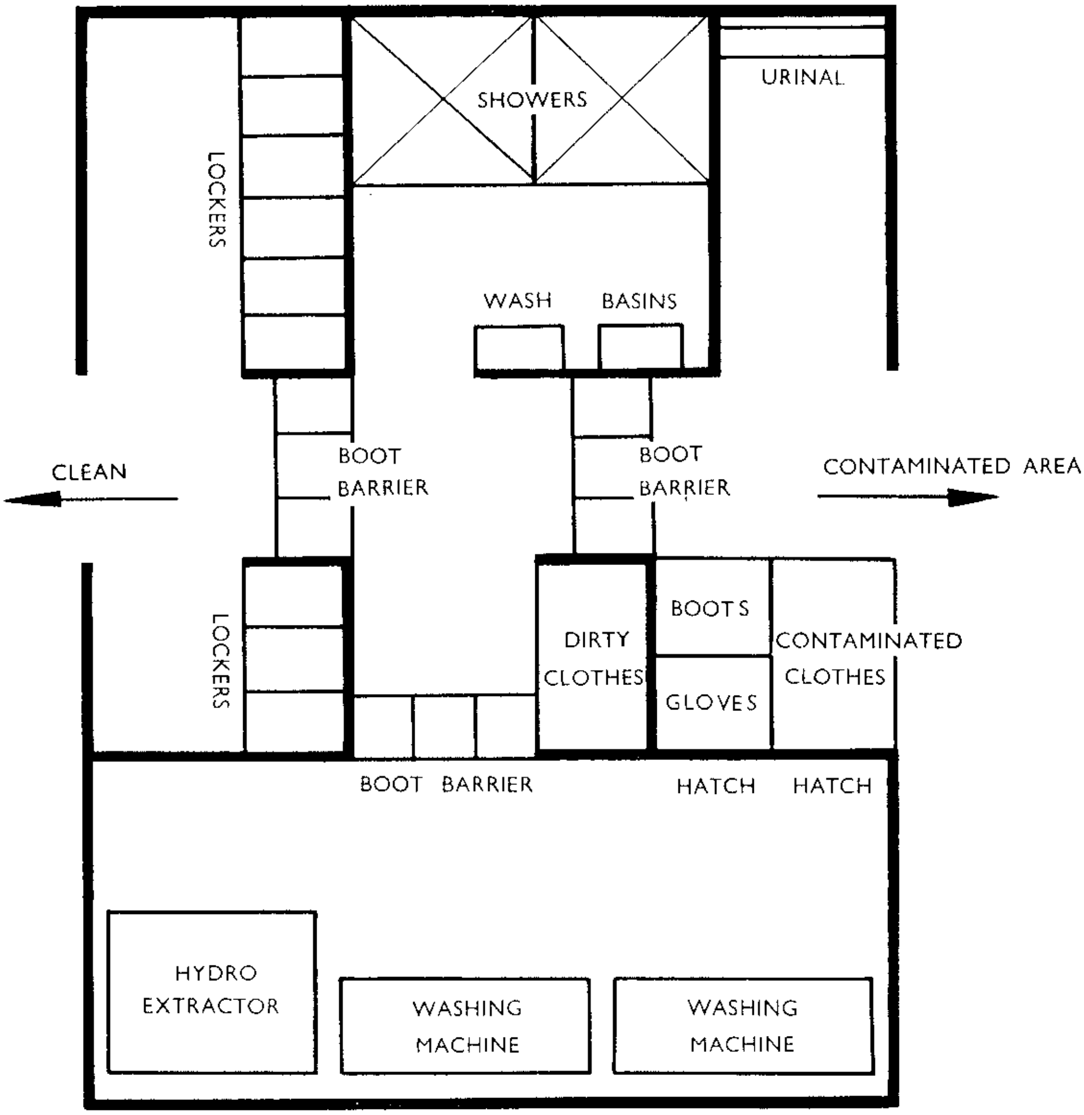

FIG. 2—PERSONNEL DECONTAMINATION AREA AND LAUNDRY

The compartment should be designed for ease of cleaning down. The bulkheads and deckheads should be painted with Epoxy resin paint. The floors and dado to be of Sapapagn.

