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APAE No. 43

Volume III

MASTER 37

APPR-1  
RESEARCH AND DEVELOPMENT PROGRAM  
DECONTAMINATION PROGRAM  
TASK II

VOLUME III  
RECOMMENDED PROCEDURE FOR DECONTAMINATION  
OF A STAINLESS STEEL STEAM GENERATOR

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Vol. III

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RESEARCH AND DEVELOPMENT PROGRAM

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TASK II

VOLUME III

RECOMMENDED PROCEDURE FOR DECONTAMINATION  
OF A STAINLESS STEEL STEAM GENERATOR

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## ABSTRACT

A decontamination procedure for a stainless steel steam generator similar to the APPR-1 using a fill-flush application of a caustic permanganate-citrate combination solution is recommended. The isolation of the steam generator is to be accomplished by means of specially designed plugs at the reactor vessel outlet and at the primary coolant pumps. Anticipated results, including corrosion rates and decontamination factors, are presented.

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## 1.0 INTRODUCTION

The Army Package Power Reactor (APPR-1), a pressurized water reactor employing Type 304 stainless steel clad fuel elements, has been in operation since April 1957. Present estimates (January 1959) of the gamma radiation level within the steam generator at the end of core 1 life (November 1959) indicate a dose rate of approximately 8 R/hour at the inlet side. The pressurizer elbow is expected to have a dose rate of approximately 2 R/hour at that time. This activity is due primarily to the buildup of activated corrosion products on the primary system surfaces; a small amount may be due to fission product activity. This buildup of radioactivity can be both a hazard and a hindrance to maintenance.

Laboratory bench experiments and loop studies on chemical decontamination have been carried out under the APPR-1 Research and Development Program and a promising method has been developed. The application of this method to contaminated plant equipment, however, has yet to be demonstrated. Following a successful demonstration, plans and equipment for decontamination can be included in future military reactors.

## 2.0 OBJECTIVE

The application of the caustic permanganate-citrate combination decontamination method to a stainless steel steam generator using the present APPR-1 steam generator as a reference design.

## 3.0 RECOMMENDATIONS

1. The APPR-1 steam generator should be decontaminated at the end of core 1 life using the caustic permanganate-citrate combination treatment. The decontamination should be performed according to the procedure given in this report.
2. A waste disposal system should be incorporated into the present APPR-1 system to handle decontamination waste solutions.
3. Additional laboratory studies should be undertaken on the following subjects:
  - (a) The use of the caustic permanganate-citrate combination treatment for removal of fission product and uranium dioxide contamination.
  - (b) The corrosion and allied metallurgical problems connected with using the caustic permanganate-citrate combination on the various other materials of construction used in the primary system.
  - (c) The relative effect of flow rate and aeration time on decontamination.

- (d) Activity buildup and corrosion rates after a decontamination treatment.
- 4. A preliminary study of the decontamination of the entire primary loop and its possible application to the various military reactors now being considered should be undertaken.

## 4.0 DISCUSSION

### 4.1 The Problem

The purpose of decontamination is to reduce the dose rate from a particular system or component sufficiently to permit required maintenance. Ordinarily, therefore, direct access to the contaminated area is precluded. In general, when it becomes necessary to decontaminate a particular component such as the steam generator, the component must be isolated from the remainder of the system. A means must then be provided to introduce and remove the decontaminating solution, and facilities provided for disposal of the radioactive wastes produced.

The APPR-1 system does not have any provision for isolation of the various component parts for purposes of decontamination. Consequently, it is necessary to provide a means of isolating the steam generator in such a manner that decontamination can be carried out rapidly and with a minimum hazard to plant personnel and equipment. Since the system was not planned for eventual decontamination the procedures used will not represent the best possible engineering practice. The effectiveness of decontamination, however, can be evaluated by a demonstration at APPR-1 if due allowance is made for engineering improvements.

### 4.2 Operating Conditions

The use of a chemical solution appears to be the most promising method to decontaminate a stainless steel steam generator. In loop studies, a fill-flush application of a caustic permanganate-citrate combination solution at 225°F. gave the best results. A flow rate of five feet/second in the tubes of the steam generator seems to be an optimum value for decontamination. This value is a compromise between a practical pump size and optimum decontamination factor. The small increase in decontamination factor as a result of higher flow rates would not warrant the large pump necessary to obtain these flow rates. An aeration time of approximately one hour between the caustic permanganate and citrate combination solutions will enhance the final decontamination factor.

### 4.3 APPR-1 Decontamination System

Any modification to the APPR-1 for decontamination of the steam

generator must be designed on the following basis:

- 1) The steam generator must be isolated from the primary system.
- 2) Provisions must be made for an entry and exit of the chemical decontamination solution.
- 3) An external piping system must be installed for circulation of the decontamination solution.
- 4) It must be possible to install the modification while the system is in a highly contaminated state.

Several alternate modifications to the primary system to allow isolation of the steam generator were considered. The recommended modification adequately met all the above requirements.

#### 4.3.1 Recommended Modification of the Primary System

##### 4.3.1.1 Isolation of the Steam Generator

The steam generator will be isolated from the primary system at three points: the reactor vessel, the primary coolant pumps, and the presurizer. Prior to the isolation, the fuel elements shall be removed and stored in the spent fuel pit. The specially designed reactor isolation plug assembly (Fig. 1) will be lowered into the pressure vessel from the top of the shield tank. Incorporated into this plug is an 8-inch stainless steel pipe elbow to allow the decontaminating solution to pass through the plug from the steam generator inlet line. Approximately 16 ft. of stainless steel piping will be attached to the vertical section of the discharge elbow in the plug as it is lowered into the shield tank. When the plug assembly is located just above the core support, the plug is moved into the reactor outlet and locked into position. All of these manipulations are controlled from the top of the shield tank.

The primary system and inner shield tank are then drained through the bottom of the steam generator. Because the reactor outlet is plugged, the water drains through the reactor inlet line to the primary pumps into the steam generator and out of the system. When approximately four feet of water are left above the upper core supports, the siphoning action is stopped by opening the pump bleed valve. The system is then allowed to continue draining leaving approximately four feet in the reactor vessel to aid in shielding against radiation from the vessel itself. It is expected that under these conditions, the dose rate at the top of the shield tank will be approximately 50 mr/hr. This value was determined as the result of a series of film badge measurements taken during the November 1958 reactor shutdown.

