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Clinch River Breeder Reactor Plant (CRBRP)

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Cold Trap Requirements for PHTS and IHTS Sodium Purification

PREPARED BY/DATE H. L. Sletten H.L Sletten

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ABSTRACT

Cold trap requirements for the Primary Heat Transfer System (PHTS) and the Intermediate Heat Transfer System (IHTS) are defined. The bases for these requirements are (1) maintaining concentrations of oxygen and hydrogen within given limits, (2) controlling the transport of tritium by coprecipitating it in cold traps together with hydrogen, and (3) providing the necessary volume capacity for collecting impurities.

It is concluded that the 60 gpm, FFTF Type I, NaK cooled, cold trap will satisfy the PHTS requirements. For each of the IHTS loops a single, 60 gpm, cold trap is required; and an aircooled trap similar to the FFTF Type I design except for a 3-foot longer crystallizer section has been chosen for this service.

To provide adequate design margin to account for uncertainties in these requirements, a second trap in each case will be installed — making a total of 8 traps in the PHTS and IHTS.

*Red markings indicate revisions intended. H L Sletten 8-2-77

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PAGE 1

REV	SUMMARY OF CHANGE	APPROVALS AND DATE
	Change No. 1 CONTENTS on page 3 extended to include Section IX, Appendix. Table A-I and Figure A-1 added to lists on pages 3 and 4. Second paragraph of page 8 expanded to make note of steam generator leak results. Footnote added on page 13 making reference to additional duty of IHTS cold traps due to steam generator leaks. References 18 and 19 added to page 57. Appendix A (pages 58-65) added to incorporate the IHTS cold trap requirements to account for potential steam generator leaks and emergency dump cleanup.	8/14/74 8-19-74

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I. INTRODUCTION

Preliminary requirements for PHTS cold traps were reported in Sept. 1973.(1) The requirements are herein revised for the following reasons: (1) There have been significant changes in the design of the PHTS and other systems of the plant, such as Refueling, that affect cold trapping. (2) There have been changes in basic data, such as surface contamination of replacement fuel assemblies. (3) The method of evaluating trapping time has been improved with the use of a more realistic mathematical model and the computer. (4) Advantage has now been taken of a higher expected trapping efficiency for sodium oxide. (5) The requirements for tritium control through cold trapping of sodium hydride have been incorporated.

Also included in this report are the cold trap requirements for the IHTS. These are not independent of the PHTS cold traps because they are coupled by the diffusion of hydrogen and tritium through the IHX. Otherwise, these would be entirely separate cold trap systems. Most of the tritium from the reactor would be transported to the water of the steam plant if it were not for the presence of hydrogen and the coprecipitation of both in the cold traps of both PHTS and IHTS. These traps can collect up to 99% of the tritium released by the reactor. The source of the hydrogen is the water corrosion of the 2-1/4 Cr - 1 Mo tube alloy of the steam generator.(3)

II. SUMMARY OF REQUIREMENTS

A. PHTS Cold Traps

Analyses show that a single FFTF Type I (4) cold trap, which is shown in Figure 1, would adequately satisfy all of the cold trapping requirements of the PHTS for all conditions of initial cleanup, normal operations including refueling and tritium control, and maintenance shutdown operations. However, because of the uncertainties in the source levels of the impurities, the efficiency and capacity of this particular cold trap, and the trapping rate requirements, it is recommended (5) that two of these traps be installed in the RCB of the CRBRP.

The FFTF Type I cold trap is rated at 60 gpm at the higher sodium temperatures that exist in the reactor overflow system during normal reactor power operation and it is rated at 80 gpm at the lower temperatures during refueling and maintenance shutdowns. The wire mesh crystallizer volume is 59 ft^3. The residence time in the trap for the sodium flowing at 80 gpm is 5.5 minutes.

The separate capacities of this trap for collecting oxygen and hydrogen are about 197 ~~530~~ and 12.8 ~~28~~ lb, respectively. The trap capacity will be expended in the first 4.4 ~~15.5~~ years of plant operation, and 74 ~~81~~% of it will be consumed by sodium hydride.

B. IHTS Cold Traps

The analyses show that a 60 gpm cold trap in each of the IHTS loops would adequately satisfy all of the cold trapping requirements for all conditions of initial cleanup, normal operations involving tritium and hydrogen control, and maintenance shutdown operations. However, as in the case of the PHTS, a second cold trap is recommended (5) to be installed in each loop to provide

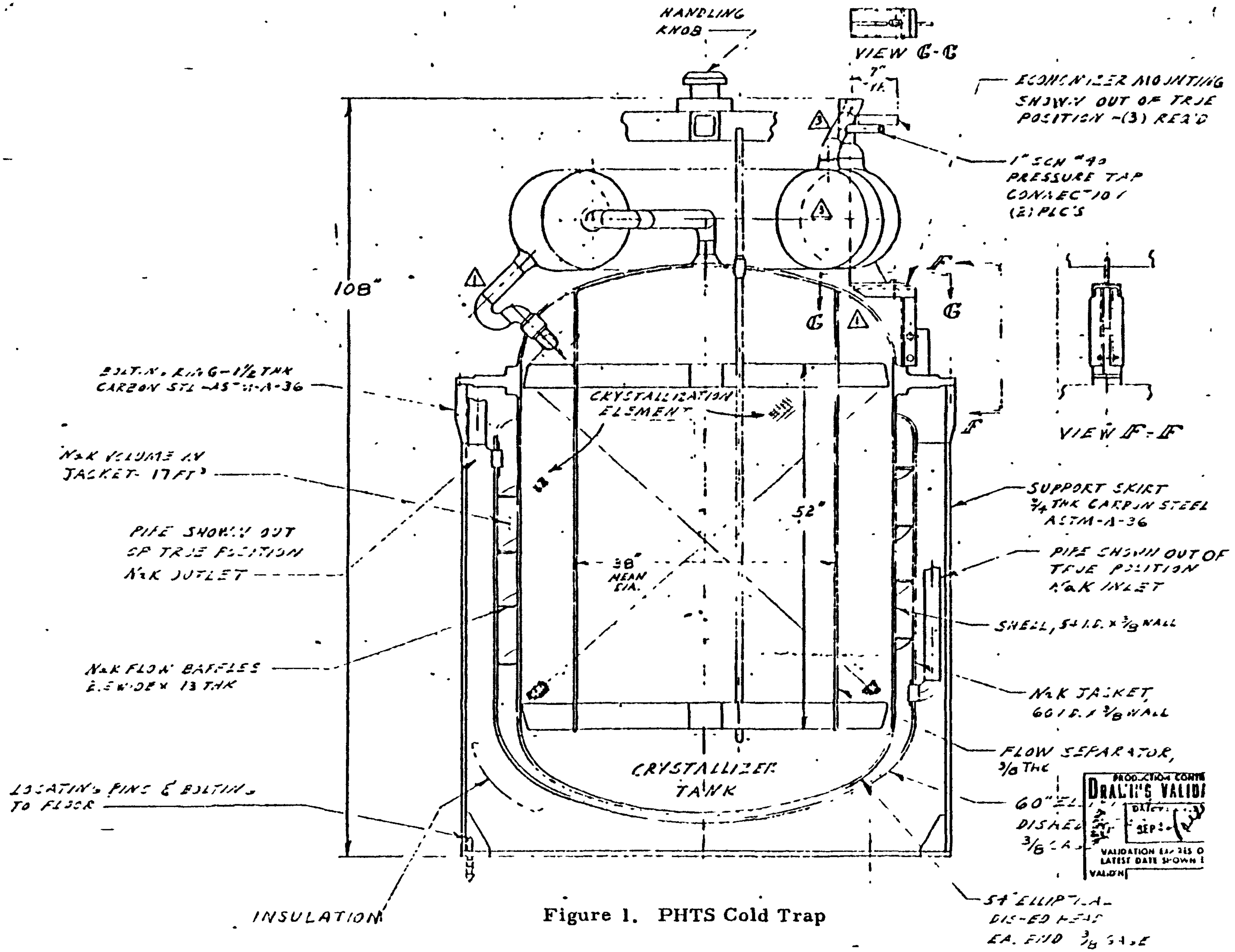

Figure 1. PHTS Cold Trap

the margin judged to be required to cover the uncertainties in source levels of impurities, the efficiency and capacity of the trap, and the trapping rate requirements.

The IHTS cold traps are proposed to be air cooled and to be much like the FFTF Type I cold trap except that they would have a 3-foot longer crystallizer section (wire mesh), having a volume of about 100 ft^3, and a gas cooling annulus instead of a NaK cooling jacket. A sketch of this cold trap is given in Figure 2. The residence time for the sodium in the crystallizer zone at the rated flow of 60 gpm is about 12.5 minutes. The separate capacities of this trap for collecting oxygen and hydrogen are about ~~900~~ 333 lb and ~~47~~ 21.7 lb, respectively. The trap capacity will be expended in the first ~~13.4~~ 4.33 years of plant operation, and will be about ~~94~~ 87% consumed by sodium hydride, based on no steam generator leaks. The trap lifetime will be reduced to ~~10.6~~ 7.44 years when statistically accounting for the possibility of leaks in the steam generator. This additional duty of the trap is discussed in Appendix A.

III. RESULTS OF ANALYSIS

A. PHTS

Table I summarizes cold trap flow rate requirements for the various operating conditions. Each operation and impurity are treated separately and the table shows which are controlling. It is assumed that the trapping of oxygen and hydrogen occurs simultaneously. Hence, the larger of the two trapping times (one for oxygen and one for hydrogen) for a particular operation and trap flow rate indicates the one which controls. Thus, we see in Table I that on initial cleanup the oxygen in the system determines the cleanup time. At 80 gpm it takes 331 hr (~ 2 weeks) to reduce the oxygen concentration to 2 ppm and 229 hr to reduce the hydrogen concentration to 0.2 ppm. These are the maximum permissible concentrations during reactor operation.(6)

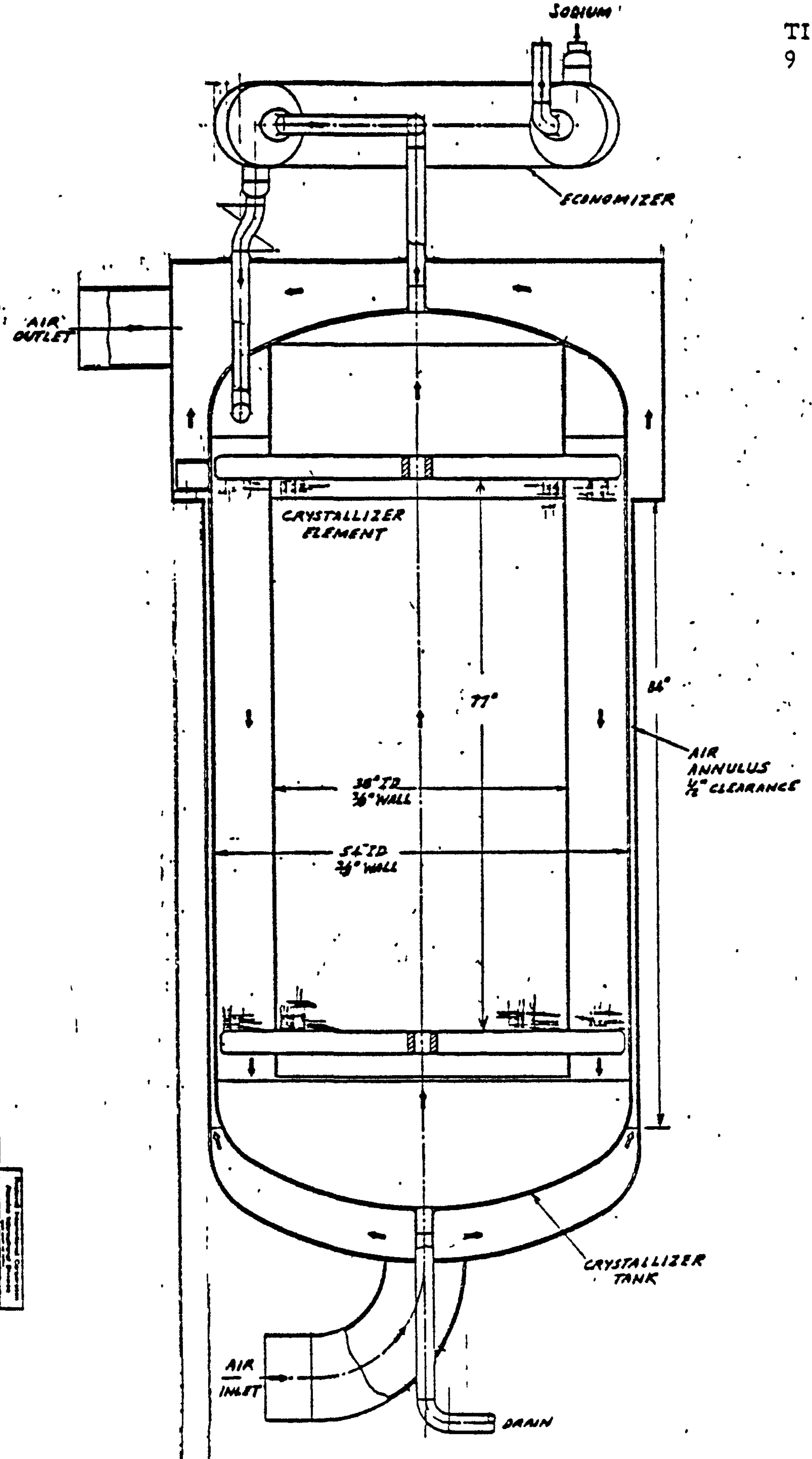

FIGURE 2
IHTS COLD TRAP

TABLE I
PHTS COLD TRAP FLOW RATE REQUIREMENTS

Operation	Impurity	Contamination	Flow Rate (gpm)	Time (hr)	Remarks
Initial Cleanup	Oxygen	14.3 ppm	80	331	*
			160	167	
			240	110	
	Hydrogen	1.93 ppm	80	~~229~~ 23	*
			160	~~115~~ 120	
			240	~~77~~ 80	
Normal Refueling Operation	Oxygen**	1.35 ppm in 410 hr	20	474	*** 50% refueling efficiency
			80	<410	
		1.35 ppm in 205 hr	80	<205	100% refueling efficiency
	Hydrogen	0.63 ppm in 410 hr	40	~~445~~ 454	50% refueling efficiency
			80	<410	
		0.63 ppm in 205 hr	40	~~321~~ 328	100% refueling efficiency
			80	~~223~~ 226	
Maintenance Shutdown	Oxygen	0.73 ppm	80	24	1.0 lb O_2 admitted at end of of maintenance period, time zero
			160	12	
	Hydrogen	None	—	—	

* Time does not include the time required to clean up the sodium in storage prior to filling PHTS.
** New fuel oxygen contamination = 0.57×10^{-4} lb/ft^2 of surface.
*** Time includes refueling time of 205 hr at 100% efficiency or 410 hr at 50%.

On a normal refueling operation (Table I), neither the oxygen or hydrogen contamination restrict the subsequent operation of the reactor, when cold trapping at 80 gpm. The refueling efficiency will probably be 50% (2.4 hr handling time for each core assembly) and require 410 hr to exchange 171 assemblies. Then, as may be seen in Table I, the trapping time required is <410 hr for both oxygen and hydrogen. This means that the oxygen does not exceed the operating limit of 2 ppm during the 410 hour refueling operation, and the hydrogen does not exceed its 0.2 ppm limit. The oxygen concentration at the start of refueling was taken as 1.52 ppm, which is the steady-state concentration during normal power operation. The corresponding initial hydrogen concentration in the PHTS is ~~0.040~~ .042 ppm.

Major maintenance on the PHTS involving either removal of a main pump impeller or the opening of the main pipes is estimated to admit 1 lb of oxygen (0.73 ppm) and an insignificant amount of hydrogen. Assuming this takes place at the end of the maintenance period, the time required afterwards to restore the oxygen concentration to the 2 ppm limit is 24 hr (See Table I). This is based on an initial oxygen concentration of 1.52 ppm, which is the expected steady-state concentration in the PHTS prior to shutdown.

Normal operation at power is not included in Table I because it has been shown previously (1) that the oxygen contamination at this time is so low as to require much less cold trap flow than the 60 gpm provided by one trap to control tritium. The hydrogen trapping rate during normal operation is about 1 lb/year.

Table II shows how the volume of the first trap used in the PHTS would be consumed and its corresponding lifetime. Initial cleanup would use ~~12.3~~ 23.5 ft^3 or ~~21~~ 49% of the trap volume capacity. Subsequently most of the trap volume is used to remove hydrogen. If the 59 ft^3 trap were used exclusively for this purpose it would last ~~24~~ 11 years, as shown by its lifetime in the table. The combined lifetime due to all operations shown is ~~15.5~~ 44 years. Thus, the first changeout of a PHTS cold trap should not be required for at least ~~16~~ 5 years after plant startup, assuming the spare trap can be cut in at [illegible] years.

TABLE II
PHTS COLD TRAP CAPACITY REQUIREMENTS

Operation	Impurity	Contamination	Volume	Lifetime	Remarks
Initial Cleanup	Oxygen	32.7 lb	~~3.6~~ 9.8 ft^3	-	Includes storage facilities once during life of plant
	Hydrogen	4.14 lb	~~8.7~~ 19.0 ft^3	-	
Normal Operations Including Refueling	Oxygen	2.4 lb/yr	~~0.26~~ .72 ft^3/yr	~~225~~ 82 yr	New core component surface contamination not removed in EVST: 0.27 $\times 10^{-4}$ lb H/ft^2 on 171 assys. 0.57 $\times 10^{-4}$ lb O/ft^2 on 171 assys.
	Hydrogen	1.2 lb/yr	~~2.5~~ 5.5 ft^3 yr	~~24~~ 11 yr	
Maintenance Shutdown	Oxygen	2.0 lb/yr	~~0.22~~ .60 ft^3/yr	~~268~~ 95 yr	Two major maintenance shutdowns per year, requiring opening the PHTS
	Hydrogen	None	-	-	

Combined Lifetime = ~~15.5~~ 4.4 yr

* Based on 1 cold trap volume = 59 ft^3

B. IHTS

Table III summarizes cold trap flow rate requirements for the various operations* of one of the three independent loops of the IHTS. We see that on initial cleanup of oxygen, ~~472~~ 361 hours (~ ~~20~~ 15 days) of trapping time is required with 1, 60 gpm cold trap. A second trap which will be installed and available in each loop could cut the initial cleanup time to ~~10~~ 7.5 days. This time could also be reduced by raising the system temperature above the 400 °F assumed. For example, at 500° F it is estimated that the 60 gpm cold trap could do the job in ~~8.0~~ 6 days, and at 600° F it would take ~~7.2~~ 5.4 days.