Ventilating arrangements should be designed to give from three to five changes an hour, both supply and exhaust to be filtered.

A separate store is required for the stowage of shielding materials, polyethylene sheet and lead bricks. These materials will be required for use both in the material decontamination space and in the radio-active store room.

Personnel Decontamination

Personnel employed in the reactor compartments of nuclear submarines and in depot ship material decontamination rooms will wear special protective clothing and boots. Facilities must be provided where personnel can change and wardrobe their clothing and decontaminate themselves before leaving contaminated areas. These facilities should be so sited that only planned access routes to and from contaminated areas can be used. These routes to be so defined as to avoid trespass by unauthorized persons and should, of course, be as short as possible.

The decontamination facility should be divided into two areas :

(*a*) The dirty room where boots and contaminated protective clothing are removed and placed in a suitable bin. Boots are slipped off on stepping over the boot barrier into --

(*b*) The clean area. This is equipped with showers, wash-basins and suitable Clothes lockers.

Laundry facilities are required for the washing of contaminated protective clothing. Since no such special laundry machinery is fitted in nuclear submarines clothing contaminated in submarines during cruises will be stored in suitable bins for subsequent transfer to the depot ship for laundering.

All the water supplies to the personnel decontamination area should be demineralized in order to reduce the load on the radio-waste disposal system demineralizers. All drains from the area will, of course, be led to the radio-active waste disposal system.

The space should be designed for ease of cleaning down : the bulkheads and deckheads to be painted with Epoxy resin paint, the floor and dado to be of Sapapagn.

Ventilation arrangements should be designed to give from three or five changes an hour.

Radio-Chemistry Laboratory

Determination and maintenance of water quality is a continuous and vital function when dealing with nuclear propulsion plants. A small radio-chemistry laboratory is therefore required for analysing samples of primary circuit water taken from nuclear submarine systems and for checking the purity of water used in the depot ship for cleaning and testing of primary coolant system components. Samples of water from the radio-active waste disposal system must also be checked before such waste water is discharged to the sea.

Equipment will be required to determine :—

(*a*) Dissolved hydrogen and inert gas concentration in primary coolant water

(*b*) Dissolved oxygen content

(*c*) *p*H value of pure water

(*d*) Total quantity of solids by evaporation

(*e*) Conductivity

(*f*) Iron content

(*g*) Ammonia content.

Health Physics Room and Radiac Instrument Room

The maintenance of nuclear plants introduces distinctive problems in industrial hygiene. These are health physics problems. The radiation sources to be dealt with will be highly localized and the actual levels of radiation generally quite low. Serious over-exposures to radiation would not be expected.

Radio-active sources will be encountered :

(*a*) In the repair and maintenance of components in the submarine reactor compartment

(*b*) In disposal of radio-active wastes from decontamination of components and from demineralizer resin beds

(*c*) In handling components removed from submarines for repair or storage for subsequent disposal.

Personnel dosimetry and appropriate radiation exposure records will be required for all personnel who have a reasonable possibility of receiving a weekly dose of all radiations exceeding a quarter of the permissible maximum.

The health physics room should be large enough to allow counting instruments to be left in a set up position. Storage space should be provided for the miscellaneous equipment required for sample preparation and sources for instrument calibration.

Storage space should be provided for portable equipment and for storage and issue of clean protective clothing. Files for personnel records and film badges are also required.

Photographic dark room facilities should be provided for the development of personnel film badges.

The room to be designed for ease of cleaning down using an Epoxy resin paint for bulkheads and deckhead.

Ventilation to be such as to give three to five changes of filtered air each hour ; the exhaust to be led direct to atmosphere.