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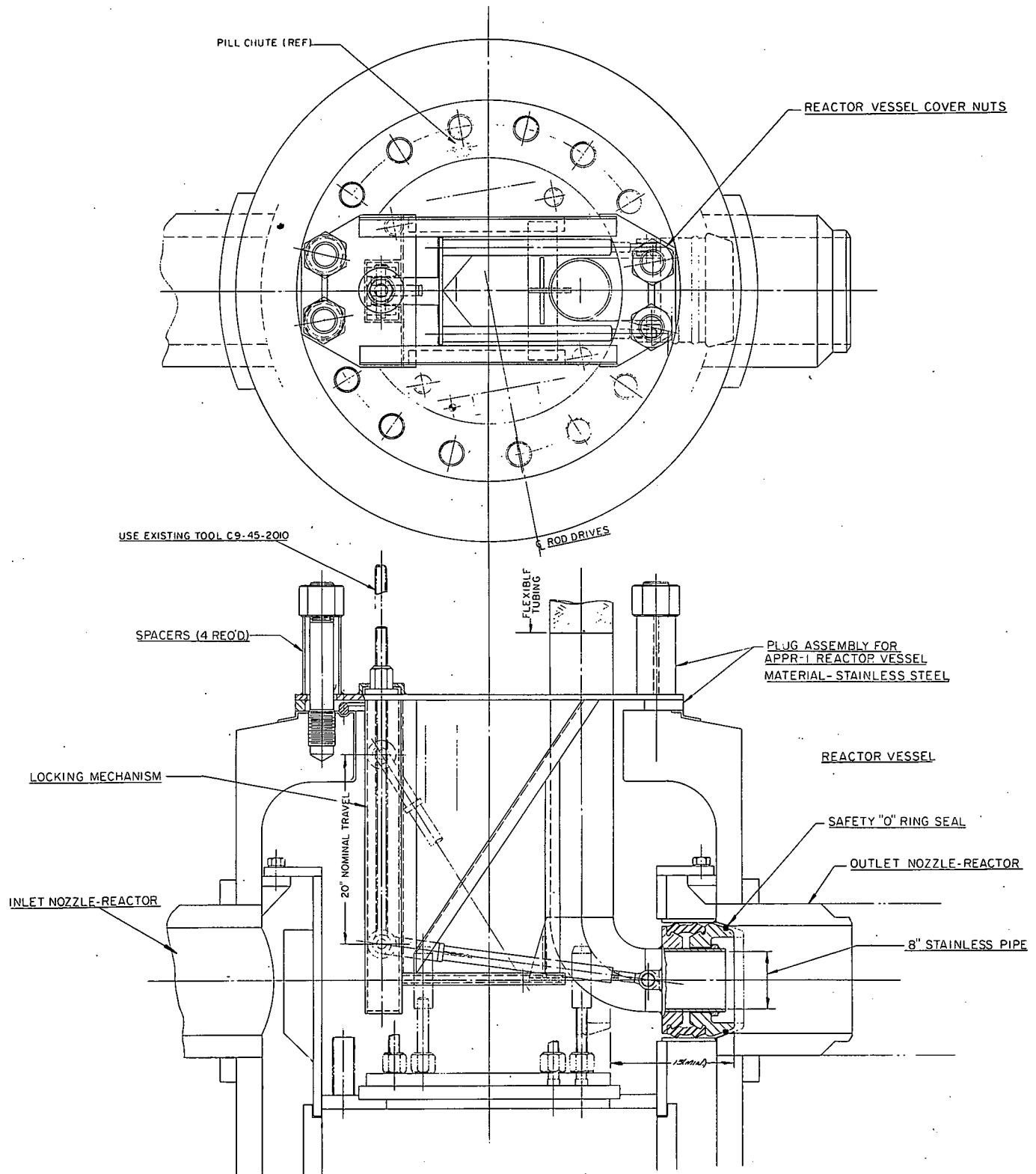


Fig. 1 Reactor Isolation Plug Assembly

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When the system has been drained as outlined above, both primary coolant pump motor and impeller assemblies will be removed from the pump cases. The stationary element plug (Fig. 2) will be located in the inlet of one of the pumps and bolted in place. This point will serve as the entrance for the decontamination solution. A similar type plug provided with a small bleed line in place of the large inlet line will be bolted into the second primary coolant pump case in a similar manner.

The heating element in the pressurizer will be removed to allow access to the 4-inch connecting line. A pressurizer plug (Fig. 3) will be used to complete the isolation of the steam generator.