As far as normal operation of each of the IHTS loops is concerned, continuous operation of the cold trap is not required to maintain oxygen purity. The source of oxygen is normally so low as to require only 13 hours of cold trap operation per month when only 10 gpm are flowing. Hydrogen diffusing through the steam generator tubes is the primary demand for cold trapping flow rate; however, even in this case less than full-flow for the 60 gpm cold trap would be sufficient to maintain the <0. 1 ppm hydrogen concentration required for leak detector sensitivity.

Major maintenance shutdown of one loop could cause about 1 lb of oxygen contamination and require approximately 40 hours of trapping time to restore its concentration to 2 ppm. This time would probably be available because of other startup activities, so no system unavailability would accrue due to cold trapping.

Table IV shows how the volume of the first trap used in each loop of the IHTS would be consumed. Initial cleanup would take ~~8~~ 19.8 ft^3 (~~8~~19.8%) of the crystallizer volume. Subsequently, most of the useful trap volume is taken up by the hydrogen. If the 100 ft^3 trap were used exclusively for this purpose, it would last ~~15.3~~ 4.3 years according to the table. The lifetime of the trap when combining all operations shown is ~~13.4~~ 4.33 years. Thus, the

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*The additional duty of the IHTS cold traps for cleanup following steam generator leaks and emergency dump is discussed in Appendix A.

TABLE III

IHTS LOOP COLD TRAP FLOW RATE REQUIREMENTS

Operation	Impurity	Contamination	Flow Rate & Time for 70% Efficiency		Remarks
Initial Cleanup	Oxygen	~~93.3~~ ppm 91.6	50 ~~60~~ gpm 160 ~~120~~ gpm	~~472~~ hr 361 ~~238~~ hr 174	System temperature = 400° F 11.433 ppm/hr for 8 hours constant production rate
	Hydrogen	~~3.7~~ ppm 3.2	50 ~~60~~ gpm 160 ~~120~~ gpm	~~121~~ hr 103 61 hr 51	System temperature = 400° F
Normal Operation	Oxygen	0.76 ppm/yr	.18 gpm 10 gpm	continuous 13 hr/mo	Continuous operation of a cold trap not required
	Hydrogen	8.45 ppm/yr	19 gpm	steady-state	Flow rate required to maintain <.1 ppm H_2 concentration in IHTS
Maintenance Shutdown	Oxygen	2.8 ppm	60 gpm 120 gpm	40 hr* 20 hr	1 lb of oxygen contamination from opening system
	Hydrogen	(Same as for Normal Operation in loops that are not shutdown and drained.)			
Startup	Hydrogen	8.48 ppm/[illegible]	80 gpm	1000 hr	H_2 concentration rises from .10 to .314 ppm equilibrium in 1000 hr.

* Assumes in-leakage occurs at end of maintenance period

TABLE IV

IHTS EAST LOOP COLD TRAP VOLUME CAPACITY REQUIREMENTS

Operation	Impurity	Contamination	Volume	Lifetime*	Remarks
Initial Cleanup	Oxygen	38.7 ~~38.8~~ lb	~~4.3~~ ft^3 11.1	6	Once during life of plant includes storage tanks and piping
	Hydrogen	1.35 ~~1.78~~ lb	~~3.7 ft^3~~ 6.2	N/A	
Normal Operation	Oxygen	0.27 lb/yr	.08 ~~0.03~~ ft^3/yr	>>30 yr	Based on no leaks in steam generator
	Hydrogen	3.2 lb/yr	14.7 ~~6.7~~ ft^3/yr	6.8 ~~15.5~~ yr	
Maintenance Shutdown	Oxygen	1.0 lb/yr	0.3 ~~0.11~~ ft^3/yr	>>30 yr	One major maintenance shutdown per loop per year, requiring opening the IHTS
	Hydrogen	-	-	-	Water and sodium drained during this major maintenance

Combined Lifetime = 4.45 ~~13.4~~ yr

* Based on 1 cold trap volume = 100 ft^3

Startup | Hydrogen | 3.6 lb/1000 hr | 16.6 ft^3/1000 hr | N/A | Once during the life of plant first changeout of an IHTS cold trap is not expected for at least ~~13~~ 4.33 years after plant ~~startup~~ initial operations. The installed second trap in each loop could be operated before or after this ~~13~~ 4.3 year period to extend the actual changeout time on the first trap. The lifetime is reduced to 2.41 years when statistically accounting for water leaks in the steam generators (See Appendix A).

C. TRITIUM TRANSPORT

1. Steady - State

A steady-state mathematical model of diffusion, cold trapping, and transport of tritium and hydrogen in the heat transport systems has been programmed at AI(2) for computer solution. The input and output data for nominal conditions are presented in Tables V and VI. Table V lists the system parameters for the reference design and Table VI gives the calculated results.

Of the 89 Ci/day released in the reactor, 1.11 Ci/day is transported to the steam system, 23.3 Ci/day is removed by the 60-gpm PHTS cold trap, and 64.2 Ci/day is removed by the 3, 60-gpm IHTS cold traps. Most of the hydrogen (97%) is removed by the IHTS cold traps. The steady-state concentration of hydrogen in the IHTS sodium is .057 which is <.1 ppm as specified (3) for hydrogen detector sensitivity.

Table VII shows: (1) the effect of reducing IHTS cold trap flow rate to 30 gpm/loop and (2) the effect of hydrogen flux uncertainty. It may be seen that the reduction in cold trap flow to one-half has a minor effect on the tritium flux to the steam generator, and the resultant hydrogen concentration in the IHTS is below the limit (.1 ppm) required for leak detection. The uncertainty in hydrogen flux from the steam generator yields a calculated range in the tritium flux to the steam generator from 0.76 to 2.14 Ci/day. The corresponding variation in IHTS hydrogen concentration is .047 to .067 ppm.

TABLE V

PARAMETERS USED IN THE CALCULATION OF SIMULTANEOUS HYDROGEN-TRITIUM TRANSPORT IN CRBRP

(Sheet 1 of 2)

Primary Circuit System Parameters		
Total Weight of Sodium in Primary Circuit	1.317 ~~1.3~~7E+6 lbs	2.70E+7g mole Na
Temperature of Piping	950°F	780°K
Area of Primary Piping (Excluding IHX)	8358 ft^2	7.76E+6 cm^2
Thickness of Primary Piping	0.625 in	1.59 cm
Total Cold Trap Flow Rate (based on 250°F)	60 gpm	151.7g moles Na/sec
Minimum Cold Trap Temperature	250°F	394°K
Cold Trap Efficiency for Hydrogen Removal	70%	0.70
Hydrogen Flux to Primary Circuit (not including IHX)	0	0
Tritium Flux to Primary Circuit	89 Ci/day	0.0362 μgm at T/sec
Total Volume of Nitrogen in Primary Cells	698,000 ft^3	7.74E+5g mole N_2
Exchange Rate of Nitrogen in Primary Cells	10%/day	0.896g mole N_2/sec
IHX Parameters		
Log Mean Total Diffusional Area of IHX	43,270 ft^2	4.02E+7 cm^2
Wall Thickness of IHX Tubing	0.047 in	0.119 cm
Hydrogen and Tritium Diffusion Coefficient for IHX	---	1.083E-6 cm^2/sec

TABLE V

PARAMETERS USED IN THE CALCULATION OF SIMULTANEOUS HYDROGEN-TRITIUM TRANSPORT IN CRBRP

(Sheet 2 of 2)

Intermediate System Parameters		
Total Weight of Sodium in Intermediate Circuit	1.125E+6 lbs	2.22E+7g mole Na
Temperature of Piping	900	756°K
Area of Intermediate Piping (Excluding IHX)	23,606 ft^2	2.19E+7 cm^2
Thickness of Intermediate Piping	0.5 in	1.27 cm
Total Cold Trap Flow Rate (based on 250°F)	180 gpm	455.1g mole Na/sec
Minimum Cold Trap Temperature	250°F	394°K
Cold Trap Efficiency for Hydrogen Removal	70%	0.70
Total Volume of Air in Intermediate Cells	386,000 ft^3	4.28E+5g mole air
Hydrogen Content in Intermediate Cell Air	0.5 vppm	1 µgm at H/mole air
Exchange Rate of Air in Intermediate Cell	1%/day	0.049g mole N_2/sec
Steam Generator Parameters		
Total Inside Area	45,130 ft^2	4.19E+7 cm^2
Total Outside Area	69,300 ft^2	6.44E+7 cm^2
Wall Thickness of Tube	0.109 in	0.277 cm
Hydrogen Flux	2.0E-11 lb H/sec-ft^2 inside tube H_2 diffusion area	136 µgm at H/sec
Tritium Diffusion Coefficient	---	1.384E-6 cm^2/sec
Hydrogen Diffusion Area (Superheater Inside of Tubes)	15,000 ft^2	1.39E+7 cm^2
Temperature of Superheater	890°F	750°K
Temperature of Evaporator	755°F	675°K

TABLE VI

RESULTS OF ANALYSIS OF SIMULTANEOUS HYDROGEN-TRITIUM TRANSPORT IN CRBRP

CONCENTRATION

	Hydrogen		Tritium	
	μgm at H/mole*	wppm	μgm at T/mole	μCi T/gm Na
Sodium Side of Primary Piping (SS)	0.244	---	5.27E - 4	---
Sodium Side of Intermediate Piping (SS)	0.322	---	6.18E - 5	---
Nitrogen Side of Primary Piping (SS)	0.183	---	4.49E - 4	---
Primary Sodium (Na)	0.915	0.040	1.98E - 3	2.46
Sodium Side of Steam Generator Piping (SS)	0	---	3.09E - 5	---
Air Side of Intermediate Piping (SS)	0.452	---	6.07E - 5	---
Intermediate Sodium (Na)	1.301	0.057	2.50E - 4	0.31
Primary Cell Atmosphere (N_2)	8.06E - 3	---	1.70E - 4	---
Intermediate Cell Atmosphere (Air)	1.0	---	6.68E - 5	---

FLUX

	Hydrogen	Tritium	
	μgm at H/sec	μgm at T/sec	Ci/day
Through IHX to Intermediate Sodium	-4.45	~~0.0266~~ .0263	~~65.4~~ 64.66
To Primary Cold Trap	4.39	~~0.00948~~ .00972	~~23.5~~ 23.92
To Primary Cell	0.0624	~~7.99E - 5~~ 7.58E-5	~~0.20~~ .186
By R/A Decay in Primary	-	~~9.29E - 5~~ 9.19E-5	~~0.25~~ .246
To Steam Generator	-140	~~4.50E - 4~~ 4.37E-4	~~1.11~~ 1.074
To Intermediate Cold Trap	135.9	~~0.0261~~ .0259	~~64.2~~ 63.65
To Intermediate Cell	-.342	~~3.93E - 6~~ 7.66E-6	~~0.0072~~ .019
By R/A Decay in Intermediate	-	~~9.69E - 6~~ 9.42E-6	~~0.024~~ 02

* mole sodium, stainless steel, nitrogen or air, as applicable

TABLE VII

TRITIUM TRANSPORT AND HYDROGEN CONCENTRATION CHANGES WITH IHTS COLD TRAP FLOW AND HYDROGEN FLUX

Hydrogen* Flux ($lb/sec\text{-}ft^2$)	IHTS Cold ** Trap Flow (gpm)	IHTS H_2 Concentration (ppm)	Tritium Flux to Steam System (Ci/day)
1×10^{-11} (minimum)	180	.047	2.12
2×10^{-11} (nominal)	90 180	.074 .057	1.16 1.11
3×10^{-11} (maximum)	180	.066	0.76

* Hydrogen flux uncertainty from Reference 3.

** Reference cold trap flow rate is 180 gpm (60 gpm/loop). PHTS cold trap flow is constant at 60 gpm.

Table VIII shows the effect of hydrogen injection into the PHTS, which might be required if there should be an insufficient hydrogen source due to corrosion in the steam generator. We see that a hydrogen source in the PHTS is more effective in reducing tritium flux to the steam generator than the steam generator hydrogen source. If there should be a minimum source from the steam generator or 1.0×10^{-11} lb H/sec - ft^2 (1/2 of nominal or expected value), it would take only 23% more hydrogen when injected into the PHTS to obtain the same tritium flux to the steam system (1.11 Ci/day) as the nominal case without injection. Thus, the total hydrogen source would be 1.23/2 = 62% as large and would reduce the hydrogen trapping load on the cold traps accordingly.*

2. Transient

In the event of PHTS cold trap shutdown the tritium flux to the steam system will increase from the nominal steady-state value (initial condition) of 1.11 Ci/day to a final steady-state value of 1.47 Ci/day. An analysis of the transient from the initial to final conditions was made and shows that it takes about 600 hours for the tritium concentration in the IHTS sodium (and flux to the steam system) to increase by 63.2% of the difference between final and initial concentrations. This long time constant allows enough time to get the standby PHTS cold trap into operation without shutdown of the plant to limit tritium release. Figure 3 shows the transient tritium concentrations in the PHTS and IHTS sodium.

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* The net load on all system traps is reduced, but the load on the PHTS cold trap is increased. The additional H_2 in this case would increase from 1.2 lb/yr (See Table II) to 2.0 lb/yr, and the trap combined lifetime would decrease from ~~15.5~~ 4.4 yr (Table II) to ~~9.9~~ 2.9 yr.

TABLE VIII

EFFECT OF HYDROGEN INJECTION INTO PHTS

Hydrogen Flux* to IHTS From Steam Generator ($lb/sec\text{-}ft^2$)	Hydrogen Injection† Into PHTS (%)	Tritium Flux to Steam Generator (Ci/day)
2×10^{-11} (nominal)	0 (base)	1.11
	1	1.04
	10	0.68
	100	0.25
1×10^{-11} (minimum)	0	2.12
	1	2.03
	2	1.94
	10	1.46
	20	1.14
	100	0.51
	200	0.36

* Multiply these values by 15,000 ft^2 to obtain total hydrogen diffusion through 3 superheaters.

† % of total hydrogen diffusion into IHTS from the steam generator.

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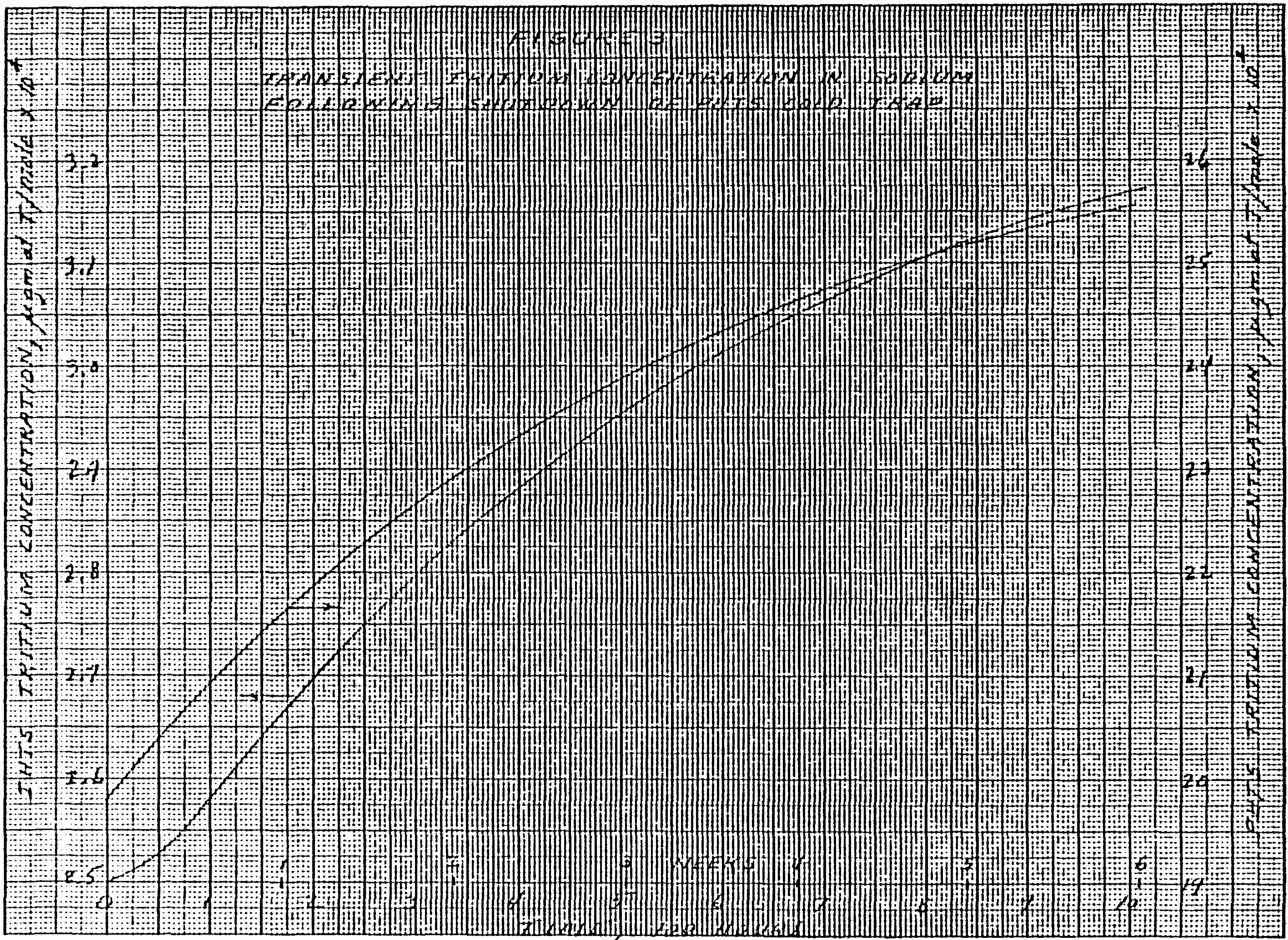


FIGURE 3

TRANSIENT TRITIUM CONCENTRATION IN SODIUM FOLLOWING SHUTDOWN OF FFTF COLD TRAP

HLS, 5-20-74

IV. BASES FOR REQUIREMENTS

A. SODIUM PURITY

The cold trap requirements are based on the purity requirements in RDT Standard A1-5(6). This standard does not permit reactor operation at oxygen concentrations greater than 2 ppm when the hot leg temperature is ≥ 800°F. Below this temperature, the concentration cannot exceed 5 ppm. Therefore, it is assumed that reactor startup will not be permitted until the oxygen concentration is ≤ 5 ppm and operation at power with the hot leg ≥ 800°F will not be permitted until the oxygen concentration is ≤ 2 ppm. These limits of the RDT Standard are assumed to apply to the IHTS as well as the PHTS.