Clean Workshops

A clean workshop is required for clean welding, in particular the sealing of nuclear system components, radiographic inspection, purging of items with nitrogen or Argon gas and for hydrostatic testing of pressure parts. The construction of the bulkheads and deckhead should be such that there are no dust collecting projections. The surface finish to be suitable for cleaning by washing down with water.

No machine tools will be required in this but stainless steel topped benches fitted with easily cleaned steel vices should be provided. Stowage will be required for gas cylinders. The hydrostatic test facilities should include a demineralized water supply.

Positive ventilation capable of maintaining the atmosphere in a clean condition and with facilities for maintaining the temperature at 65 degrees F. with the relative humidity not in excess of 60 per cent, should be provided.

Welding Facilities

Primary coolant loop piping and associated systems in the reactor compartment are fabricated generally of austenitic stainless steel materials. For other ship systems the materials used are the same as for similar systems in conventionally powered vessels. To enable components to be removed from nuclear plant systems for repair or replacement, facilities will be provided in submarines to freeze the systems on each side of components to prevent loss of primary coolant.

In addition to normal welding facilities depot ships will need to be equipped to weld stainless steel and 1 per cent chrome molybdenum steel of thickness up to $\frac{1}{8}$-inch, including seal welds of material $\frac{1}{16}$-inch thick. Because of the importance of the special properties of the materials used, and the importance of preventing leaks or the introduction of foreign material into the piping, it is essential that nothing occurs during the welding processing to impair the metallurgical properties, weld quality or strength of the component. Because of the danger of over-heating the material and/or forming slag inclusions, cutting and edge preparation by oxy-acetylene burning is not permissible. Finish cutting and edge preparation for welding must be performed by a machine using a cutting tool of a non-ferrous material.

Suitable facilities for the examination of welds will be required and these should include a gamma source for use both in the depot ship and in submarines. Reference has already been made to photographic darkroom requirements for development of personnel film badges. These requirements should also be sufficiently extensive to include for the development of radiograph film unless other suitable facilities are already available. All welders, both in the submarine crew and in the depot ship, and engineer officers should be trained so that they can interpret the results of gamma radiographic examinations.

Radio-Active Waste Disposal System

The waste water from the following centres is liable to be radio-active and must be dealt with accordingly before disposal :—