#### 4.3.1.2 External Piping System

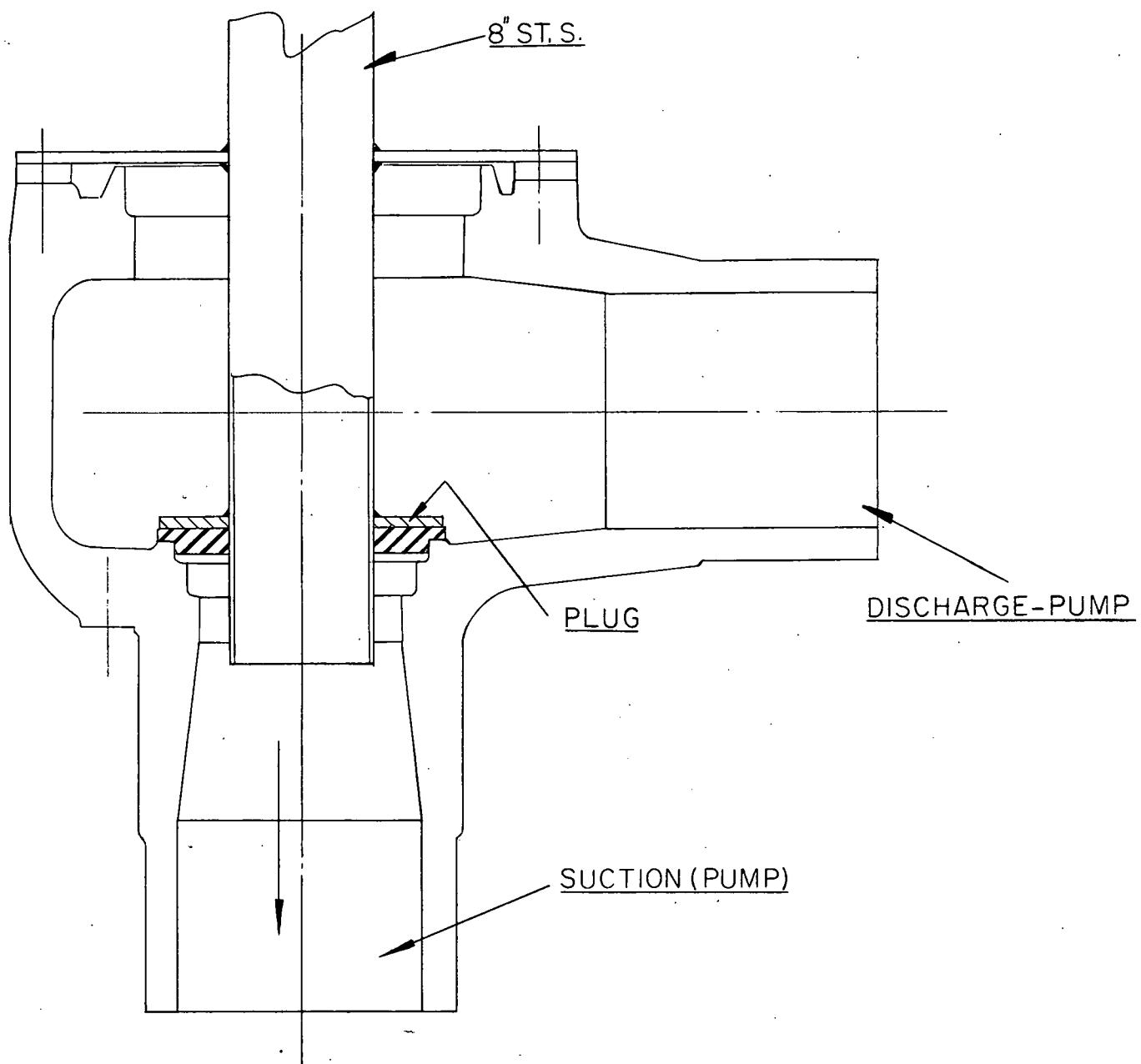
An auxiliary piping system is required to circulate the solution through the steam generator.

This external system will be connected between the reactor plug assembly and primary coolant pump stationary element plug (Fig. 4). All materials of construction of this system will be 18-8 stainless steel. A 2000-gpm centrifugal pump will be used for fluid circulation at a rate of 5 ft/sec through the tubes of the steam generator. The main external piping will be 8-inch pipe. Most secondary lines (fill, drain, bleed) will be 1-inch pipe. To heat the decontamination solution to the proper temperature during circulation, the steam generator will be used in reverse, i.e. steam is passed into the secondary side. The decontamination system will be filled in a manner similar to normal primary system filling. The piping and steam generator will first be evacuated. A connection is provided for a vacuum pump. A small 30 to 40 gpm centrifugal pump will be used to pump the solution into the system from a mixing tank. To prevent cavitation of the decontamination system circulating pump, all air must be eliminated. To remove this air, a 25 gallon tank located at the highest point in the system will serve as an air trap during startup of any cycle.

During operation, system pressure will be maintained by a cylinder of nitrogen gas. It will be introduced into the system through a make up (solution replenisher) tank. By the use of a network of valves, the fill pump will be used to pump the waste solution from the system at the completion of a cycle.

The approximate location of the major items of equipment are shown in Fig. 5. The fill and waste pump will be located on the floor of the vapor container. The mixing and waste tanks will be located outside the vapor container. The entire decontamination system can be disassembled and stored for future use at the completion of the operation.

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APPR-I P.C.PUMP  
WESTINGHOUSE MODEL Q 350 A-1

Fig. 2 Stationary Element Plug

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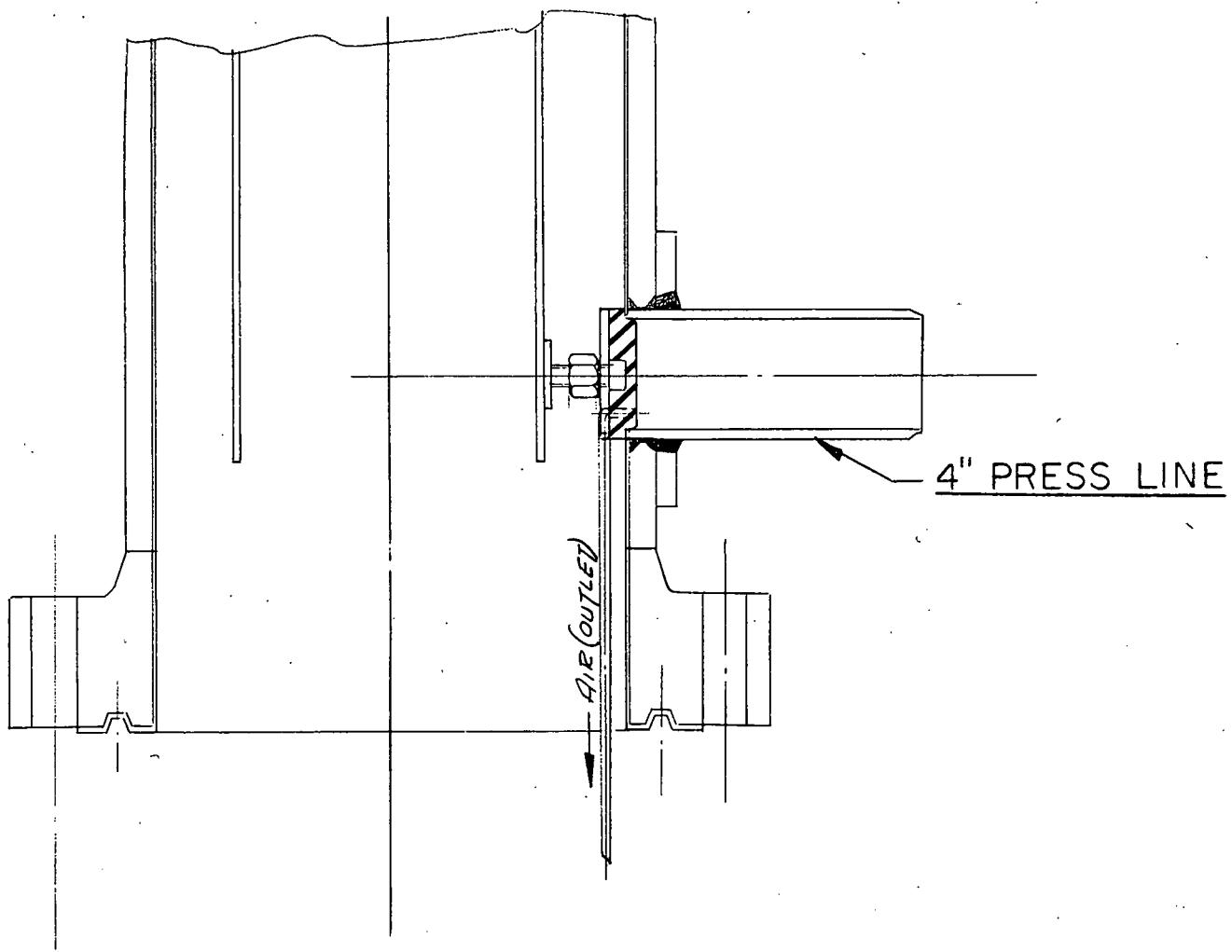