The maximum concentration of hydrogen according to RDT A1-5 is 0.2 ppm above 800°F and 0.4 ppm below 800°F. For the purpose of obtaining good hydrogen detector sensitivity in the IHTS, however, General Electric(3) has placed a limit of 0.1 ppm of hydrogen in the IHTS sodium.

B. AVAILABLE TRAPPING TIME

The objective of the cold trap design is to provide enough trapping capability such that there will be no plant unavailability specifically attributable to sodium purification during normal plant operation or following a regularly scheduled fuel handling shutdown(8).

Available cold trapping time is determined by the time spent on other plant operations. During normal steady-state operation, the trapping rate must be large enough to keep the oxygen and hydrogen below the specified limits. Those plant operations which will determine available trapping times for initial cleanup and after refueling and maintenance have not been specifically identified and firmly established for this plant, except in the case of refueling for which a good estimate has been made.

Tentative values of available trapping times are as follows:

Initial Cleanup	2 weeks(*)
After Annual Refueling	75 hours
After Major Maintenance	48 hours(*)

The tentative values indicated by (*) were chosen more on the basis of the amount of time that will be required for cold trapping than on the basis of available time. However, they are judged to be reasonable values for these operations.

C. TRITIUM TRANSPORT

One of the main functions of the cold traps in the PHTS and IHTS is to remove tritium from the sodium and thus minimize its transport to the steam system. Tritium is released by the reactor and diffuses readily through the tubes of the IHX and steam generator unless a mechanism is provided that will remove it at a faster rate. This mechanism is provided when a sufficient hydrogen source is present to act as a vehicle for cold trapping these two isotopes. There isn't enough tritium by itself to saturate the sodium so that it can be collected in the cold trap by precipitation.

The fraction of the tritium released by the reactor which must be removed by cold trapping or the tritium activity which is permitted to be transported to the steam system depends on the facilities for processing the leakages, blowdown, etc. from this system and the maximum permissible concentration of the tritium in the effluents from the plant. While these factors are being studied, with the objective of minimum or "no release" from the plant, the tritium flux to the steam system has been tentatively limited to 1.5 Ci/day.(17) This is about 1.7% of the maximum which could be released by the reactor to the heat transfer system.

The analysis of transport of tritium assumes the feasibility of coprecipitation of tritium with hydrogen in the cold traps due to the combined differential solubility of these isotopes in sodium with respect to temperature. This process is currently in the research and development stage; and, therefore, the cold trap requirements are subject to its successful demonstration by tests.

D. HYDROGEN DETECTION

The technique proposed for determining the possible initiation of a leak in the steam generator is the sensing of an increase in hydrogen concentration in the IHTS sodium. The hydrogen detector has been developed for this purpose. Its sensitivity to small leaks ($\sim 10^{-5}$ lb H_2O/sec), which could precede tube rupture, is important to IHTS maintenance and plant availability. This sensitivity depends on maintaining a low level of hydrogen concentration in the sodium. A limit has been established at from 0.08 to 0.1 ppm by General Electric(3) who has the responsibility for the Steam Generator System (53) and for implementing the instrumentation for detecting leaks in the steam generator.

E. HYDROGEN DIFFUSION

Corrosion of 2-1/4 Cr-1 Mo alloy steel tubes of the steam generation by water produces hydrogen. This is the principal source of hydrogen on which the removal of tritium by the cold traps depends. Initially the formation of hydrogen is rapid and the diffusion rate through the steam generator tubes is quite high at 2.3 x 10^{-10} lb H_2/ft^2-sec. After a magnetite layer is formed and steady-state conditions are established the diffusion rate is 2 x 10^{-11} lb H_2/ft^2-sec. It was decided(3) that this steady-state value be used as the basis for determining cold trap requirements, although this might require that the steam system be operated at a reduced temperature at first to hold down the corrosion rate and the hydrogen concentration in the IHTS.

F. COLD TRAP PERFORMANCE

Two basic cold trap performance parameters which are important to cold trap design requirements are efficiency and capacity*. Flow-rate requirements depend on efficiency while cold trap lifetime depends on volume capacity.

The best estimate of the efficiency for trapping both oxygen and hydrogen is 70%. This is probably a good estimate for oxygen since there is substantial experience to support it. However, in the case of hydrogen there is considerable uncertainty in this value because no quantitative test data on cold trapping sodium hydride have been found.

The capacity of the trap is stated in terms of the pounds of oxygen or hydrogen that the trap could contain when "full" or at the end of its "lifetime". The trap is full when the pressure drop for flow indicates near plugging conditions, and this has been determined by experiments with sodium oxide to occur when 9.12 ~~20~~% of the wire-mesh volume is effectively solid sodium oxide. The capacity for sodium hydride is assumed to be the same. Thus, the cold trap volume required per pound of each are†:

Oxygen 0.3 ~~0.111~~ ft^3/lb O_2
Hydrogen 4.6 ~~2.105~~ ft^3/lb H_2

---

*See Section VI for definition of efficiency and capacity.
†See Section VI.B. for further details of capacity and lifetime.

V. SYSTEM DESCRIPTION

A. PHTS

The PHTS sodium includes the sodium in the reactor, 3 heat transfer loops, overflow system, primary storage tanks, and primary cold traps. The sodium storage and processing flow diagram for the PHTS is given in Figure 4. The volume and mass of sodium is distributed during normal operation as shown in Table IX.

The sodium volume involved in the cold trapping analysis of the PHTS during initial cleanup, refueling, and major maintenance is 195,870 gallons. This does not include the storage vessel heel. The corresponding PHTS sodium mass is 1.347×10^6 lb.

The PHTS wetted surface area was estimated to be 98,000 ft^2. This area is used only to determine the total contamination of the initial sodium fill by surface oxygen and hydrogen. The estimate was made by multiplying a previously determined area(9)(1) of 127,000 ft^2 by the ratio of the new volume of 195,870 gallons to the old volume of 254,000 gallons(1).

The PHTS is all 304 SS which has an initial surface contamination of 2.0×10^{-4} lb O_2/ft^2 and 0.27×10^{-4} lb H_2/ft^2(10).

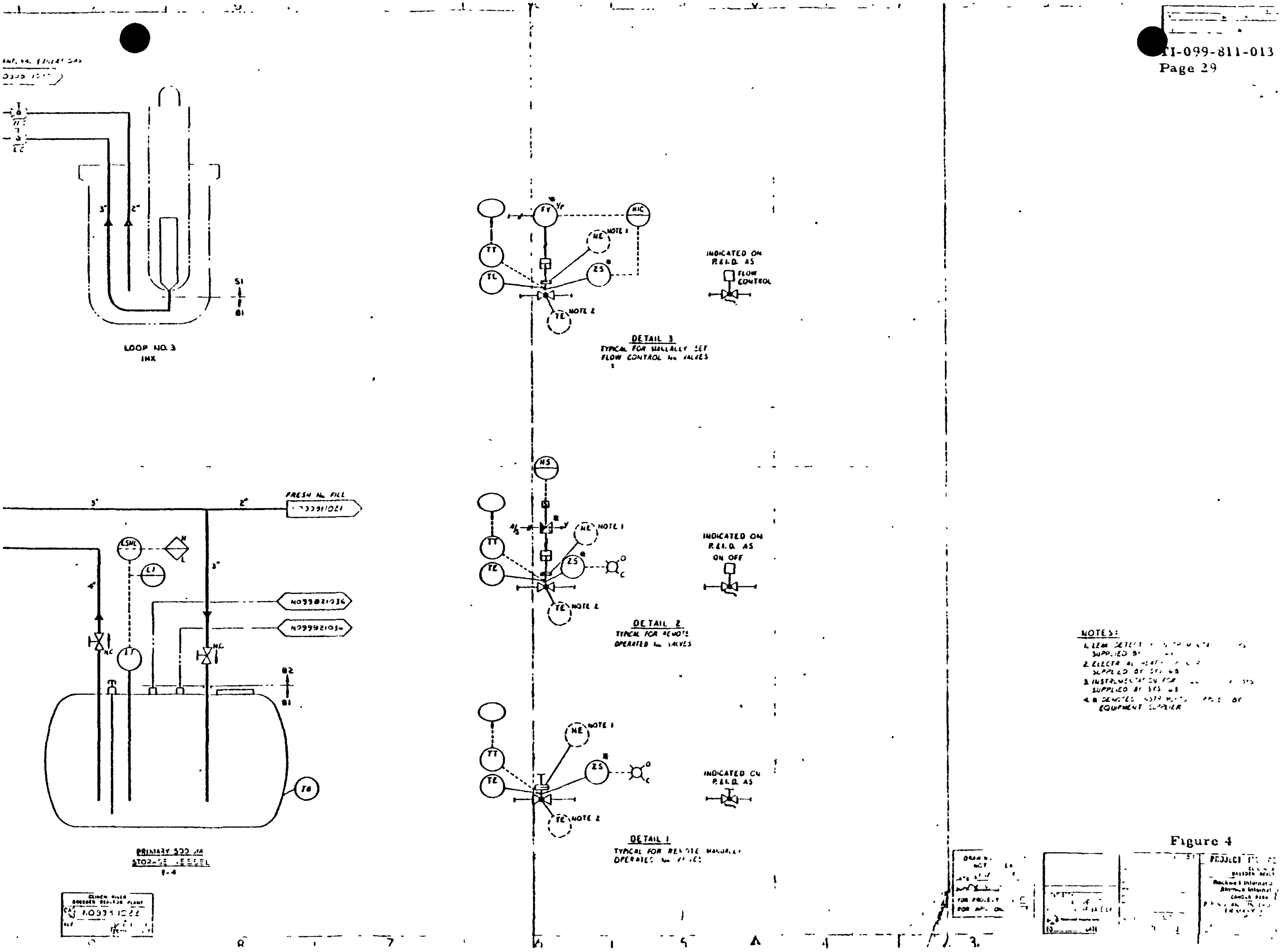
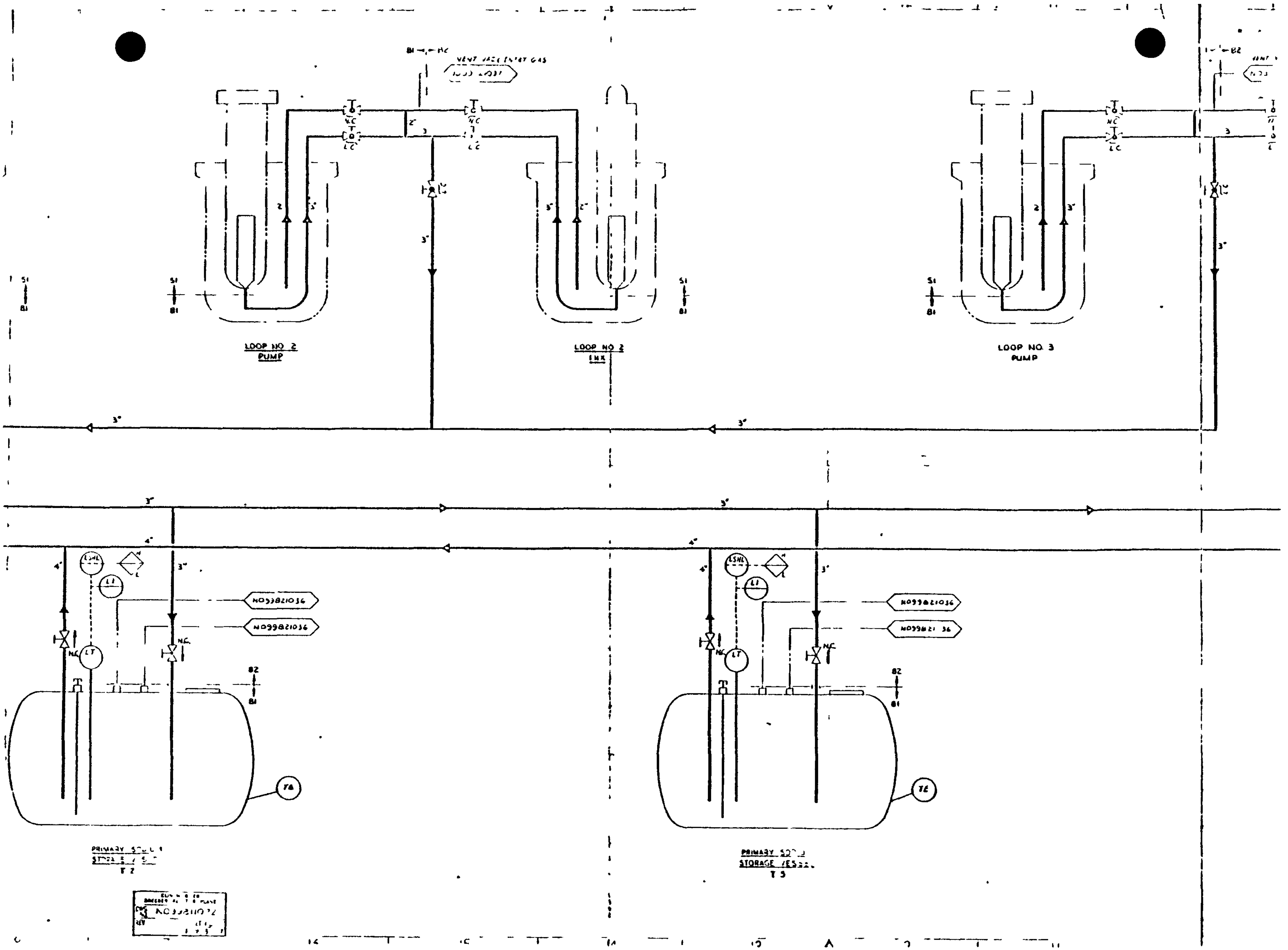
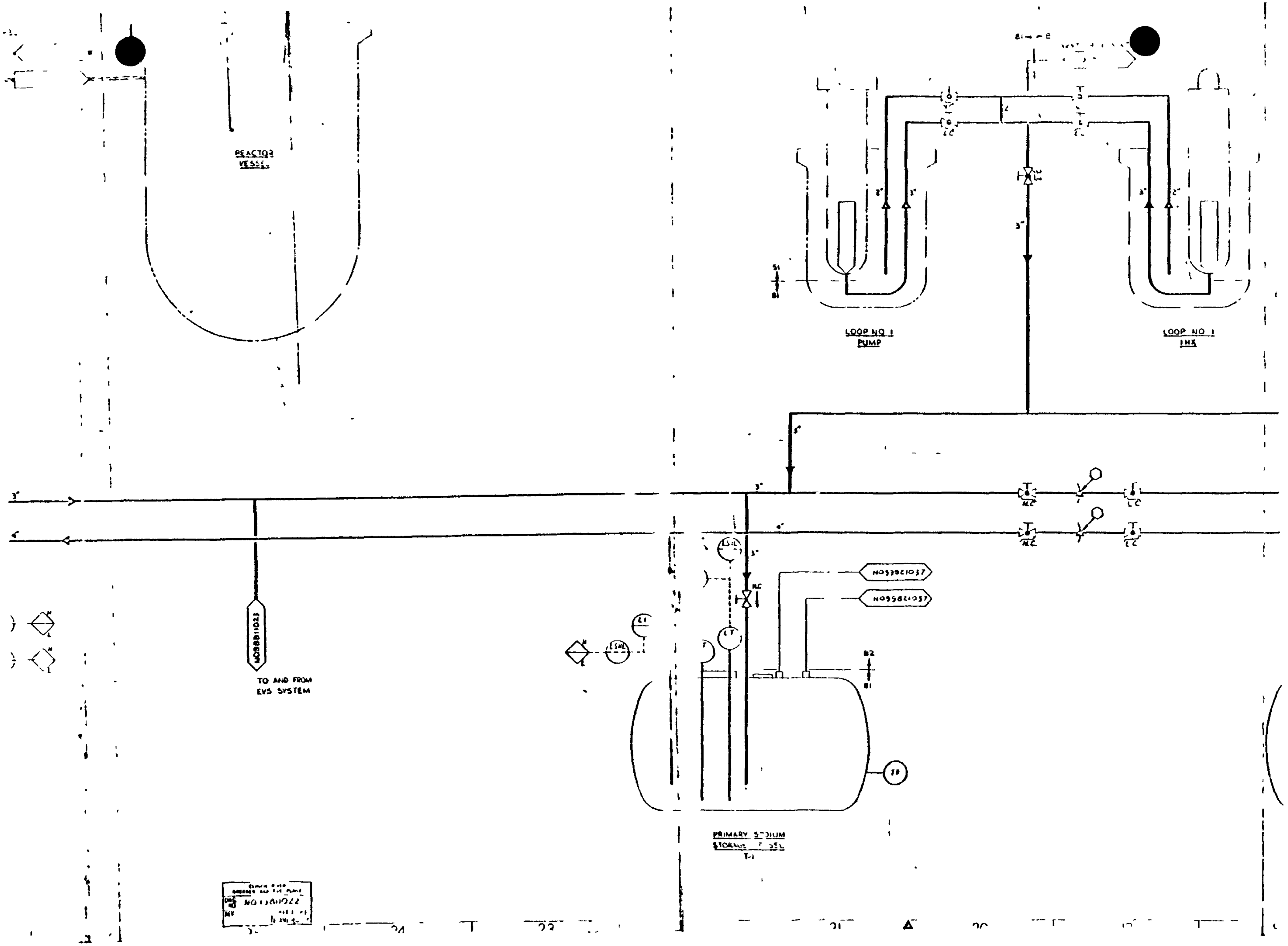
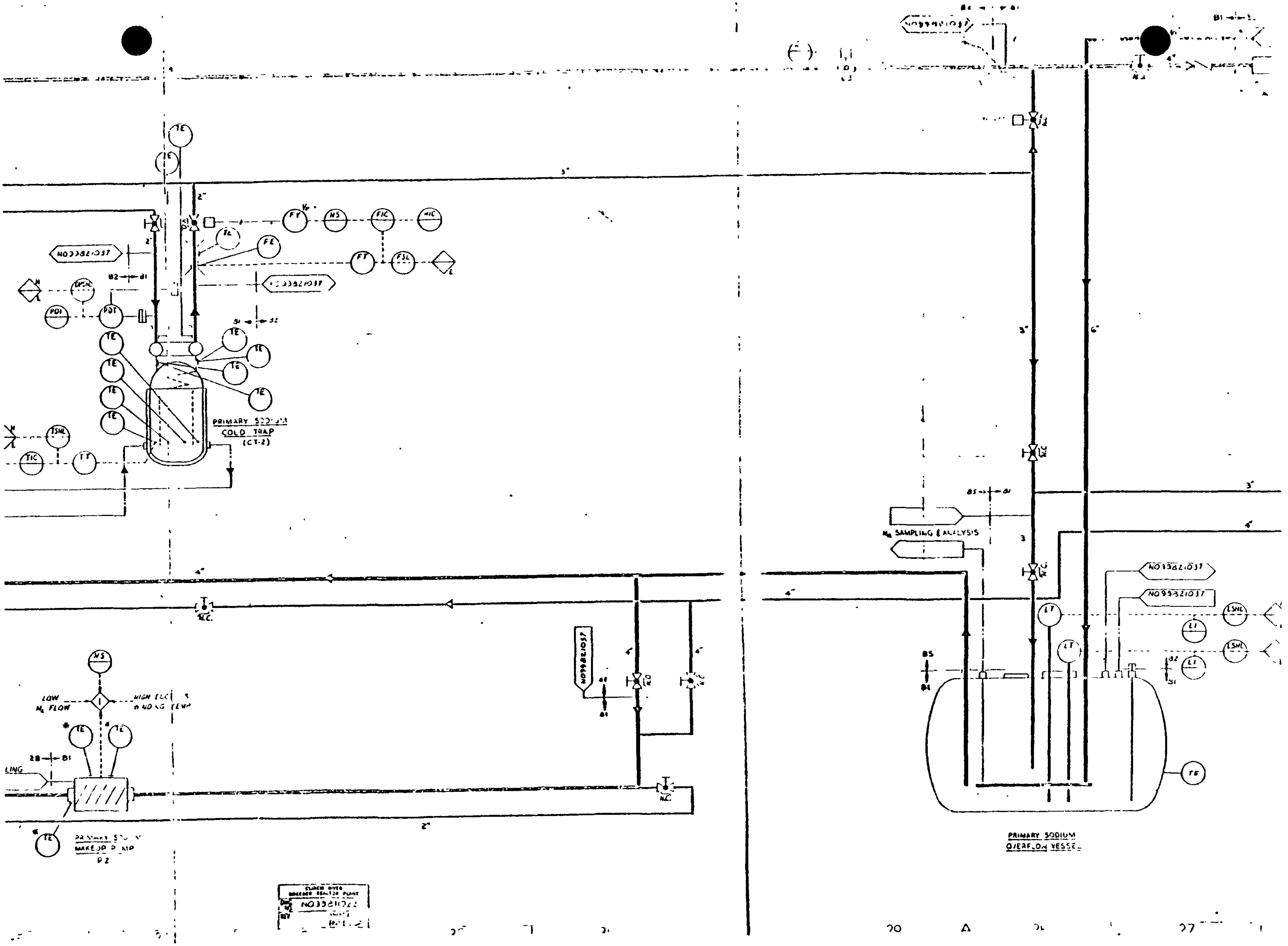
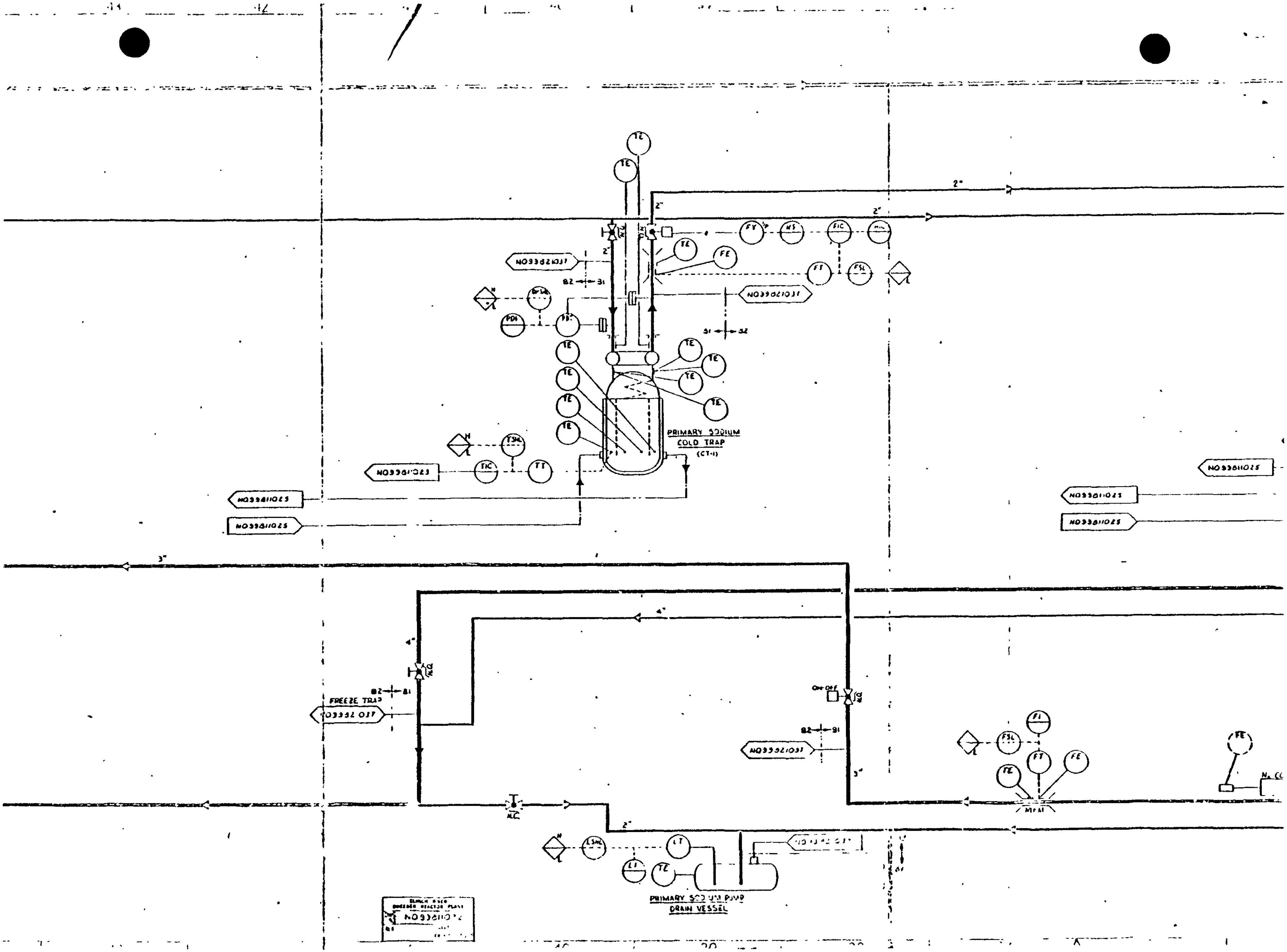