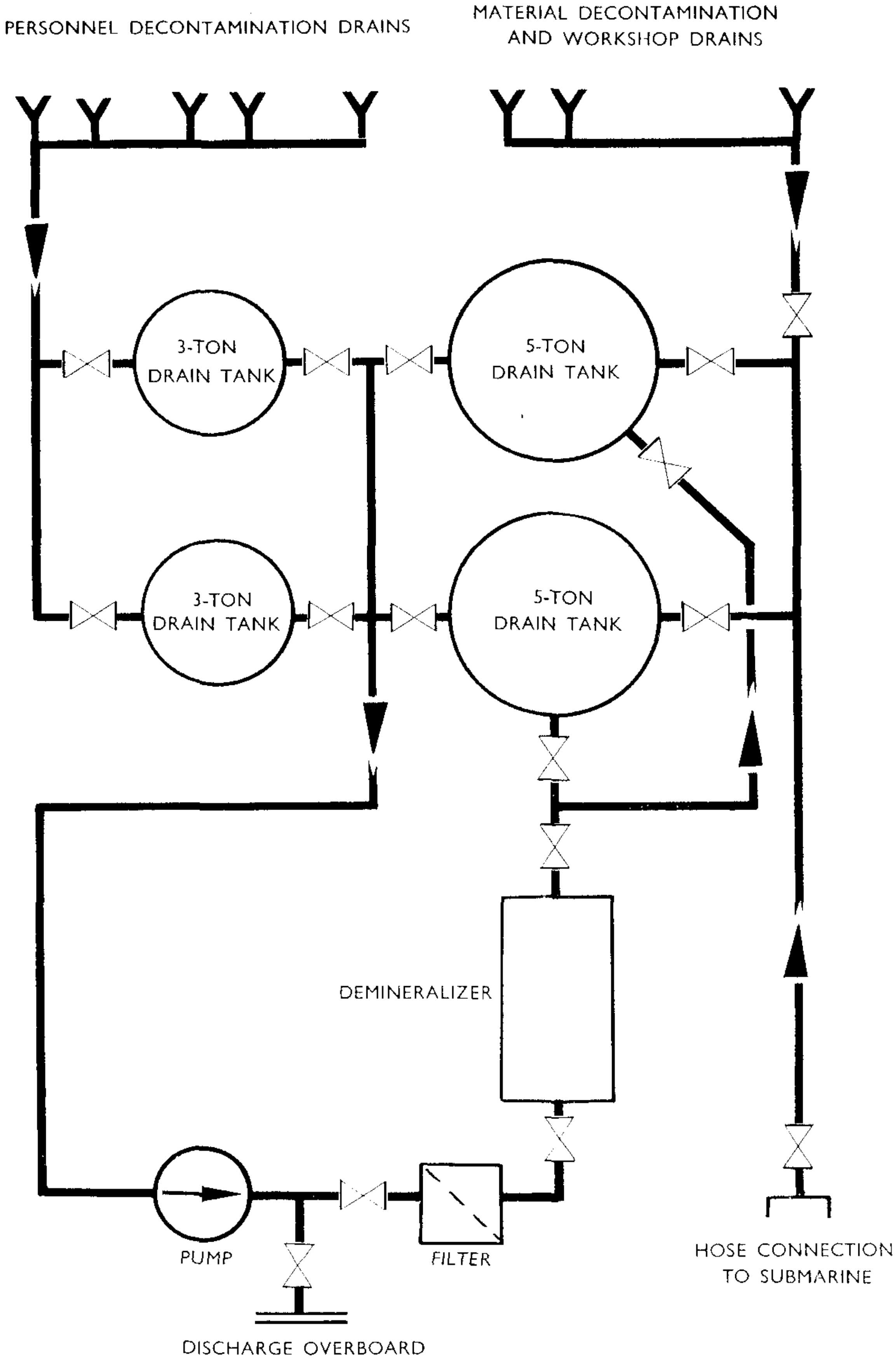

Fig. 3—Nuclear Waste Disposal System

(*a*) Material decontamination
(*b*) Personnel decontamination
(*c*) Clean workshop
(*d*) Radio-chemistry laboratory
(*e*) A nuclear submarine.

The treatment applied will be according to whether the water is free or not of ionic detergents. FIG. 3 shows an arrangement of a suitable disposal system.

Waste water free of ionic detergents will drain to one of two tanks. It is suggested on the basis of an estimate of usage rates that these tanks should each be of about five tons capacity. The water will be monitored and if found non-active may be pumped directly overboard. If active the water will be pumped through a demineralizer column in a closed system back to the tank, the process being maintained until the water is clean when it will be pumped overboard. Meanwhile, the second tank is being used to hold further drainage. It is estimated that both the pump and the demineralizer should be designed for a flow of about 200 gallons per hour. (N.B. Non-ionic detergents are safe and will not choke ion exchange columns.)

Contaminated water which cannot be demineralized because it contains detergents or some exceptional radio-active source must be held up until activity is reduced by decay, when it can be discharged overboard into the sea or to a lighter. It is considered that two to three-ton capacity tanks should be provided to meet this requirement.

No special materials are required for the system piping valves and tanks provided the design is such that the whole can be easily and properly cleaned by flushing with pure water. System piping valves pump and demineralizer, but not necessarily the tanks, should be shielded with the equivalent of $1\frac{1}{2}$ in. thickness of lead. The whole equipment should be installed in a compartment which can easily be cleaned in the event of an active leak. The tanks should be designed for easy flushing and protected internally with a Vinyl paint.