Fig. 3 Pressurizer Plug

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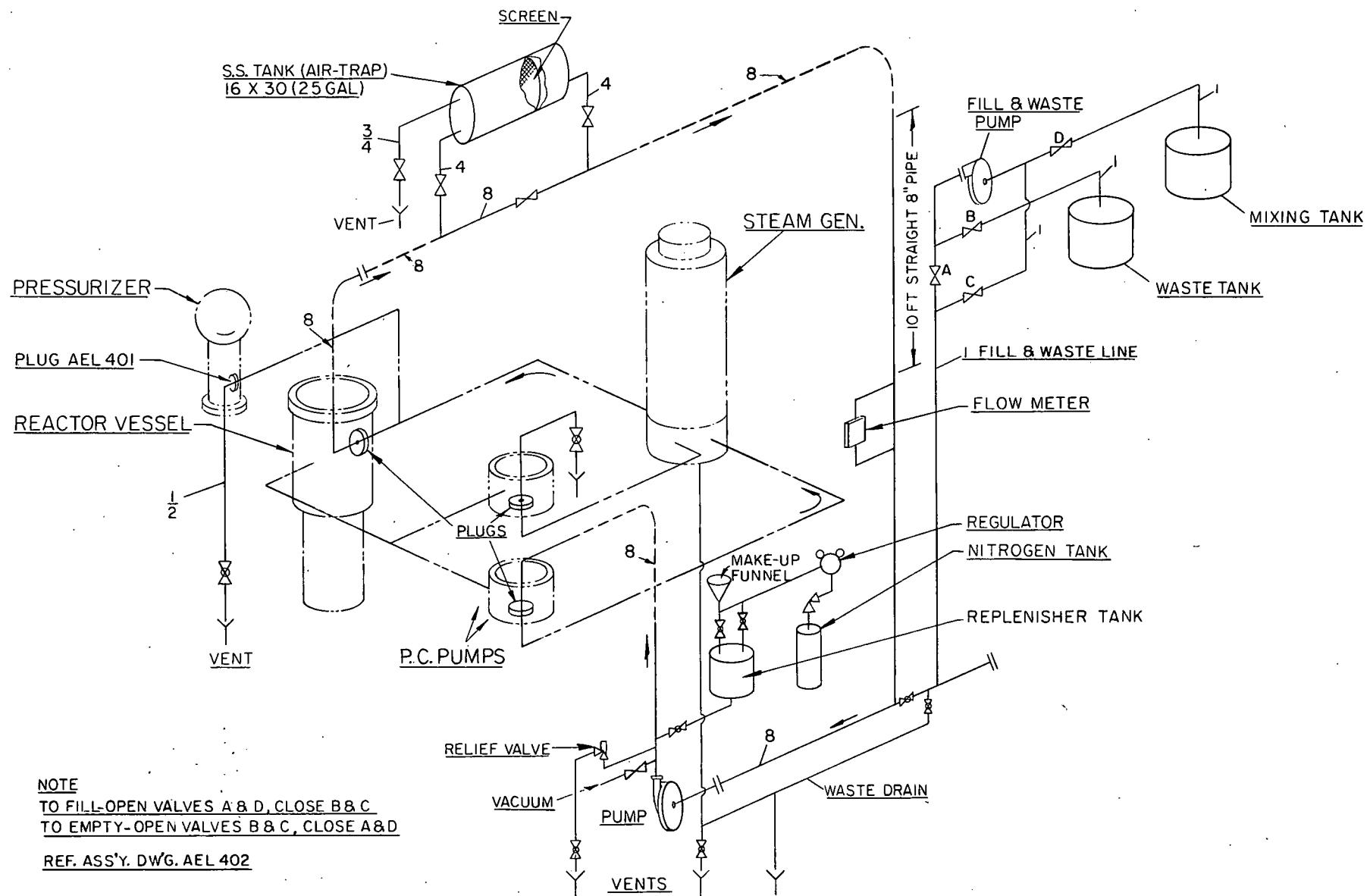
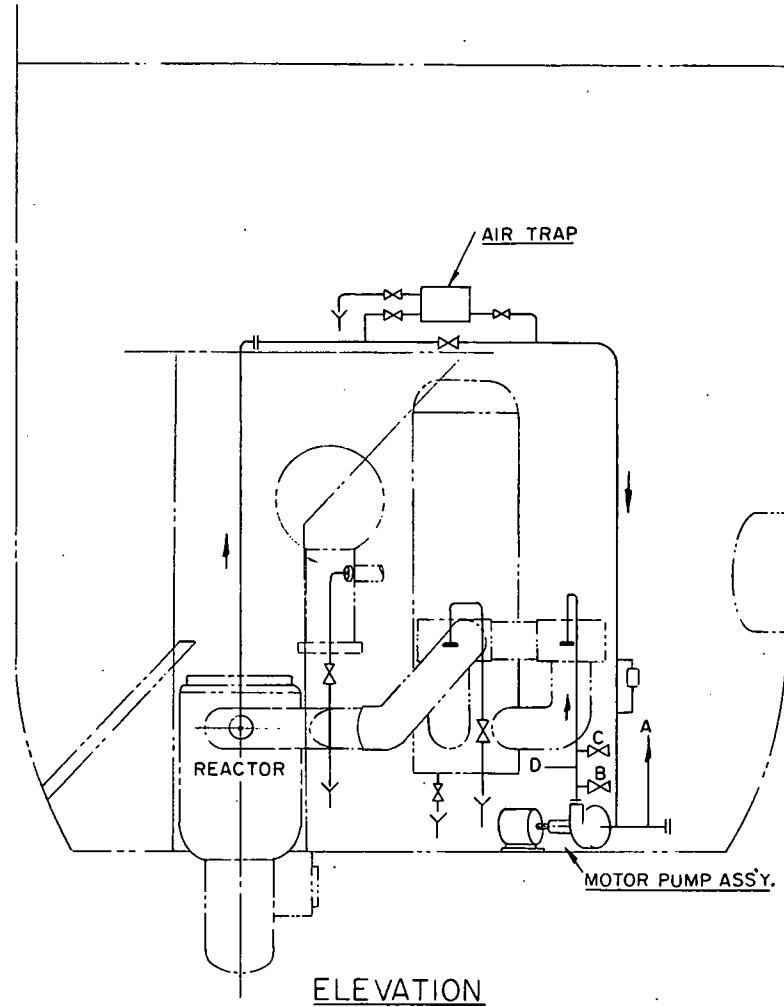
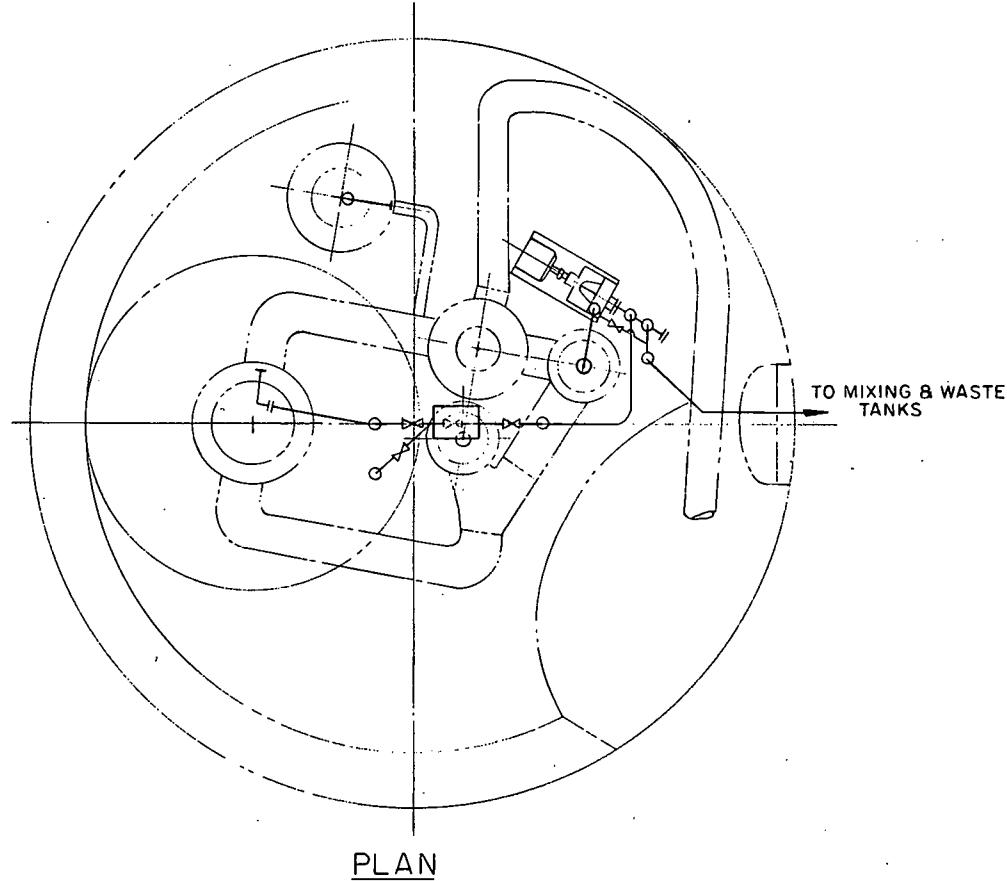