LOOP NO. 3
IHX
3"
2"
S1
B1
FRESH Na FILL
3"
2"
4"
3"
LSHL
LI
LT
NC
NC
N0998Z1036
N0998Z1054
B2
B1
TE
PRIMARY 500 ..
STORAGE VESSEL
1-4
CLINCH RIVER
BREEDER REACTOR PLANT
FY
HIC
NE
NOTE 1
TT
TE
ZS
TE
NOTE 2
INDICATED ON
P.&I.D. AS
FLOW
CONTROL
DETAIL 3
TYPICAL FOR MANUALLY SET
FLOW CONTROL Na VALVES
HS
NE
NOTE 1
TT
TE
ZS
O
C
TE
NOTE 2
INDICATED ON
P.&I.D. AS
ON OFF
DETAIL 2
TYPICAL FOR REMOTE
OPERATED Na VALVES
NE
NOTE 1
TT
TE
ZS
O
C
TE
NOTE 2
INDICATED ON
P.&I.D. AS
DETAIL 1
TYPICAL FOR REMOTE MANUALLY
OPERATED Na VALVES
NOTES:
1. LEAK DETECT
SUPPLIED BY
2. ELECTR AL HEAT
SUPPLIED BY SYS 63
3. INSTRUMENTATION FOR
SUPPLIED BY SYS
4. ■ DENOTES INSTRUMENTS BY
EQUIPMENT SUPPLIER
PROJECT
Rockwell International
Atomics International
8
7
6
5
4
3

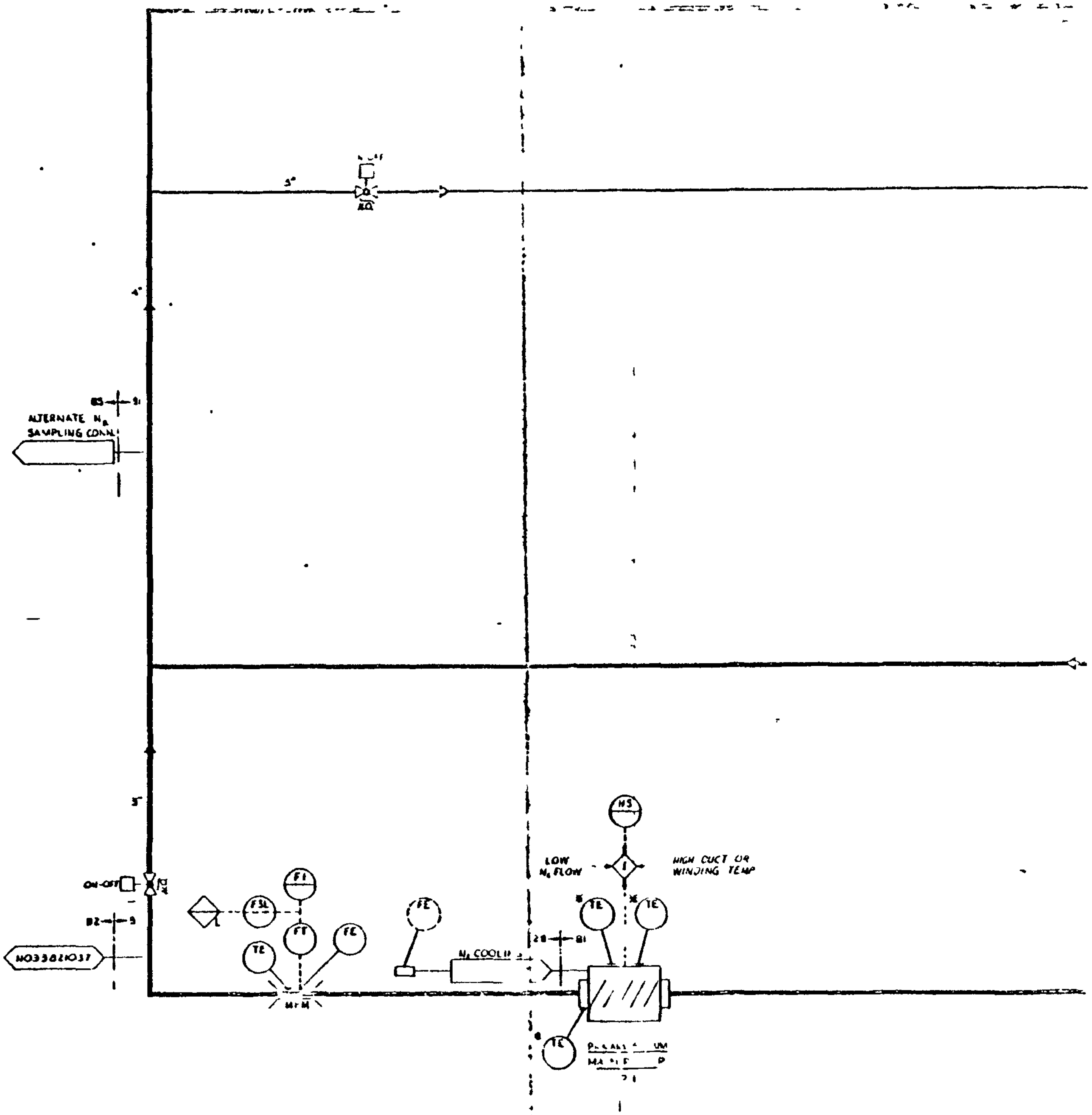
Figure 4


VENT VACC INERT GAS
LOOP NO 2
PUMP
LOOP NO 2
IHX
LOOP NO. 3
PUMP
3"
2"
4"
NC
LC
SI
BI
BZ
LSHL
LI
LT
TE
NO99821036
NO99821036
NO99821036
NO99821036
PRIMARY SODIUM
STORAGE VESSEL
T 2
PRIMARY SODIUM
STORAGE VESSEL
T 3
BREEDER
PLANT
DWG
NO99811072
REV

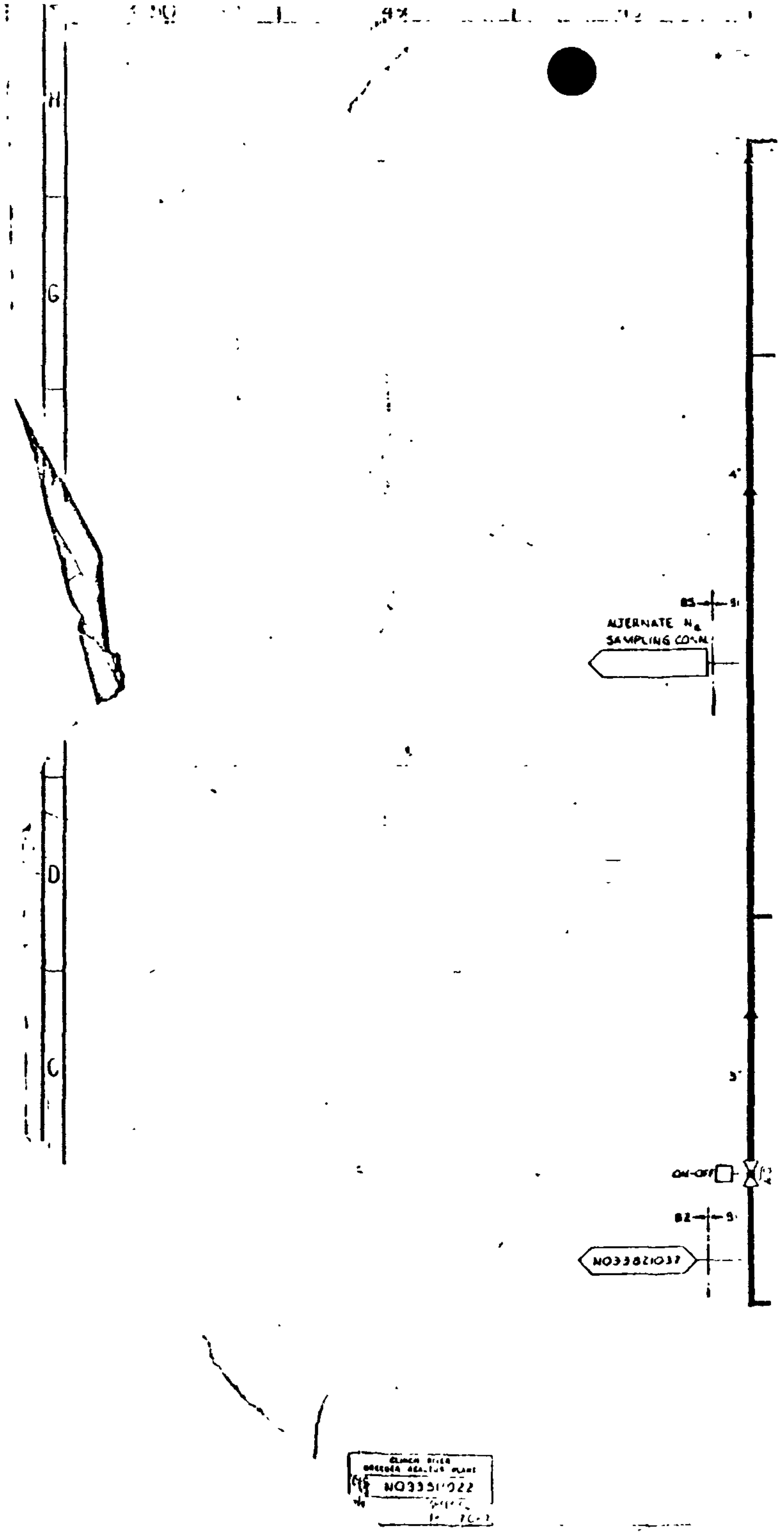

REACTOR VESSEL
LOOP NO 1 PUMP
LOOP NO 1 IHX
3"
2"
4"
NC
LC
S1
B1
B2
NO9BB11022
TO AND FROM EVS SYSTEM
NO99821037
LSHL
LT
LE
TE
PRIMARY SODIUM STORAGE VESSEL
T-1
NO 11BH022


TE
2"
3"
FY
HS
FIC
HIC
FE
FT
FSL
NO33B21037
B2 B1
PDSH
PDI
PDT
B1 B2
PRIMARY SODIUM
COLD TRAP
(CT-2)
TSHL
TIC
TT
4"
N.C.
NO99B21037
N.O.
HS
LOW Na FLOW
HIGH ELEC WINDING TEMP
2B B1
PRIMARY SODIUM
MAKEUP PUMP
P2
2"
3"
6"
B5 B1
Na SAMPLING & ANALYSIS
3
4"
NO33B21037
NO99B21037
LT
LI
LSHL
B5
B1
B2
B1
TE
PRIMARY SODIUM
OVERFLOW VESSEL
CLINCH RIVER
BREEDER REACTOR PLANT
DWG NO 33B11022
REV
20
A
27]


TE
TE
2"
2"
FY
HS
FIC
TE
FE
FT
FSL
NO33821037
82
81
NO33821037
81
82
PDI
PDI
TE
TE
TE
TE
TE
TE
TE
TE
PRIMARY SODIUM
COLD TRAP
(CT-1)
H
L
TSHL
TIC
TT
NO33811023
NO33811025
NO33811025
NO33811025
NO33811023
NO33811025
3"
4"
4"
82
81
FREEZE TRAP
NO3332 037
ON-OFF
82
81
NO33321037
3"
FI
FSL
FT
FE
FE
FE
2"
N.C.
H
L
LSHL
LI
LT
TE
PRIMARY SODIUM PUMP
DRAIN VESSEL
CLINCH RIVER
BREEDER REACTOR PLANT
NO9381102?
40
20



CLINCH RIVER
BREEDER REACTOR PLANT
NO3351 022
SHEET



H
G
D
C
4"
85
91
ALTERNATE N2 SAMPLING CONN.
5"
ON-OFF
82
91
NO33821037
CLINCH RIVER BREEDER REACTOR PLANT
NO3351'022

TABLE IX
PHTS SODIUM VOLUME AND MASS

	Volume (gallons)	Temperature (°F)	Density (lb/ft^3)	Mass (lb x10^{-6})
Reactor Vessel	99,700	863	52.5	0.700
Piping, Reactor Vessel to High Point	14,590	863	52.5	0.102
Loops, High Point on out	75,000	863	52.5	0.526
Overflow Vessel Heel	3,600	880	52.4	0.025
Primary Cold Traps	1,410	560	55.0	0.010
Pumps and Piping, System 81	1,570	880	52.4	0.011
Subtotal	195,870			1.374
Storage Vessel Heel	4,340	400	56.3	0.033
Total	200,210			1.407

B. IHTS

The IHTS sodium is contained in three separate and independent heat transfer loops, three ~~six~~ storage tanks, six cold traps, and associated pumps, expansion tanks, and piping. The sodium storage and processing flow diagram for the IHTS is given in Figure 5. The distribution of the loop volumes is given in Table X. These volumes were obtained from General Electric Co.(3) The small volumes associated with the purification system were neglected in the total for the purposes of the analysis of cold trapping the loop-sodium.