Demineralizer resin when no longer effective will be discharged to the resin bed discharge tanks for subsequent disposal via lighter.

Resin Bed Discharge System

FIG. 4 shows the arrangement of the required discharge and collecting system for both the submarine resin discharge and that from the depot ship radio-active waste disposal system demineralizer.

It is preferred that the system be installed in the same area as the radio-active waste disposal system with the spent resin tanks in the area allocated as a radio-active store room.

The spent resin is flushed out of the demineralizer with pure water at a pressure of about 100 lb/sq in. into the spent resin tanks. These tanks will be designed with a built-in filtering arrangement which will retain the resin but allow the water to flow through to one of the radio-active waste disposal tanks. The maximum volume of resin that it is expected will need to be dealt with at any one time is 14 cu ft. The catch tanks for this resin will need to be protected with heavy shielding but will at the same time need to be designed within the loading limits imposed by the depot ship deck structure and within the heavy lift capacities available. It is possible that these tanks may be designed for manufacture on board the depot ship using concrete 24 to 30 in. thick for the shielding. Such tanks would be suitable for disposal at sea. Alternatively the tanks would be of steel shielded with lead about 4 in. thick. These would be designed for ease of cleaning and would be re-usable.

The requirement for pressurized water might be met by the use of the waste disposal system pump in conjunction with a demineralized water supply.

A 100 lb/sq in. air supply is also required for blowing through the demineralizer after discharging the spent resin to ensure the column is clear before recharging with fresh resin.