Fig. 4 APPR-1 Decontamination System Schematic

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NOTES

- A - LINE TO FILL & WASTE TANK
- B - VACUUM CONN.
- C - LINE TO REPLENISHER
- D - TO RELIEF VALVE

Fig. 5 APPR-1 Decontamination System Assembly

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Since the major part of the corrosion product activity is removed by the citrate solution, it may be necessary to limit access to the vapor container or even shield the external section during this phase of the de-contamination treatment. The gamma dose rate at any point 3 inches from the pipe is estimated to be as high as 3.6 R/hr depending upon the deposit thickness and a number of assumptions all of which are included in Appendix section A-2 entitled, "Calculation of Dose Rate from Schedule 5 Piping during the Citrate Combination Phase of the APPR-1 Steam Generator Decontamination."

#### 4.3.2 Other Modifications Considered

There are two other modifications to accomplish this operation which warrant discussion. In the first alternate method, the head of the steam generator would be lowered and the horizontal baffle plate removed. This would permit access to the steam generator inlet and the discharge pipes. These pipes would then be plugged with a suitable stopper. A specially fabricated head would then be used in place of the permanent head. The temporary head would be designed so that, when raised into position, it would separate the inlet and discharge area of the tube sheet into two compartments. The entry and exit of the solution to the steam generator would be made through this temporary head. The external piping system would be connected directly to this head. This external system would be very similar to the system mentioned above, but would most likely occupy a smaller area.

A major disadvantage of this method is that when the APPR-1 steam generator is to be decontaminated, the radiation level may be too high to permit dropping the head. It would then be impossible to employ this method. Since both the permanent head and horizontal baffle plate are removed, all surfaces within the steam generator would not be decontaminated. Space under the steam generator is limited, especially when the head is dropped. Most likely, this method would necessitate removing the head from under the steam generator. This operation would require cutting out the steam generator supports. This, in itself, would be an extremely hazardous and difficult operation.