The IHTS total wetted surface area is approximately 147,000 ft^2. Because of the different lengths of piping in the 3 loops this area is not divided equally between loops. The breakdown of the area is indicated below(3).

Steam Generator	23,100 ft^2/loop
Pump	700
Expansion Tank	400
IHX	16,950
	41,150 ft^2/loop
	123,450 ft^2/3 loops
Piping, Loop 1 Est	8,954
Loop 2	6,138
Loop 3	8,514
Total	147,056 ft^2/3 loops

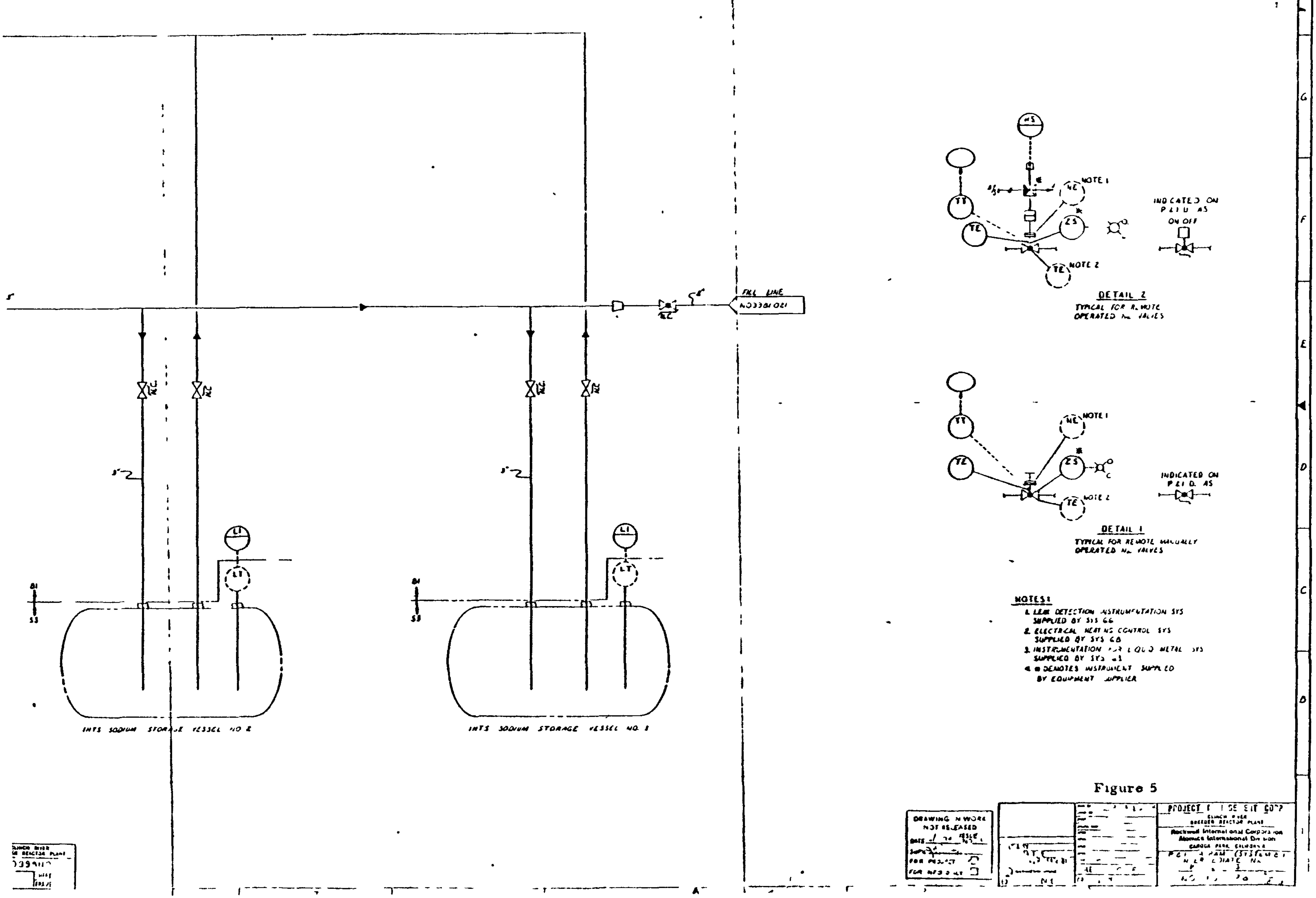
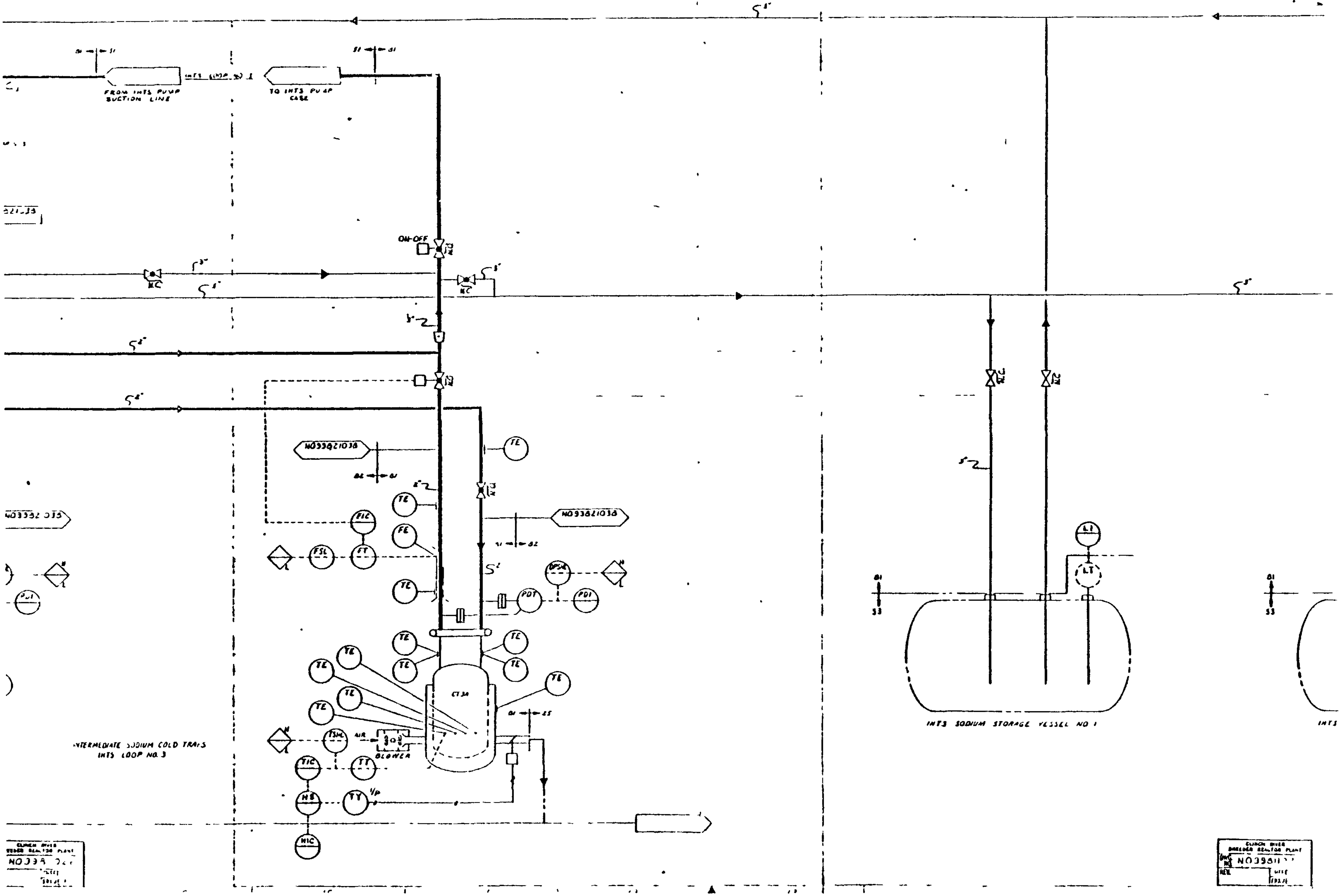
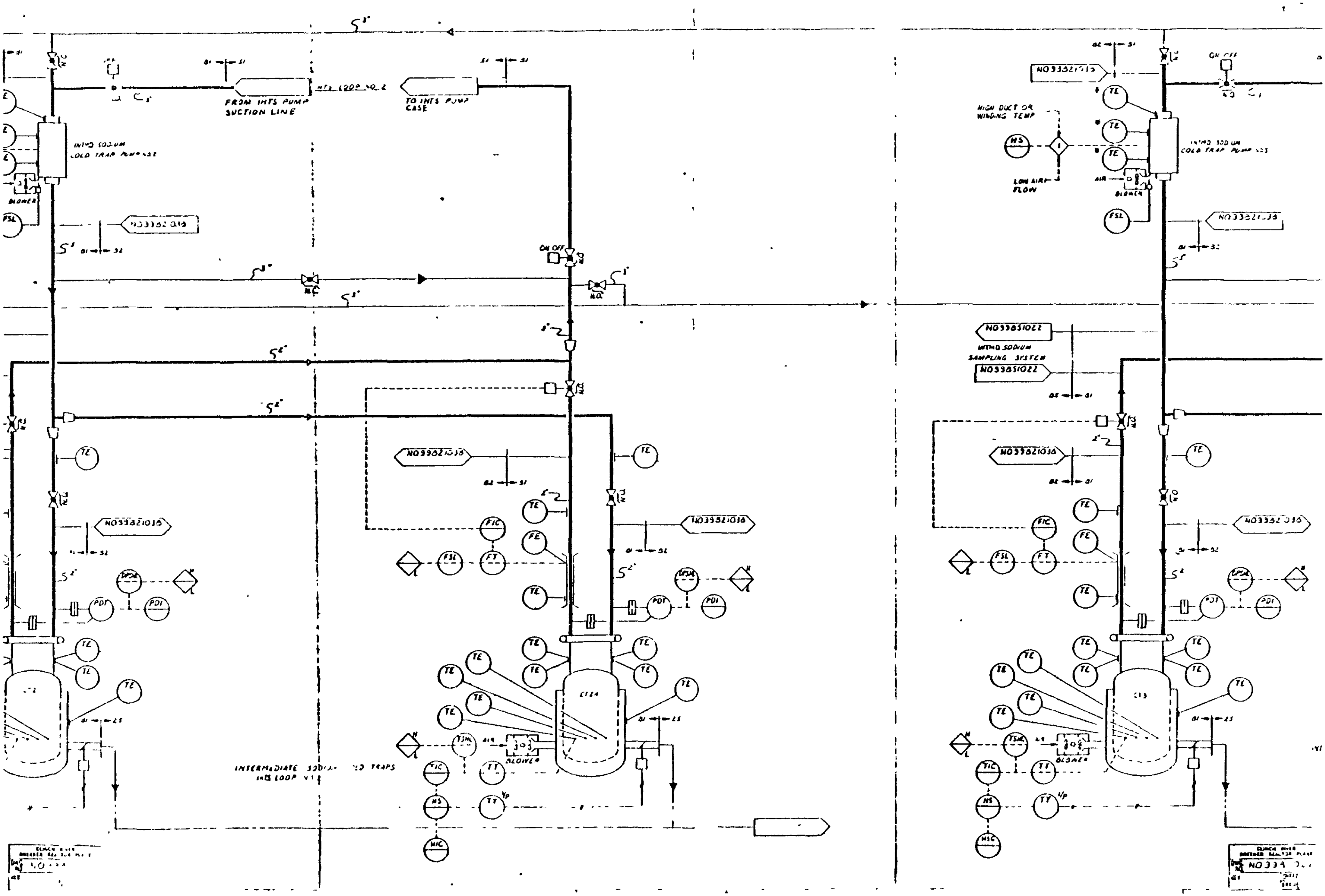
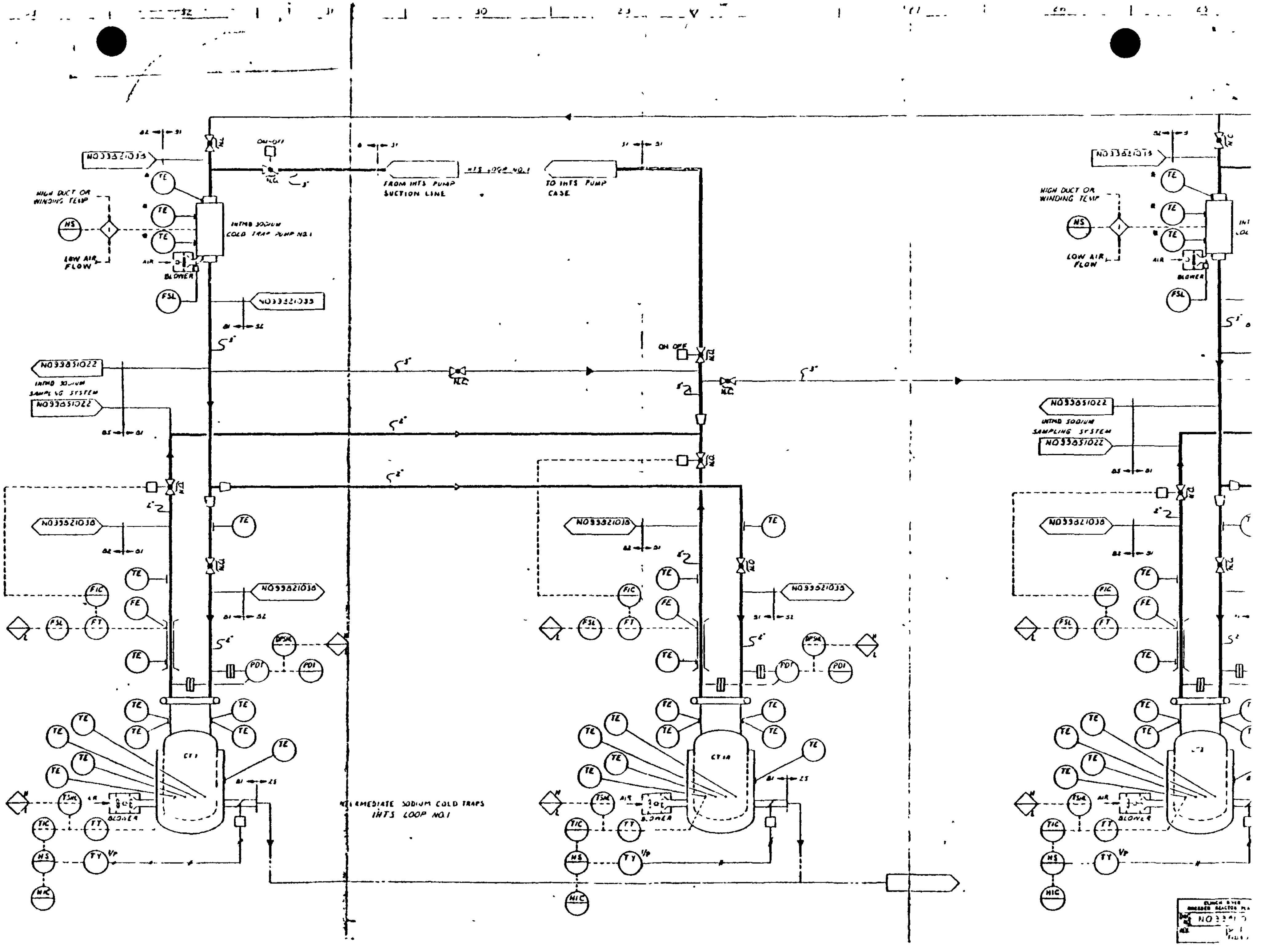