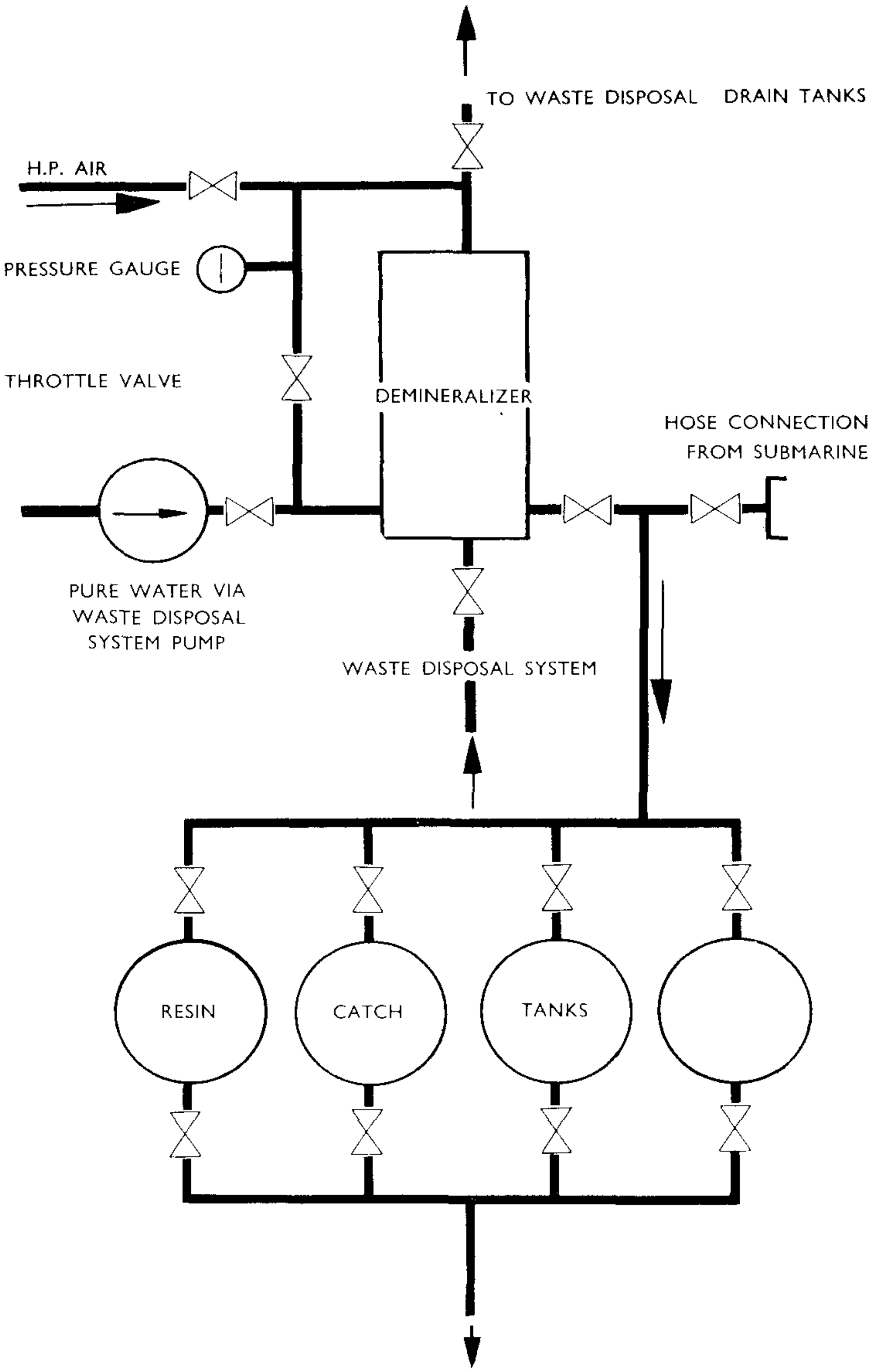

FIG. 4—RESIN DISCHARGE SYSTEM

Radio-Active Store Room

A space will be required with a floor area of up to about 200 sq ft for holding stores and equipment which cannot be decontaminated on board the depot ship. Such stores will be shielded by lead bricks and/or polyethylene sheet until such time as the opportunity arises to land them.

Facilities for cleaning down the store with pure water should be available, the store being constructed and painted accordingly.

The store should be sited for direct access by crane to assure direct and speedy disposal of heavy equipment such as spent resin tanks without undue risk of unnecessary contamination of other areas in the depot ship.

A limited amount of waste which cannot be decontaminated will, however, be combustible. Such waste should be burnt and the ashes subsequently packed and shielded to ease the stowage problem.

Logistic Support

Nuclear submarines have certain special requirements calling for logistic support from the depot ship additional to that normally provided for conventional submarines. Some examples are listed below.

Oxygen Candles

Until an electrolyser is available, suitable for installation in a submarine, the breathable oxygen will be supplied by burning oxygen candles. It is considered that the depot ship should provide storage for 3,000 candles each 5 inches diameter and 15½ inches long (including canister) for each nuclear submarine supported.

Lubricating Oil

The depot ships should be able to supply make-up quantities of lubricating oil for the submarine turbine plants.

Spare Gear Stowage

At present it is not possible to estimate precise requirements, but it is considered that the List B spare gear for a nuclear submarine will occupy about double the volume of that carried for a conventional Diesel submarine.

Ships Office

A vast number of reports and safety documents, instruction books, spare gear lists and stores lists will be required for each nuclear submarine. It will be quite unnecessary to carry all these in a submarine on patrol. The proposed office would house an engineer officer's writer for administering spare gear and store demands while the submarine is away, and to relieve the Engineer Officer of a load of paperwork while the submarine is alongside the depot ship. It is considered that an office about the size of a normal single cabin would suffice.

Naval and Special Srores

Normal Naval Stores and Engineer's Special Stores held in the depot ship will need to be supplemented by supplies of :

(i) Hydrogen, used for de-oxygenating primary circuit water

(ii) Nitrogen, for purging cleaned compartments and pressurizing some header tanks

(iii) Freon ; much more will be used in large nuclear submarines than in Diesel submarines

(iv) Boiler water treatment chemicals, etc.

(v) Resin for recharging demineralizers.

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