The second alternate method would differ from the proposed method only in the isolation of the steam generator inlet. Instead of the reactor vessel plug assembly (Fig. 1), a 12 x 12 x 12-inch tee would be welded into the system. This tee would be located in the 12-inch main coolant line between the reactor vessel outlet and steam generator inlet. Space requirements for this installation would require draining and removing part of the shield tank.

The tee would then have to be welded permanently into the primary system. For decontamination, the reactor side of the tee would have to be plugged. Access for this plugging operation would be made through the

outlet run of the tee. This outlet run would then be used as a discharge point for the decontamination solution. After decontamination, the tee would be capped to allow normal reactor operation. The primary coolant pumps and pressurizer would be employed in the exact manner as the proposed procedure (Fig. 2, 3). The external loop would be almost identical to the proposed method (Fig. 4, 5).

Draining and removing part of the shield tank may present a radiation hazard. This may be further complicated because of the length of time required to perform the necessary cutting and welding on the primary piping. Because of this modification the entire system would have to be code approved. This would be time consuming and add an additional expense. The cost of this modification compared to the cost of the reactor vessel plug assembly for the proposed method is a further reason to consider it undesirable.

#### 4.4 Caustic Permanganate-Citrate Decontamination Solution

##### 4.4.1 Chemical Composition

The chemical decontamination solution is discussed fully in Volume II of this report.

The recommended chemical decontaminating method involves the use of two chemical solutions. These solutions are: (1) a caustic permanganate solution consisting of 10% sodium hydroxide and 5% potassium permanganate by weight (2) a citrate combination solution consisting of 5% ammonium citrate (dibasic), 2% citric acid and 1/2% Versene 9 by weight. Demineralized water with a resistivity of greater than 100,000 ohm-cms is used to make up all solutions. The chemicals should be reagent grade or better; this is to prevent the introduction of any halides or other foreign matter that might have a deleterious effect on the reactor system.

##### 4.4.2 Mixing Procedure

The caustic permanganate solution is prepared by first filling a mixing tank with the required volume of demineralized water. The required amount of sodium hydroxide is then added while the water is being agitated by means of a mechanical stirrer. The sodium hydroxide is soluble in water and will enter solution within 15 minutes. The solution will begin to heat up slowly due to the heat of solution. Approximately 5 minutes after the addition of the sodium hydroxide, the potassium permanganate is added. With proper agitation complete solution is achieved within 15 minutes. The solution is then ready for use. At this point the solution should be dark purple in color and the pH should be 12.8.

The citrate combination solution is prepared by first filling the mixing tank with the required volume of demineralized water. The

ammonium citrate, citric acid, and Versene 9 are then added in order. With proper stirring complete solution can be achieved within a matter of minutes. The solution should be clear and have a pH of approximately 4.2.

#### 4.4.3 Necessary Precautions

Extreme caution must be exercised when handling the sodium hydroxide and permanganate when mixing the solution

The solution and its fumes are capable of producing severe burns on the skin and can be injurious to the eyes. Consequently, proper clothing must be worn when handling the solution, i.e. the use of laboratory coats, rubber gloves, boots, and air-face masks. The citrate combination solution does not require special care and the only precaution that must be exercised is thorough washing after handling of the solution or its constituents.

### 4.5 APPR-1 Decontamination Procedure

#### 4.5.1 Recommended Conditions for Decontamination

The recommended method of decontamination is a fill-flush procedure, in which the solutions are introduced into the system, circulated at temperature and pressure for the requisite time, and then drained. The conditions under which the activated corrosion product scale is most effectively removed are as follows:

Caustic Permanganate Step . . . . .	30 Minutes at 225 $\pm$ 5°F at 60 to 70 psig pressure (nitrogen)
Water Flush Step . . . . .	5 Minute water flush with demineralized water
Citrate Combination Step . . . . .	30 Minutes at 220°F at 60-70 psig pressure (nitrogen)
Successive Water Flushes . . . . .	15 Minute water flushes to restore system to operating levels of purity

#### 4.5.2 Sequence of Operations

Due to the time required for filling the decontamination system, heating the solution to the proper temperature, and the time necessary to cool the system prior to draining, the total exposure time of the system to the

decontaminating solutions will be increased over the times indicated in section 4.5.1. The stepwise procedure given below is based on decontamination of the APPR-1 steam generator where the system has been modified according to the recommendations of section 4.3.1.

	Operation	Time Required (hours)
<b>A. Caustic Permanganate Step</b>		
1. Evacuate system to less than 18" mercury	0.50	
2. Fill system, remove air, pressurize to 60-70 psig	2.00	
3. Commence circulation (5 fps); Heat up System (85° F/hr)	2.00	
4. Residence time at temperature (225 ± 5° F)	0.50	
5. Cool system below boiling point of solution	1.00	
6. Drain system	0.50	
	<b>Total</b>	<b>6.50</b>
<b>B. Water Rinse Step</b>		
1. Repeat 1A	0.50	
2. Repeat 2A	2.00	
3. Pump on, Circulate at 5 fps	0.08	
4. Pump off, drain	0.50	
5. Aeration time (System exposed to atmosphere)	2.00	
	<b>Total</b>	<b>5.08</b>
<b>C. Citrate Combination Step</b>		
Repeat steps A 1-6 except solution is heated to 220 ± 5° F	6.50	
	<b>Total</b>	<b>6.50</b>

Operation	Time Required (hours)
<b>D. Water Flushing Step</b>	
1. Repeat 1A . . . . .	0.50
2. Repeat 2A . . . . .	2.00
3. Repeat 3B . . . . .	0.25
4. Repeat 4B . . . . .	0.50
	Total <u>3.25</u>
<b>E. Repeat D 4 times . . . . .</b>	<b>Total . . 13.00</b>
<b>Grand Total Decontamination Time . . . . . 34.33 Hours</b>	