FILL LINE
NO3361021
3"
3"
3"
NC
LI
LT
81
53
INTS SODIUM STORAGE VESSEL NO 2
INTS SODIUM STORAGE VESSEL NO 1
HS
TT
TE
HE
ZS
NOTE 1
NOTE 2
DETAIL 2
TYPICAL FOR REMOTE OPERATED Na VALVES
INDICATED ON P&ID AS ON OFF
DETAIL 1
TYPICAL FOR REMOTE MANUALLY OPERATED Na VALVES
INDICATED ON P&ID AS
NOTES:
1. LEAK DETECTION INSTRUMENTATION SYS SUPPLIED BY SYS 66
2. ELECTRICAL HEATING CONTROL SYS SUPPLIED BY SYS 68
3. INSTRUMENTATION FOR LIQUID METAL SYS SUPPLIED BY SYS 91
4. * DENOTES INSTRUMENT SUPPLIED BY EQUIPMENT SUPPLIER
DRAWING IN WORK NOT RELEASED
DATE
FOR PROJECT
FOR INFO ONLY
PROJECT
CLINCH RIVER BREEDER REACTOR PLANT
Rockwell International Corporation
Atomics International Division
CANOGA PARK, CALIFORNIA
CLINCH RIVER BREEDER REACTOR PLANT
H
G
F
E
D
C
B
A

Figure 5


FROM INTS PUMP SUCTION LINE
INTS LOOP NO 3
TO INTS PUMP CASE
ON-OFF
NC
NO3382103B
NO3382103B
NO3382 035
TE
FE
FIC
FT
FSL
DPSH
PDT
PDI
PDI
CT3A
TSHL
AIR
BLOWER
TIC
TT
HS
TY
I/P
HIC
LI
LT
INTERMEDIATE SODIUM COLD TRAPS
INTS LOOP NO. 3
INTS SODIUM STORAGE VESSEL NO 1
INTS
CLINCH RIVER BREEDER REACTOR PLANT
NO338
CLINCH RIVER BREEDER REACTOR PLANT
DWG NO NO3381
REV


FROM IHTS PUMP SUCTION LINE
IHTS LOOP NO. 2
TO IHTS PUMP CASE
IHTS SODIUM COLD TRAP PUMP
BLOWER
FSL
NO3382103S
ON OFF
NO
NC
TE
FIC
FE
FT
FSL
DPSH
PDT
PDI
TSHL
AIR
BLOWER
TIC
HS
HIC
TT
TY
I/P
INTERMEDIATE SODIUM COLD TRAPS
IHTS LOOP
CLINCH RIVER BREEDER REACTOR PLANT
HIGH DUCT OR WINDING TEMP
LOW AIR FLOW
HS
IHTS SODIUM COLD TRAP PUMP
NO3385I022
IHTS SODIUM SAMPLING SYSTEM
NO3385I022
NO3382I036
NO3382103S
CLINCH RIVER BREEDER REACTOR PLANT


INTERMEDIATE SODIUM COLD TRAPS
INTS LOOP NO.1
NO33821035
NO33821035
NO33821036
NO33821036
NO33851022
NO33851022
INTMD SODIUM SAMPLING SYSTEM
INTMD SODIUM COLD TRAP PUMP NO.1
HIGH DUCT OR WINDING TEMP
LOW AIR FLOW
BLOWER
AIR
ON-OFF
ON OFF
N.C.
FROM INTS PUMP SUCTION LINE
INTS LOOP NO.1
TO INTS PUMP CASE
CT 1
CT 1A
TE
HS
FSL
FIC
FE
FT
DPSHL
PDT
PDI
TSHL
TIC
TT
TY
I/P
HIC
3"
2"
CLINCH RIVER
BREEDER REACTOR PLA
NO33

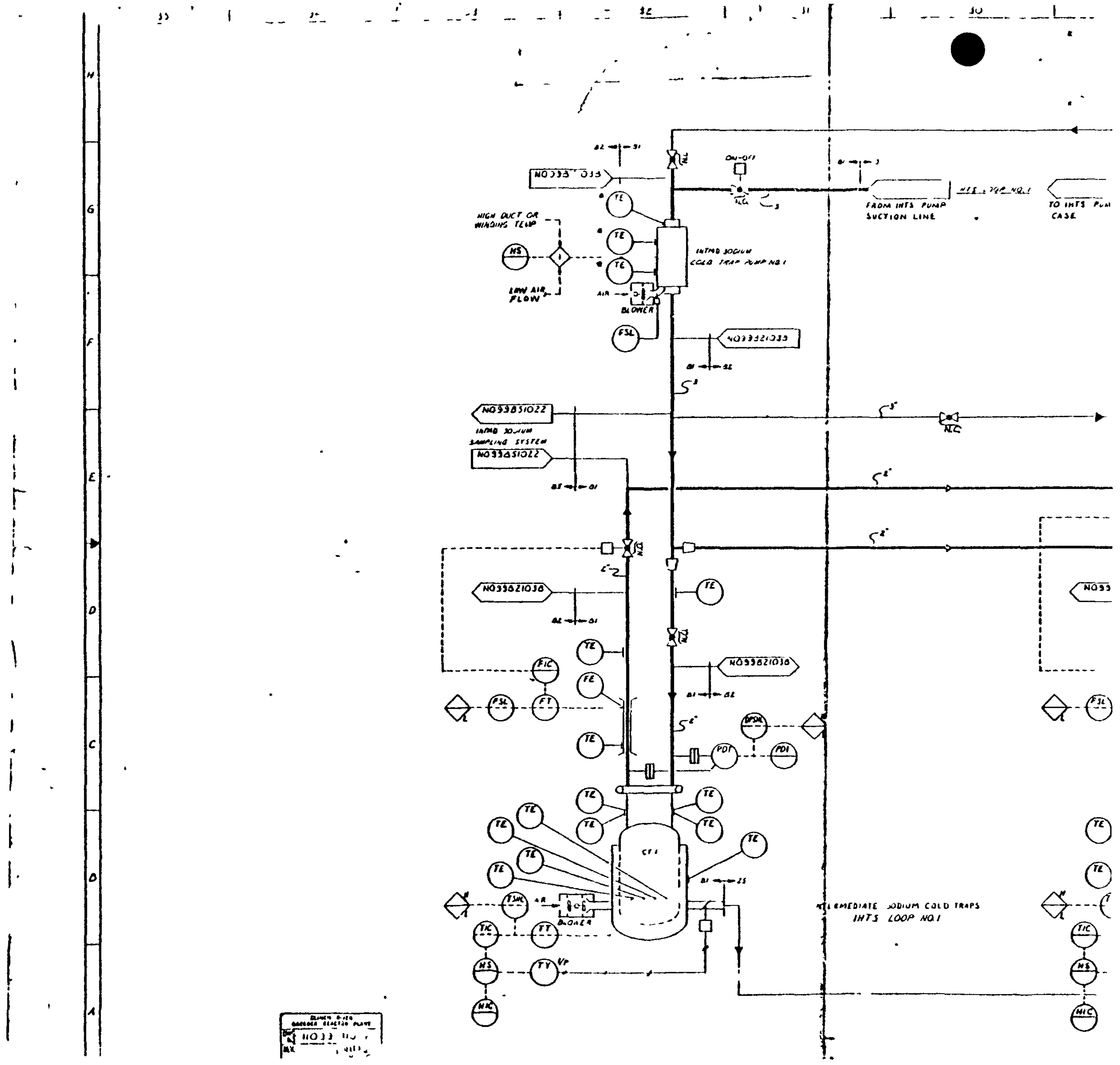

INTERMEDIATE SODIUM COLD TRAPS
IHTS LOOP NO.1
INTMD SODIUM COLD TRAP PUMP NO.1
INTMD SODIUM SAMPLING SYSTEM
FROM IHTS PUMP SUCTION LINE
TO IHTS PUMP CASE
HIGH DUCT OR WINDING TEMP
LOW AIR FLOW
BLOWER
AIR
ON-OFF
N.C.
CT1
NO33821038
NO33821038
NO33851022
NO33A51022
NO33321033
NO33 033
NO33
TE
TE
TE
FSL
HS
FE
FT
FIC
FSL
DPSH
PDI
PDT
TSHL
TIC
TT
TY
VP
HS
HIC
A
B
C
D
E
F
G
H
30
31
32
33
CLINCH RIVER BREEDER REACTOR PLANT
NO33

TABLE X
IHTS SODIUM VOLUMES* (ft^3/loop)

Piping from IHX to Superheater	
Loop 1	1734
Loop 2	1289
Loop 3	1981
Superheater (1)	741
Piping from Superheater to Evaporator	453
Evaporators	1457
Piping from Evaporators to Pump	255
Pump	840
Piping from Pump to IHX	
Loop 1	1530
Loop 2	764
Loop 3	1343
IHX Tubeside	237
Expansion Tank	131
Piping Appendages	105
Totals	
Loop 1	7483
Loop 2	6272
Loop 3	7543
3 Loops	21,298 ft^3

*Thermal-Hydraulic Design data obtained from GE, Reference 3.

The material of the IHTS is either 304 or 316 stainless steel except for the steam generator which is 2-1/4 Cr-1 Mo alloy steel. This design information is important to the initial oxygen contamination and cleanup calculations. The surface oxygen contamination of the low alloy steel of the steam generator is 12.7×10^{-4} lb/ft^2 while that for the stainless steels is 2.0×10^{-4} lb/ft^2(10). The hydrogen contamination for both surfaces was taken as 0.27×10^{-4} lb/ft^2, although a lower value is indicated(10) for 2-1/4 Cr-1 Mo.

VI. ANALYSIS

A. COLD TRAPPING

1. Equations

The fundamental equation derived for the time dependent concentration C_s of an impurity in the system sodium due to cold trapping while there is a source of contamination is,

$$\frac{dC_s}{dt} + \alpha \frac{60W}{M} C_s = \alpha \frac{60W}{M} C_e + \dot{C}_a \qquad \ldots.(1)$$

where

C_s = concentration in the system sodium of impurity species being trapped (oxygen or hydrogen in this report), ppm*

t = time, hours

α = trapping efficiency = $(C_s - C_o)/(C_s - C_e)$

C_o = concentration of impurity in sodium leaving the cold trap, ppm

C_e = saturation concentration of impurity in sodium at the minimum cold trap temperature, ppm

W = cold trap sodium flow rate, gpm

M = system sodium volume, gallons

$\dot{C}_a$ = source rate of impurity contamination of sodium system, ppm/hour

In the derivation of this equation it was assumed that the sodium returning to the system from the cold trap is mixed instantaneously with the system sodium and the impurities in the system are uniformly distributed.

---

*The following definition is used throughout this report: ppm = mass parts of impurity per million parts of sodium.

In the solution of the above trapping equation, α, W, and M were held constant. In reality α (trapping efficiency) probably depends on concentration of the impurity involved, the "temperature margins," and the amount of impurity collected. However, for a particular trapping run being calculated it is expected to remain fairly constant.

Experience in cold trap operations has taught that the minimum cold trap temperature should not be permitted to go much lower than the saturation temperature corresponding to the cold trap inlet concentration in the case of oxygen. Otherwise, the oxide will precipitate too soon and might even plug the economizer. The rule at AI is to provide or aim for a 50°F temperature margin between the inlet saturation temperature and the minimum cold trap temperature. Accordingly, C_e in Equation 1 becomes a function of the dependent variable, C_s. If T_s is the inlet saturation temperature and T_e is the minimum cold trap temperature, the temperature margin ΔT_m is defined as,

$$\Delta T_m = T_s - T_e \qquad \ldots.(2)$$

The particular solubility curve for the impurity would determine the functional relationship between C_s and C_e which satisfied $\Delta T_m =$ constant. This relationship is non-linear and complicates the solution of the trapping equation. Accordingly, the finite difference method was applied, utilizing the computer to obtain the time variation in concentration by taking a large number of small time steps.

The rate of impurity addition, $\dot{C}_a$, was considered to be either constant or some simple function of time. Hence, it did not contribute to non-linearity nor complicate the solution.

The finite difference approximation of Equation 1 gives the concentration, C_{s_n}, at the end of a time step, Δt, as follows:

$$C_{s_n} = \frac{\frac{1}{\Delta t} - \frac{\alpha W}{2M}}{\frac{1}{\Delta t} + \frac{\alpha W}{2M}} \; C_{s_{n-1}} + \frac{\frac{\alpha W}{M} C_e + \dot{C}_a}{\frac{1}{\Delta t} + \frac{\alpha W}{2M}} \qquad \ldots.(3)$$

where $C_{s_{n-1}}$ is the concentration at the beginning of the time step.

To obtain the steady-state cold trapping rate, Equation 1 is applied directly. Thus, for the system,

$$\frac{dC_s}{dt} = \dot{C}_a - \alpha\frac{60W}{M}(C_s - C_e) \text{ ppm/hr} \qquad \ldots.(4)$$

The rate of mass transfer ~~for~~ to the cold trap is equal to the rate contamination is added to the system minus the rate contamination is accumulating in the system. Thus,

$$\begin{aligned} \dot{w} &= \dot{C}_a - \frac{dC_s}{dt} \\ &= \alpha\frac{60W}{M}(C_s - C_e) \text{ ppm/hr} \\ &= .0703\ \rho\alpha W(C_s - C_e) \text{ lb/yr} \qquad \ldots.(5) \end{aligned}$$

where ρ = sodium density in lb/ft^3 and α, W, C_s, and C_e are as previously defined.

2. Solubility of Oxygen and Hydrogen

a. Oxygen

The relationship between sodium temperature and oxygen solubility is nearly a straight line when plotted as ℓn C (ppm) vs 1/T(°R), except at the lower end of the temperature range where there is a significant deviation.(11) Rather than trying to fit some other analytical function to the data, the solubility relationship was supplied to the computer for the trapping calculations in tabular form. The pairs of data points provided are $\left[10^3/T\ (°R),\ \ln C\ (ppm)\right]$.

On these particular data points, linear interpolation was performed in the program to obtain intermediate points as required. The oxygen solubility data are given in Table XI.

TABLE XI

OXYGEN SOLUBILITY IN SODIUM

(Reference 11)

Computer Data Input		Corresponding Data	
$10^3/T$ (°R)	$\ln$ C (ppm)	T (°F)	C (ppm)
.90	5.94	650	178
.95	5.18	590	164
.99	4.59	550	98
1.04	3.83	500	46
1.10	3.00	450	20
1.16	2.28	400	9.8
1.20	1.85	370	6.2
1.23	1.56	355	5.0
1.25	1.39	340	4.0
1.30	.99	310	2.7
1.35	.69	280	2.0
1.41	.41	250	1.5
1.47	.26	220	1.3
1.52	.18	200	1.15

b. Hydrogen

The solubility of hydrogen in sodium was approximated (12) by the equation,

$$\ln C\ (\text{ppm } H_2) = \overset{13.970}{\cancel{15.105}} - \frac{\overset{11937}{\cancel{13014}}}{T(^{\circ}R)}$$

This analytical function was used directly in the computer program for calculating hydrogen cold trapping by differential solubility.

3. Computer Programs

A number of specialized timesharing computer programs were written to perform the various calculations of cold trapping oxygen and hydrogen in the PHTS and IHTS. Equation 3 is the basic relationship which determines the impurity concentration as a function of time (or the steady-state if the program is allowed to run for a long time in some cases), and it is common to all of the programs written for cold trapping. The different programs represent optional variations as to:

1) Impurity (oxygen or hydrogen)
2) Whether or not there is impurity contamination during the first part of the trapping period
3) Whether or not impurity concentration in the sodium entering the cold trap is limited to the saturation concentration, although system concentration exceeds saturation.

To illustrate the method, program REFUEL which was used to calculate the oxygen transient in the PHTS as a result of the refueling operation is presented in Table XII and a sample computer output is given in Table XIII. Input and output of the program are discussed next.