#### 4.5.3 Anticipated Results

The success that can be achieved by employing the recommended decontamination procedure must be based on loop decontamination results which are presented in Volume II of this report. Two loop decontamination tests were performed under the same conditions given in section 4.5.2. Based on the experimental results given in Volume II of this report, it is estimated that a decontamination factor of at least 10 and probably 30 would be obtained in the APPR-1 with the recommended decontamination treatment. Corrosion results indicate a weight loss on contaminated Type 304 stainless steel coupons of  $16.2 \text{ mg/dm}^2$  (.008 mils penetration) and  $35.6 \text{ mg/dm}^2$  (.017 mils penetration) for the annealed and sensitized condition respectively. The weight loss on Babcock and Wilcox 16-1 Croloy was  $58.6 \text{ mg/dm}^2$  (annealed) and Inconel showed a weight loss of  $3.5 \text{ mg/dm}^2$ . The majority of these specimens have been reinserted into the APPR-1 primary system for long term corrosion and contamination studies. However, previous loop results indicated no evidence of intergranular corrosion or cracking on Type 304 stainless steel components that might be exposed to the solution. Decontamination of KAPL 120 Loop using the Turco 4501 process revealed no evidence of intergranular corrosion, stress corrosion or cracking.<sup>(1)</sup> This process employs a highly concentrated caustic permanganate solution as part of the decontamination treatment. Recent data from Westinghouse Commercial Corporation indicated no embrittlement problem existed as a result of the basic permanganate reagent (18% sodium hydroxide and 3% potassium permanganate).<sup>(2)</sup>

Data presented in Volume II of this report indicates that the decontamination treatment will not increase the corrosion rate or the activity

buildup of the decontaminated surface. The decontamination treatment creates a surface which exhibits the corrosion rate characteristics of an already corroded surface rather than a virgin metal surface.

#### 4.5.4 Waste Disposal

The APPR-1 decontamination system as outlined above would have an estimated volume of 450 gallons. Therefore, the total volume of contaminated liquid wastes (decontaminating solutions plus rinses) is estimated to be 3600 gallons (450 x 8). It is assumed that all wastes would be placed in a large tank (5000 gallon capacity). The mixing of the caustic permanganate and citrate solutions will reduce the corrosive nature of both solutions and may even destroy the citrate solution entirely. Preliminary data indicates that the solution will still be highly caustic (pH greater than 11) as a result of mixing. Consequently, either a stainless steel tank or a carbon steel tank provided with a caustic resistant liner is recommended to contain the liquid wastes.

Present estimates are that the solution activity may be as high as 20 microcuries per cc in the citrate solution and 2.5 microcuries per cc in the final waste solution. The latter demineralized water flushes will have negligible activity (less than  $10^{-7} \mu\text{c}/\text{cc}$ ) and could be passed into Gunston Cove.

Provisions will have to be made to process the large volume of contaminated waste solutions resulting from the decontamination. Concentration by means of an evaporator appears the most feasible method of reducing the volume. This could be followed by a precipitation and/or ion exchange step to purify the waste solution. Manganese dioxide and ferric hydroxide are excellent scavengers and could be prepared in situ. The resulting solid waste could be stored underground or packaged for disposal.

## **APPENDIX**

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## A-1 Calculation of Activity of Decontamination Solutions

### A-1.1 Contaminated Area for Recommended Decontamination:

Steam Generator	$8.60 \times 10^5 \text{ cm}^2$
Pressurizer Section	$.03 \times 10^5 \text{ cm}^2$
Piping, pumps	$.76 \times 10^5 \text{ cm}^2$
	$9.39 \times 10^5 \text{ cm}^2$
or	$9.39 \times 10^3 \text{ dm}^2$

### A-1.2 System Volume of Recommended Decontamination System:

Steam Generator	$21.37 \text{ ft}^3$
Pressurizer Section	$0.71 \text{ ft}^3$
Piping, pumps	$17.06 \text{ ft}^3$
External Section (60 ft. of 8 in. pipe)	<u><math>20.95 \text{ ft}^3</math></u>
	$60.09 \text{ ft}^3$
Equivalent capacity	450 gallons $(1.7 \times 10^6 \text{ cc})$

### A-1.3 Deposit Thickness and Radiochemical Analysis:

Chemical descaling of a baffle plate section removed in November 1958 from the APPR-1 steam generator indicated a deposit thickness of  $64.5 \text{ mgs/dm}^2$  on the inlet side and  $32.2 \text{ mgs/dm}^2$  on the outlet side. Radiochemical analysis of loose particulate matter removed from the steam generator drain line at the same time gave the following results:

Nuclide	November 1958 dpm x $10^6/\text{mg crud (avg. of 8)}$
$\text{Co}^{60}$	20.6
$\text{Co}^{58}$	51.6
$\text{Fe}^{59}$	13.0
$\text{Mn}^{54}$	8.34
$\text{Cr}^{51}$	<u>25.7</u>
Total	119.24

Present estimates are that  $\text{Co}^{60}$  will increase 30% by the end of core 1 life (November 1959). Assuming the other nuclide specific

activities remain the same, the total specific activity at the end of core life will be  $1.25 \times 10^8$  dmp/mg of crud.

#### A-1.4 Decontamination Solution Activity

##### A-1.4.1 Total Microcuries ( $\mu$ c)

$$= \frac{64.5 \text{ mgs} \times 9.39 \times 10^3 \text{ dm}^2 \times 1.25 \times 10^8 \text{ dpm}}{\text{dm}^2 3.7 \times 10^4 \text{ dps}/\mu\text{c} \times 60 \text{ sec/min}} \text{ mg} = 3.41 \times 10^7 \mu\text{c}$$

##### A-1.4.2 Solution Activity ( $\mu$ c/cc) Assuming All Activity is Removed by the Citrate Combination Solution:

$$\mu\text{c/cc citrate solution} = \frac{3.41 \times 10^7 \mu\text{c}}{1.7 \times 10^6 \text{ cc}} = 20 \mu\text{c/cc}$$

##### A-1.4.3 Solution Activity ( $\mu$ c/cc) Assuming All Waste Solutions (3600 gallons) are placed in one tank

$$\mu\text{c/cc} = \frac{3.41 \times 10^7 \mu\text{c}}{1.7 \times 10^6 \text{ cc} \times 8} = 2.5 \mu\text{c/cc}$$

#### A-2 Calculation of Dose Rate From Schedule 5 Piping During Citrate Combination Phase of Steam Generator Decontamination

The gamma dose rate emanating from the 8 inch external piping section of the decontamination system during the citrate phase of the decontamination cycle may require certain precautions in order to prevent exposure to operating personnel. The gamma dose rate 3 inches from the piping may be as high as 3.6 R/hr depending on the validity of the assumptions used in the calculations below:

1. It is assumed that all the deposited corrosion product activity will be removed by the decontamination treatment.
2. It is assumed that all the deposited activity will be removed by the citrate combination solution phase of the decontamination treatment. Experimental loop work indicated that the caustic permanganate cycle removed on the average approximately 17% of the initial activity, i.e. decontamination factor of 1.2. Little, if any, removal was observed in the final water flushing steps. For an estimated final decontamination factor of 30 (97% removal), the activity removed by the citrate combination solution would, therefore, be 80% (97-17).