TABLE XII
COMPUTER PROGRAM REFUEL LISTING (Sheet 1 of 2)

```
LIST

REFUEL

100 PRINT "COLD TRAPPING DURING AND AFTER REFUELING"

120 PRINT
130 DIM X(15), Y(15)
140 REM VOLUME OF SYSTEM, GALLONS
150 LET M = 195870
152 REM RATE OF O2 CONTAMINATION DURING REFUELING, PPM/HOUR
154 LET C4 = .00329
156 REM REFUELING TIME TO PUT ELEMENTS INTO REACTOR
158 LET D4 = 410
160 REM EFFECTIVENESS OF COLD TRAP
170 LET A1 = .7
180 REM FINITE DIFFERENTIAL TIME INCREMENT, HOUR
190 LET D9 = 1.0
200 REM MINIMUM-COLD-TRAP-TEMP. MARGIN
210 LET T9 = 50
220 REM MINIMUM COLD TRAP TEMP.
230 LET T8 = 250
240 REM NUMBER OF TIME INCREMENTS BETWEEN PRINTOUTS
250 LET K0 = 41
260 LET X8 = 1000/(T8 + 460)
300 FOR I = 1 TO 14
310 READ X(I), Y(I)
320 NEXT I
322 REM X(I) = 10E-3/T(DEG.R.) ,  Y(I) = LOG C(PPM)
325 DATA 0.90, 5.94, 0.95, 5.18
330 DATA 0.99, 4.59, 1.04, 3.83, 1.10, 3.00
340 DATA 1.16, 2.28, 1.20, 1.85, 1.23, 1.56
350 DATA@1.25, 1.39, 1.30, 0.99, 1.35, 0.69
360 DATA 1.41, 0.41, 1.47, 0.26, 1.52, 0.19
370 PRINT "                          CONSTANTS"
380 PRINT "   SODIUM SYSTEM VOLUME (GALLONS)                ="; M
385 PRINT "   RATE OF O2 CONTAMINATION (PPM/HR)             ="; C4
386 PRINT "   REFUELING TIME (HOURS)                        ="; D4
390 PRINT "   COLD TRAP EFFECTIVENESS                       ="; A1
400 PRINT "   COLD TRAP TEMP. LOWER LIMIT (F.)              ="; T8
410 PRINT "   MINIMUM-COLD-TRAP-TEMP. MARGIN (F.)           ="; T9
420 PRINT "   FINITE DIFFERENTIAL TIME INCREMENT (HR)       ="; D9
430 PRINT "   NUMBER OF TIME INCREMENTS/PRINTOUT            ="; K0
440 PRINT
450 PRINT "INPUT INITIAL AND FINAL OXYGEN CONCENTRATIONS (PPM) AND"
460 PRINT "SODIUM FLOW RATE THROUGH COLD TRAP (GPM)."
470  NPUT C1, C2, W
471 LET A = A1 * 60 * W / M
472 LET R = (1/D9 - A/2)/(1/D9 + A/2)
473 LET S = A/(1/D9 + A/?)
474 LET U = 1/(1/D9 + A/2)
480 PRINT
490 PRINT"TIME            SYSTEM OXYGEN    MIN.C.T.TEMP.    MIN.C.T.OXYGEN"
500 PRINT" HR                  PPM             DEG. F.             PPM "
510 PRINT
520 REM INITIALIZE TIME TO ZERO
530 LET D = 0
```

TABLE XII
COMPUTER PROGRAM REFUEL LISTING (Sheet 2 of 2)

```
540 REM INITIALIZE COUNTER ON TIME INCREMENTS PER PRINTOUT
550 LET K = 0
560 REM INDEX TO PROVIDE PRINTOUT OF INITIAL CONDITIONS
570 LET N = 0
580 LET Y = LOG(C1)
585 LET C9 = C1
590 LET K = K + 1
600 IF Y < Y(1) THEN 630
610 PRINT "INITIAL O2 CONCENTRATION BEJOND DATA RANGE"
620 GO TO 980
630 FOR I = 2 TO 14
640 IF Y > Y(I) THEN 670
650 NEXT I
660 REM INTERPOLATION FOR INVERSE TEMP. FROM SOLUBILITY DATA
670 LET Y0 = (Y - Y(I-1))/(Y(I) - Y(I-1))
680 LET X = X(I-1) + Y0 * (X(I) - X(I-1))
690 LET T = 1000/X - 460 - T9
700 LET X = 1000/(T + 460)
710 IF X < X8 THEN 740
720 LET X = X8
730 LET T = T8
740 IF K < K0 THEN 760
750 PRINT D, C1, T,
760 FOR I = 2 TO 14
770 IF X < X(I) THEN 800
780 NEXT I
790 REM INTERPOLATION FOR LOG CONCENTRATION FROM SOLUBILITY DATA
800 LET X0 = (X - X(I-1))/(X(I) - X(I-1))
810 LET Y = Y(I-1) + X0 * (Y(I) - Y(I-1))
820 LET C3 = EXP(Y)
830 IF N > 0 THEN 860
840 PRINT "  0  ", C1, T, C3
850 LET N = 1
852 LET K = 0
854 GO TO 890
860 IF K < K0 THEN 885
870 PRINT C3
880 LET K = 0
885 IF D < D4 THEN 890
886 LET C4 = 0
887 IF K = 0 THEN 890
888 IF D > D4 THEN 890
889 PRINT D, C1, T, C3
890 LET C1 = R*C1 + S*C3 + U*C4
900 LET D = D + D9
905 IF C1 > C9 THEN 580
910 IF D > 820 THEN 960
920 LET Q = (C1 - C2)/C2
930 IF Q > .001 THEN 580
940 PRINT D, C1, T, C3
950 GO TO 980
960 PRINT "TRAPPING TIME EXCEEDS 820 HOURS"

970 GO TO 980
980 END
```

TABLE XIII
PHTS COLD TRAPPING ON REFUELING

```
RUN


REFUEL

COLD TRAPPING DURING AND AFTER REFUELING


                      CONSTANTS
   SODIUM SYSTEM VOLUME (GALLONS)             = 195870
   RATE OF 02 CONTAMINATION (PPM/HR)          = .00329
   REFUELING TIME (HOURS)                     = 410
   COLD TRAP EFFECTIVENESS                    = .7
   COLD TRAP TEMP. LOWER LIMIT (F.)           = 250
   MINIMUM-COLD-TRAP-TEMP. MARGIN (F.)        = 50
   FINITE DIFFERENTIAL TIME INCREMENT (HR)    = 1
   NUMBER OF TIME INCREMENTS/PRINTOUT         = 41

INPUT INITIAL AND FINAL OXYGEN CONCENTRATIONS (PPM) AND
SODIUM FLOW RATE THROUGH COLD TRAP (GPM).
 ? 1.521, 2, 80

TIME          SYSTEM OXYGEN    MIN.C.T.TEMP.    MIN.C.T.OXYGEN
 HR                PPM           DEG. F.             PPM

  0            1.521            250             1.51775
 41            1.61623          250             1.51775
 82            1.66336          250             1.51775
 123           1.68668          250             1.51775
 164           1.69823          250             1.51775
 205           1.70394          250             1.51775
 246           1.70677          250             1.51775
 287           1.70817          250             1.51775
 328           1.70886          250             1.51775
 369           1.70921          250             1.51775
 410           1.70937          250             1.51775
 411           1.70612          250             1.51775



 ? 1.521, 2, 20

  0            1.521            250             1.51775
 41            1.64417          250             1.51775
 82            1.74749          250             1.51775
 123           1.83414          250             1.51775
 164           1.90682          250             1.51775
 205           1.96779          250             1.51775
 246           2.01892          250             1.51775
 287           2.06181          250             1.51775
 328           2.09778          250             1.51775
 369           2.12795          250             1.51775
 410           2.15326          250             1.51775
 451           2.05079          250             1.51775
 474           2.00072          250             1.51775
```

The first data input to program REFUEL is the PHTS volume, which is 195,870 gallons. This excludes the heel of the storage vessels (Table IX) because it does not circulate with the main primary sodium during refueling.

The rate of contamination was obtained by multiplying the surface area of 171 core assemblies by the surface contamination of $.57 \times 10^{-4}$ lb/ft^2 and dividing by the PHTS sodium mass in millions of pounds and by the refueling time of 410 hours. Thus, the input rate of contamination is,

$$C4 = \frac{171 \times 190 \times .57 \times 10^{-4}}{1.374 \times 410}$$

$$= .00329 \text{ ppm/hr}$$

The minimum cold trap temperature and its margin are input at 250°F and 50°F, respectively. In the program the minimum cold trap temperature, which occurs at the bottom of the crystallizer tank, will automatically be set greater than 250°F whenever the saturation temperature corresponding to the PHTS concentration exceeds 300°F (250 plus the margin of 50). On the other hand, when this saturation temperature is less than 300°F, the margin becomes less than 50°F, because the minimum cold trap temperature is not permitted to drop below 250°F.

The input value of initial oxygen concentration is the steady-state normal operating condition. It is based on a constant oxygen source of 10^{-6} lb/min (9) and a 60 gpm cold trap with 70% efficiency. Computer program REFUEL was run until the transient died out to yield the steady-state value of 1.521 ppm of oxygen.

The input value of final oxygen concentration was taken as the maximum permissible concentration for a reactor system operating at a hot leg temperature ≥800°F, as specified by the RDT Standard A1-5(6). This is 2 ppm oxygen.

The output in Table XIII shows that the reference design, 80 gpm, cold trap will hold the oxygen concentration below 2 ppm during the 410 hour refueling time. Hence, no additional time beyond the refueling period is required and reactor operation could commence immediately.

The second part of Table XIII shows that with one-fourth flow rate in the cold trap (20 gpm) during refueling, the oxygen will rise to only 2.15 ppm in 410 hours and subsequently drop to 2 ppm in 64 hours. Since 75 hours are available after refueling because of necessary startup operations, the 80 gpm, FFTF Type I cold trap appears to provide a large margin of trapping capability for refueling operations.

B. TRAP CAPACITY

1. Oxygen

Experience with cold traps indicates that the wire mesh crystallizer section of a forced circulation cold trap has about 9.12 ~~20%~~(13) volume capacity when pressure drop for flow begins to increase sharply and end its useful life. The apparent density of the sodium oxide at this time is about 35 lb/ft^3 of wire mesh(14). INSERT A Then, the volume of crystallizer required per pound of oxygen is.

$$\frac{1}{\underset{12.95}{\cancel{35}}}\ \frac{\text{ft}^3\ (\text{mesh})}{\text{lb}\ (\text{Na}_2\text{O})} \cdot \frac{62\ \text{lb}\ (\text{Na}_2\text{O})}{16\ \text{lb}\ (\text{O}_2)} = \overset{.30}{\cancel{111}}\ \frac{\text{ft}^3\ (\text{mesh})}{\text{lb}\ (\text{O}_2)}$$

INSERT A: Assuming .3 ft^3 of mesh/lb of oxygen, the average density of the sodium oxide would have to be 12.95 lb/ft^3

2. Hydrogen

It was assumed that the volume capacity of the cold trap for collecting sodium hydride is the same as for sodium oxide* because no specific report of experience with sodium hydride could be found. The density of sodium hydride is 57 lb/ft^3, so the volume of crystallizer required per pound of hydrogen is,

$$\frac{1}{57}\ \frac{\text{ft}^3\,(\text{NaH})}{\text{lb}\ (\text{NaH})} \cdot \frac{\text{ft}^3\ (\text{mesh})}{\underset{.0912}{\cancel{0.2}}\ \text{ft}^3\ (\text{NaH})} \cdot \frac{24\ \text{lb}\ (\text{NaH})}{1\ \text{lb}\ (H_2)} = \overset{4.6}{\cancel{2.1}}\ \frac{\text{ft}^3\ (\text{mesh})}{\text{lb}\ (H_2)}$$

3. Lifetime

Trap lifetime was calculated for each operation (refueling, maintenance, etc.) and for oxygen and hydrogen separately; and a combined lifetime was determined. The lifetime for a single operation and for either oxygen or hydrogen was obtained by simply dividing the volume of the crystallizer element by the volume rate of accumulation of the particular impurity. As an example of the results of this calculation, the oxygen accumulation for normal operation including refueling is shown in Table II to be 2.4 lb/yr. This is the sum of the refueling oxygen from surface contamination or 1.85 lb/yr, plus the normal leakage or 0.5 lb/yr. The volume rate of oxide accumulation is therefore,

$$\dot{V} = \overset{2.35}{\cancel{.235}}\ \frac{\text{lb}\ (O_2)}{\text{yr}} \times \overset{.3}{\cancel{.111}}\ \frac{\text{ft}^3\ (\text{mesh})}{\text{lb}\ (O_2)}$$

$$= \overset{.705}{\cancel{.261}}\ \frac{\text{ft}^3\ (\text{mesh})}{\text{yr}}$$

---

* Although the 20% volume capacity was not applied directly in the oxygen calculation on the previous page, the apparent density used for Na_2O is essentially equivalent to 20% volume capacity when considering the uncertainties involved.

The lifetime of a single FFTF Type I trap for this operation alone would be,

$$t = \frac{59 \text{ ft}^3 \text{(mesh)}}{\underset{.705}{\cancel{261}} \text{ ft}^3 \text{(mesh)/yr}}$$

$$= \overset{84}{\cancel{226}} \text{ yr}$$

The combined lifetime of the PHTS cold trap was calculated as follows.

Trap volume consumed during initial cleanup (from Table II):

Oxygen	11.8	~~3.6~~	ft^3
Hydrogen	14.0	~~8.7~~	ft^3
Total	25.8	~~12.3~~	ft^3

Volume fraction of trap remaining and available is,

$$F_v(A) = \frac{59 - \overset{25.8}{\cancel{12.3}}}{59} = \overset{.512}{\cancel{.7915}}$$

Oxygen contamination = 2.4 + 2.0 = 4.4 lb/yr

Hydrogen contamination = 1.2 lb/yr

Trap capacity for oxygen = $59/\overset{.3}{\cancel{.111}} = \overset{197}{\cancel{530}}$ lb

Trap capacity for hydrogen = $59/\underset{4.6}{\cancel{2.1}} = \overset{12.8}{\cancel{28}}$ lb

The sum of the trap volume fractions consumed by the oxygen and hydrogen is equal to the trap volume fraction available:

$$F_v(0_2) + F_v(H_2) = F_v(A)$$

$$\frac{4.4\, t_c}{\underset{197}{\cancel{530}}} + \frac{1.2 t_c}{\underset{12.8}{\cancel{28}}} = \cancel{.7915}\ .512$$

$$t_c = \underset{4.4}{\cancel{15.5}} \text{ year = combined lifetime.}$$

The volume fraction of the trap consumed by oxygen is found as follows:

Initial cleanup takes $\overset{9.8}{\cancel{3.6}}$ ft^3

Other operations take

$$\frac{(4.4)(\overset{4.4}{\cancel{15.5}})(59)}{\underset{197}{\cancel{530}}} = \overset{5.8}{\cancel{7.6}}\ \text{ft}^3$$

$$F_v(0_2) = \frac{\overset{9.8}{\cancel{3.6}} + \overset{5.8}{\cancel{7.6}}}{59} = \overset{26}{\cancel{19}}\% .$$

Thus, about ~~81~~ 74% of the trap volume is consumed by hydrogen.

C. TRITIUM TRANSPORT

1. Steady-State

A description of the mathematical model and the assumptions made in the analysis of steady-state diffusion, cold trapping, and transport of tritium and hydrogen in an LMFBR heat transfer system ~~is being~~ has been reported separately(15). Briefly, this analysis considers primary and intermediate sodium loops coupled by an intermediate heat exchanger (IHX) with constant sources of tritium in the primary sodium and hydrogen in the intermediate sodium.* The concentrations of tritium and hydrogen in each loop are assumed to be uniformly distributed so that transport of these dissolved gases between loops, to the cell atmospheres, to cold traps, and to the steam generator are governed by mean concentration differences. The cold trapping rate is based on a specified flow rate and a removal efficiency of 70% (See Equation 1 for definition of α = efficiency.). Appropriate diffusion coefficients were applied for the diffusion through IHX tubes, piping walls, and steam generator tubes.

---

*Hydrogen source term for the primary sodium is also included.

The tritium sources are ternary fission reactions in the fuel pins and neutron capture reactions with boron of the control rods and lithium contaminant in the sodium. The major sources are fission and boron capture and these enter the sodium by diffusion through the cladding of these reactor components.

The hydrogen source is chemical corrosion reaction between steam in the superheaters with the 2 1/4 Cr - 1 Mo alloy steel tubes; and it enters the IHTS sodium by diffusion through the tube walls.

The tritium source is given as 89 Ci/day(16) and is based on 100% release of that produced.

The steady-state hydrogen flux through the superheater tubes is given as 2×10^{-11} lb H/ft^2 - sec and the applicable area is 5000 ft^2 of each superheater unit(3).

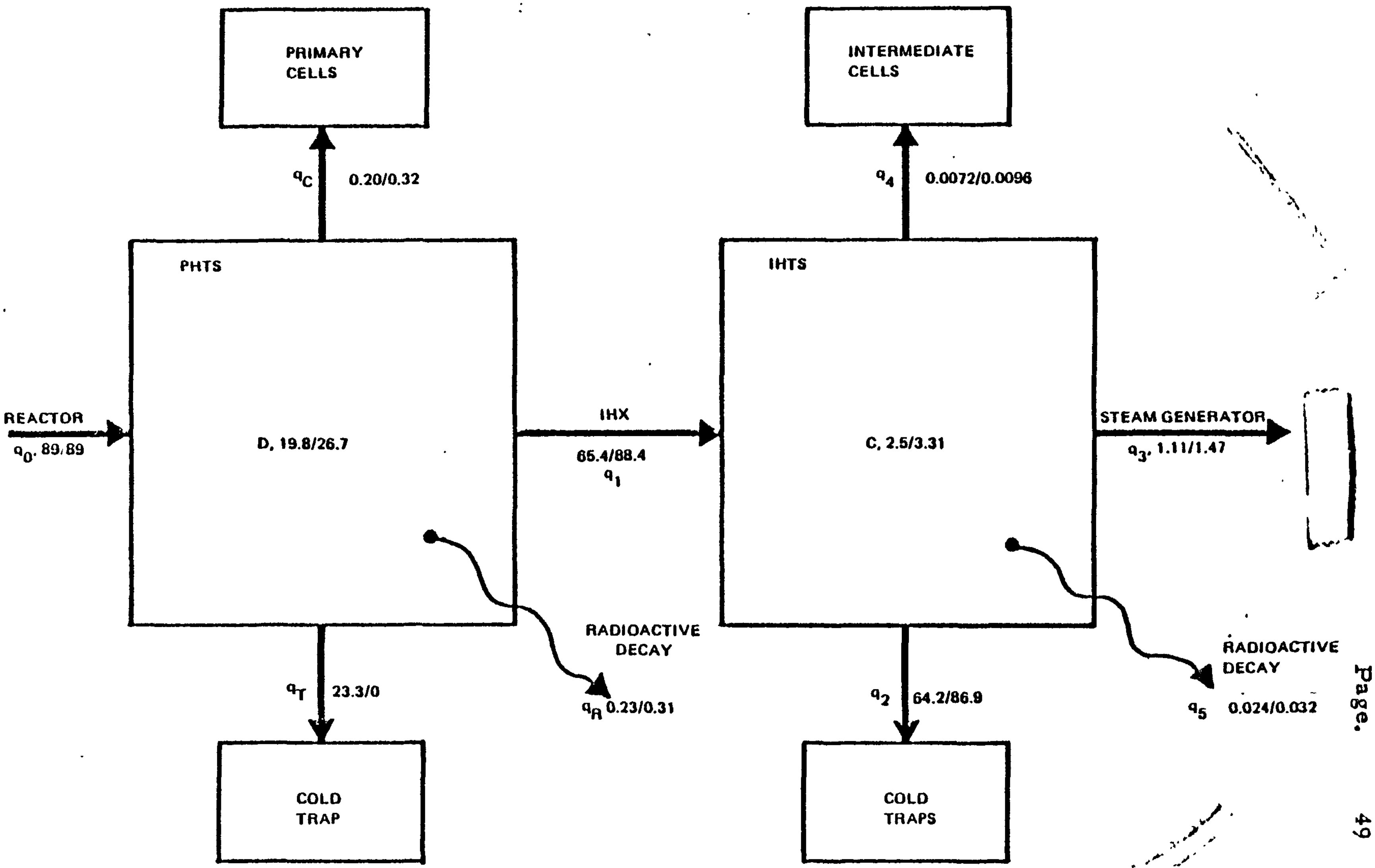
A summary of the input data to the calculation of nominal steady state conditions are given in Table V.