3. It is assumed that the thickness of the activated corrosion product scale varies from  $64.5 \text{ mgs/dm}^2$  to  $32.2 \text{ mgs/dm}^2$ . Data obtained as a result of loop studies at the Knolls Atomic Power Laboratory indicated an equilibrium deposit of  $30 \text{ mgs/dm}^2$  for activated corrosion product scale.<sup>(3)</sup>
4. It is assumed that  $\text{Co}^{60}$  accounts for  $1/2$  the total gamma dose rate consisting of  $\text{Co}^{60}, 58, \text{ Mn}^{51}, \text{ Fe}^{59}, \text{ Cr}^{51}$ . This has been verified by calculation in the Activity Buildup Program (Task I).

The gamma dose rate was calculated at distances of 3, 12, and 36 inches from the pipe using the relationship<sup>(4)</sup>

$$Q = \frac{B \cdot Sv \cdot R_o^2}{2(a + Z)} \cdot F(\theta, b_2)$$

where  $B$  = buildup factor

$Sv$  = source strength - MEV/cm<sup>3</sup> - sec

$R_o$  = radius of pipe - cm

$a$  = distance from pipe - cm

$Z$  = self-attenuation distance - cm

$$F(\theta, b_2) = \int_0^{\theta} e^{-b} \sec \theta d\theta$$

The  $\text{Co}^{60}$  solution activity was taken to be  $0.95 \times 10^7 \text{ dpm/cc}$ . The 8 inch schedule 5 pipe was treated as a cylindrical source of infinite length. The gamma doses at two values of deposit thickness are given in Fig. A-1.

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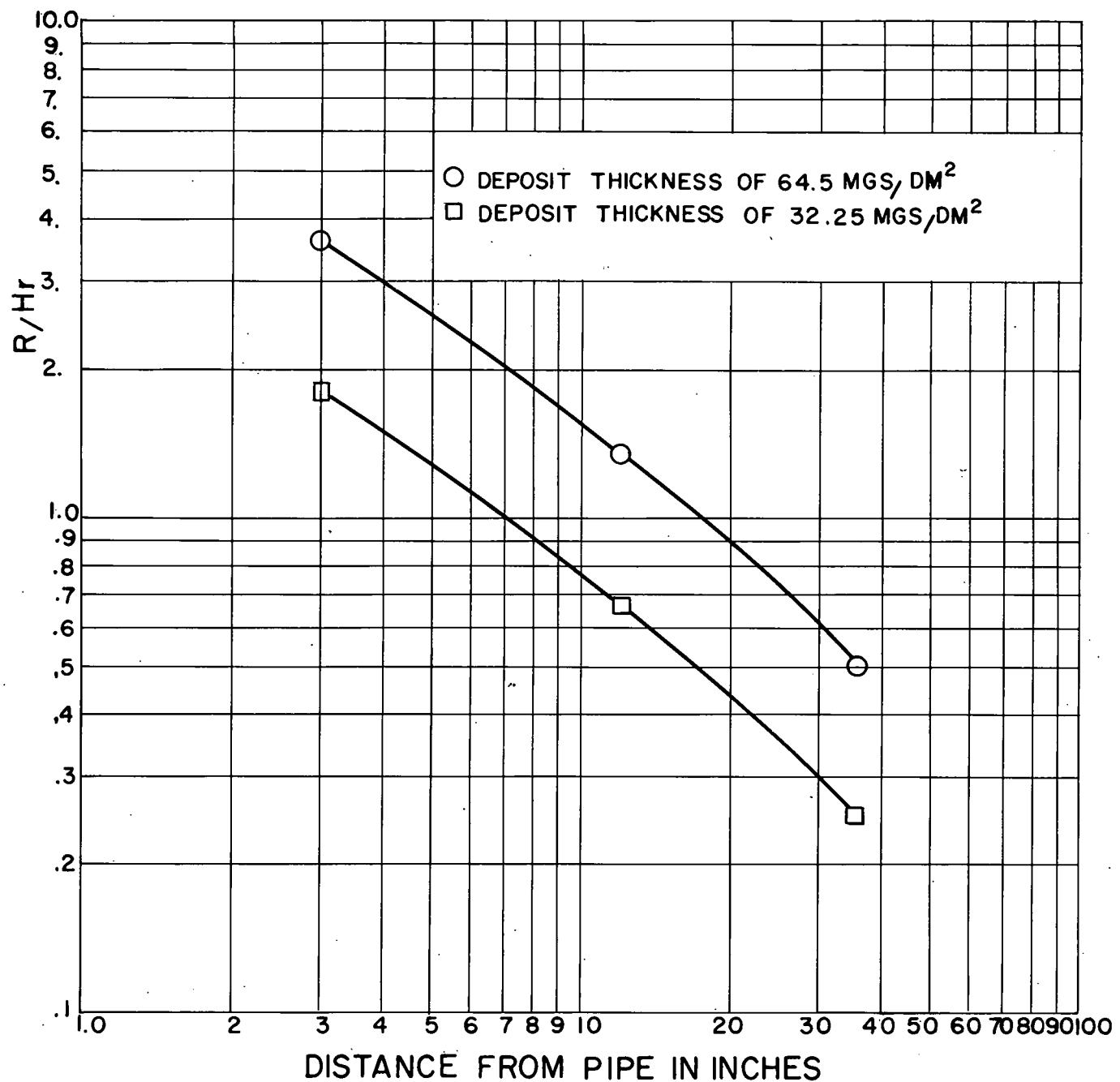


Fig. A-1 Gamma Dose Rate From 8 Inch Pipe During  
Citrate Combination Solution Phase of APPR-1  
Steam Generator Decontamination

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