2. Transient

The following describes the transient caused by the shutdown of the PHTS cold trap. Initial and final conditions were obtained from the steady-state analysis, which is described in the previous section. The steady-state values of tritium flux and concentrations are shown in the block flow diagram of Figure 6. Tritium flux in Ci/day is identified by the q vectors, while D & C are the tritium concentrations in the PHTS and IHTS, respectively, μgm at T/mole Na x 10^4.

A tritium mass balance on the PHTS at time 0^+ when the cold trap is shutdown is,

$$q_o = q_1 + q_c + q_r + q_s \qquad \text{....(6)}$$



LEGEND: INITIAL VALUE/FINAL VALUE (IN TRANSIENT ANALYSIS)
q = FLUX (Ci/day) [(Ci/day)/2460 = μgm AT T/sec]
D AND C = CONCENTRATIONS (μgm AT T/mole Na x 10^4)

Figure 6. Tritium Flux and Concentration Diagram (Steady State Data with/without Primary Cold Trap Flow)

where all q's are defined in Figure 6 except q_s which is the rate of increase of tritium activity in the PHTS, or

$$q_s = M_P \frac{dD}{dt}$$

M_P = mass of PHTS sodium

t = time.

Substituting the mass of PHTS (1.374×10^6 lb) and appropriate dimensional conversion factors, we obtain the following expression when t is in hours.

$$q_s = 1853 \frac{dD}{dt} \text{(Ci/day)}$$

Other flux values are proportional to concentration differences, except q_o = 89 Ci/day. Thus,

$$q_1 = \frac{65.4}{17.3} (D - C)$$

$$q_c = \frac{.20}{19.8} D$$

$$q_r = \frac{.23}{19.8} D$$

Then, the mass balance, Equation 6, yields,

$$\frac{dD}{dt} = -.002052 D + .04803 + .002040C \qquad \text{....(7)}$$

A tritium mass balance on the IHTS at time 0^+ is (see Figure 6),

$$q_1 = q_2 + q_3 + q_4 + q_5 + q_6 \qquad \ldots.(8)$$

$$q_1 = \frac{65.4}{17.3}(D - C)$$

$$q_2 = K(C - C_e)$$

where

K = constant of proportionality

C_e = effective concentration leaving cold trap.

From the steady state values in Figure 6,

$$64.2 = K(2.50 - C_e)$$

$$86.9 = K(3.31 - C_e)$$

Therefore, $K = 28.0$, $C_e = .207$, and

$$q_2 = 28.0(C - .207)$$

$$q_3 = \frac{1.11}{2.5} C$$

$$q_4 = \frac{.0072}{2.5} C$$

$$q_5 = \frac{.024}{2.5} C$$

$$q_6 = M_I \frac{dC}{dt}$$

M_I = mass of IHTS sodium (1.125×10^6 lb)

$$q_6 = 1517 \frac{dC}{dt} \text{(Ci/day)}$$

Then, the mass balance, Equation 8, yields,

$$\frac{dC}{dt} = -.02125\,C + .003821 + .002492\,D \qquad \ldots.(9)$$

Equations (7) and (9) were solved simultaneously with computer program DIFEQ***, which is on file in the corporate timeshare computing system. The input and output are given in Table XIV. A plot of tritium concentrations vs time is shown in Figure 3.

VII. CONCLUSIONS AND RECOMMENDATIONS

The FFTF, Type I, 60-gpm, cold trap will easily satisfy the purification requirements of the PHTS. Initial cleanup will consume about 49 ~~20~~% of the trap volume, and enough capacity remains to provide a trap lifetime of about 4.4 ~~16~~ years. The trapping rate during refueling will hold oxygen and hydrogen concentrations below maximum operating limits. With nominal hydrogen source flux* from the steam generator, 26.2% of the tritium will be captured by this trap. Shutdown of the trap for repair or replacement by a standby while continuing reactor operation will increase tritium flux to the steam system from 1.11 to 1.47 Ci/day on a 600-hour time constant. Injection of hydrogen into the PHTS is an effective means of reducing tritium flux to the steam system.

A 60-gpm cold trap in each of the 3 IHTS loops will provide adequate cold trapping capability for oxygen, hydrogen, and tritium control. The 100 ft^3 crystallizer section volume, obtained by increasing the length of the FFTF Type I trap by 3 feet, will be 19.8 ~~8~~% consumed by initial cleanup of oxygen and hydrogen. The remaining volume capacity will provide a trap lifetime of about 4.33 ~~13~~ years. When there is nominal hydrogen flux* from the steam generator, 73.8% of the tritium together with 97.1% of the hydrogen will be captured in the 3 IHTS cold traps.

---

* 2×10^{-11} lb H_2/sec-ft^2 through 5000 ft^2 of each superheater.

TABLE XIV

COMPUTER SOLUTION OF TRITIUM TRANSIENT EQUATIONS

$$\frac{dC}{dt} = .003821 - .02125C + .002492D$$

$$\frac{dD}{dt} = .04803 - .002052D + .002040C$$

```
LIST


TRIT      16:18  MR T/S MAY 20, 1974

1100 AR(1) = .003821
1110 AR(2) = .02125
1120 AR(3) = .002492
1130 AR(4) = .04803
1140 AR(5) = .002052
1150 AR(6) = .002040
1300 U(1) = 2.5
1310 U(2) = 19.8
2300 PRINT 232 , T, U(1), U(2)
2310 232 FORMAT( F5.1, 2F12.6)
2320 IF( U(2) .GT. 1000.) LF = .TRUE.
3100 DU(1) = AR(1) - AR(2) * U(1) + AR(3) * U(2)
3110 DU(2) = AR(4) - AR(5) * U(2) + AR(6) * U(1)

OK
EDI WEA DIFEQ***, TRIT

OK
340
RUN


TRIT      16:19  MR T/S MAY 20, 1974


 CASE   RR    T(0)   DT   FT   N
 ? 1, 50, 0, .2, 1000., 2

CONSTANT VALUES
 ? 6

PARAMETRIC VALUES
 ? 2
```

(Continued on next page)

TABLE XIV (Continued)

t = hours C&D = μ gm mole Na x 10^4

t	C	D	t	C	D
0.0	2.500000	19.800000	510.0	2.956658	23.933353
10.0	2.501782	19.923744	520.0	2.962941	23.982416
20.0	2.505972	20.045035	530.0	2.969113	24.030608
30.0	2.512055	20.163968	540.0	2.975175	24.077945
40.0	2.519617	20.280624	550.0	2.981129	24.124441
50.0	2.528325	20.395074	560.0	2.986978	24.170113
60.0	2.537910	20.507386	570.0	2.992722	24.214973
70.0	2.548157	20.617617	580.0	2.998365	24.259038
80.0	2.558894	20.725821	590.0	3.003908	24.302320
90.0	2.569981	20.832048	600.0	3.009353	24.344835
100.0	2.581308	20.936344	610.0	3.014700	24.386595
110.0	2.592786	21.038752	620.0	3.019953	24.427613
120.0	2.604344	21.139312	630.0	3.025113	24.467904
130.0	2.615926	21.238064	640.0	3.030181	24.507479
140.0	2.627487	21.335044	650.0	3.035159	24.546352
150.0	2.638992	21.430287	660.0	3.040049	24.584536
160.0	2.650413	21.523827	670.0	3.044852	24.622041
170.0	2.661728	21.616696	680.0	3.049570	24.658881
180.0	2.672920	21.705927	690.0	3.054204	24.695067
190.0	2.683977	21.794550	700.0	3.058756	24.730611
200.0	2.694888	21.881595	710.0	3.063227	24.765524
210.0	2.705646	21.967091	720.0	3.067619	24.799817
220.0	2.716246	22.051065	730.0	3.071932	24.833502
230.0	2.726685	22.133547	740.0	3.076170	24.866588
240.0	2.736961	22.214562	750.0	3.080332	24.899088
250.0	2.747071	22.294138	760.0	3.084420	24.931011
260.0	2.757015	22.372300	770.0	3.088435	24.962367
270.0	2.766795	22.449073	780.0	3.092379	24.993167
280.0	2.776410	22.524483	790.0	3.096254	25.023420
290.0	2.785861	22.598554	800.0	3.100059	25.053136
300.0	2.795151	22.671310	810.0	3.103797	25.082325
310.0	2.804281	22.742774	820.0	3.107469	25.110995
320.0	2.813252	22.812969	830.0	3.111075	25.139157
330.0	2.822068	22.881917	840.0	3.114618	25.166819
340.0	2.830729	22.949642	850.0	3.118097	25.193990
350.0	2.839239	23.016165	860.0	3.121515	25.220679
360.0	2.847599	23.081507	870.0	3.124872	25.246894
370.0	2.855812	23.145689	880.0	3.128170	25.272644
380.0	2.863881	23.208732	890.0	3.131409	25.297937
390.0	2.871807	23.270656	900.0	3.134591	25.322781
400.0	2.879593	23.331480	910.0	3.137716	25.347184
410.0	2.887242	23.391226	920.0	3.140785	25.371154
420.0	2.894755	23.449910	930.0	3.143801	25.394698
430.0	2.902135	23.507553	940.0	3.146762	25.417825
440.0	2.909385	23.564174	950.0	3.149671	25.440541
450.0	2.916506	23.619789	960.0	3.152529	25.462854
460.0	2.923501	23.674417	970.0	3.155336	25.484771
470.0	2.930372	23.728075	980.0	3.158093	25.506299
480.0	2.937121	23.780781	990.0	3.160801	25.527445
490.0	2.943750	23.832552	1000.0	3.163460	25.548216
500.0	2.950262	23.883404	1010.0	3.166073	25.568618

Because of the importance of maintaining continuous and reliable tritium control, it is essential that the necessary hydrogen source strength be assured. It would be fortuitous if the water corrosion in the steam generator at all times supplied the optimum quantity of hydrogen for the cold trapping process. Hence, it is recommended that an additional controllable hydrogen source be provided in order to assure that the tritium will be collected most effectively in the particular cold traps installed.

With a minimum hydrogen flux from the steam generator (10^{-11} lb/sec-ft^2), tritium to the steam generator almost doubles (compared to nominal conditions) to 2.12 Ci/day. If hydrogen were then injected into the PHTS in an amount equal to 20% of the minimum flux from the steam generator (12 SCFM/loop injection), the tritium flux to the steam system would drop from 2.12 to 1.14 Ci/day.

The results and conclusions in this report are based on a cold trap efficiency of 70% for both sodium oxide and sodium hydride removal. The performance of the proposed cold traps, particularly from the standpoint of coprecipitation of hydrogen and tritium through differential solubility, has not been conclusively demonstrated by actual experience. For this reason, tests have been recommended in the AEC LMFBR Development Program to determine the effectiveness of this scheme for controlling and collecting tritium and to measure cold trap efficiencies for removing oxygen, hydrogen, and tritium.

VIII. REFERENCES

1. TI-099-811-002, "Preliminary Requirements for Primary System Cold Traps," H. L. Sletten, September 12, 1973
2. IL, J. Guon to H. L. Sletten, "Calculation of Simultaneous Hydrogen-Tritium Transport in CRBRP," June 3, 1974
3. GE Letter D590-74-104. G. Billuris to W. T. Morgan, "Design Information for IHTS Purification System," April 30, 1974
4. HWS-1147, Specification for Revision 1, "Forced Circulation Cold Trap Assemblies for Removal of Sodium Impurities from FFTF and HTSF," C. L. Peckinpaugh and J. W. Hess, October 27, 1971
5. AI Letter 74AT2904, R. C. Gerber to Dr. W. M. Jacobi, "System 81 Input to Primary Na Makeup Requirements," May 7, 1974
6. RDT Standard A1-5, "Purity Requirements for Operating Sodium Reactor Systems," May 1973
7. SDD 41 Rev. 0, Reactor Refueling System, April 1, 1974
8. SDD 81 Rev. 0, Auxiliary Liquid Metal System, October 31, 1973
9. W—ARD Letter LEM-73-95 "LMFBR Demonstration Plant Project; Transmittal of Primary and Sodium Impurity Source Items," J. Kenney, August 29, 1973
10. K. G. Eickhoff, et al, "Engineering Development for Sodium Systems," London Conference on Fast Breeder Reactors, British Nuclear Engineering Society, May 17 - 19, 1966
11. LA—3879-MS, "Determination of the Solubility of Oxygen in Sodium Using the Vacuum Distillation Analytical Technique," V. J. Rutkauskas, August 30, 1967

RDT Standard F3-40T, "Methods for the Analysis of Sodium and Cover Gas," Amendment No. 2, Aug 1974

12. ~~AEDA-241, "The Solubility of Hydrogen in Liquid Sodium," S. A. Meacham, E. F. Hill and A. A. Gordus, June 1970~~

13. J. G. Yevick, Editor, "Fast Reactor Technology: Plant Design," The MIT Press, 1966

14. NAA-SR-3638, "Control of Oxygen Concentration in a Large Sodium System," R. B. Hinze, December 1, 1959

15. ~~R. L. McKisson and J. Guon, Atomics International, report to be published~~ TI-099-331-015, "The Evaluation of Tritium Transport in CRBRP," R. L. McKisson and J. Guon, Dec. 2, 1974

16. W—ARD Letter WA40052, "Clinch River Breeder Reactor Plant: Tritium Release from B_4C Control Rods in CRBRP," J. Kenney, March 14, 1974

17. PMC Ltr 24.06, Peter S. Van Nort to D. R. Riley, "Tritium in the Balance of Plant (BOP)," May 1, 1974

18. GE Letter D590-74-155, "Purification of IHTS Sodium After Emergency Dump", G. Billuris, June 18, 1974.

19. TI-099-811-011, "Cold Trapping Requirements for EVST and FHC Sodium Systems", H. L. Sletten, to be issued.

IX. APPENDIX

A. Steam Generator Leak and Emergency Dump

1. Description

General Electric Co. has supplied(18) information on the basis for providing cold trap capability to clean up the IHTS loop sodium in the event of a leak in a steam generator with and without emergency dump of the sodium. Leaks were classified as small, intermediate, and large according to leak rate and total amount of water entering the sodium. This classification as to size of leak is depicted in Figure A-1. The frequency of each is also shown.

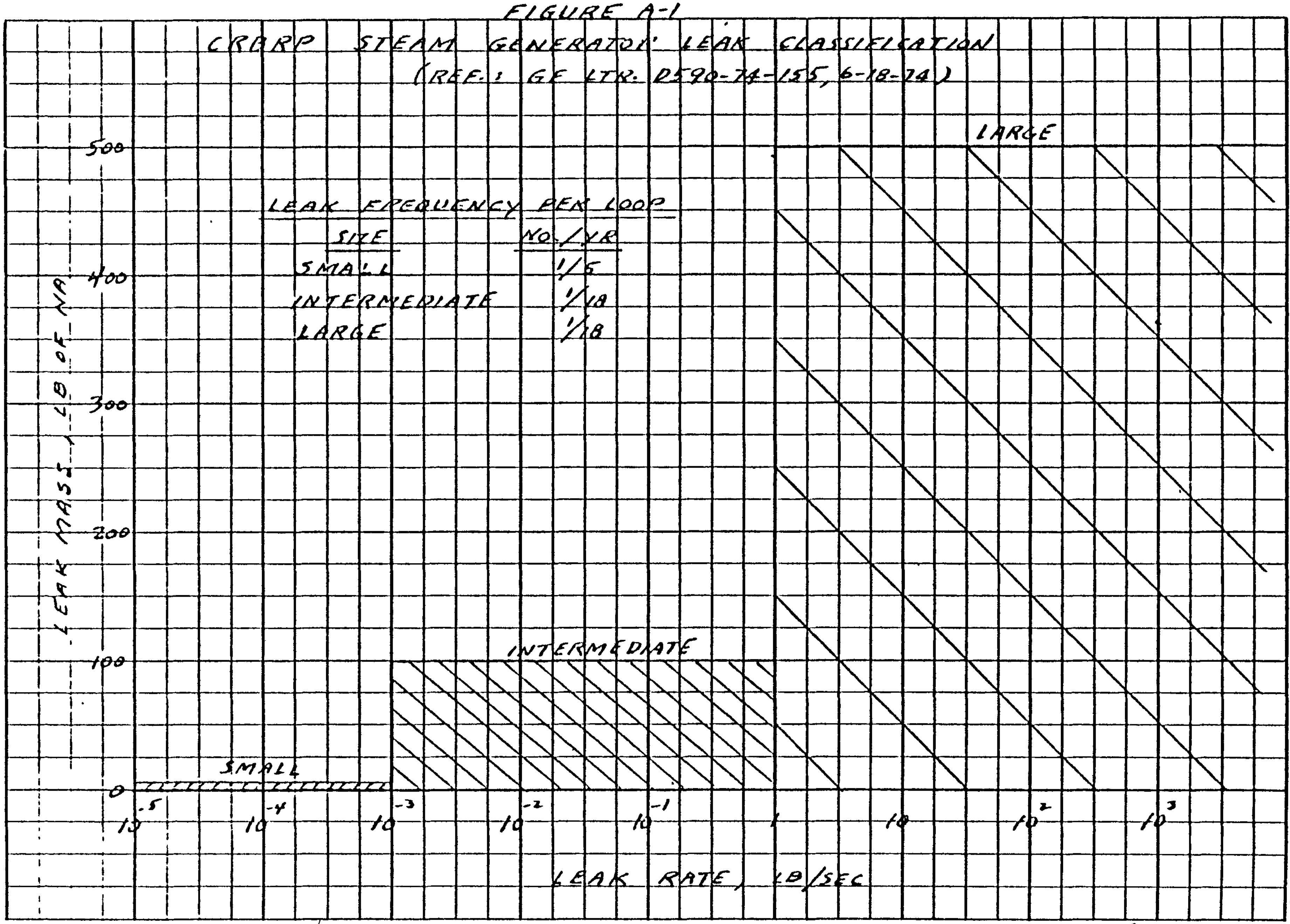
IHTS relief and emergency dump of the loop contents will occur for large and possibly upper intermediate leaks. Leaks up to average "intermediate" size will not cause or require system drain, and therefore, the particular cold trap(s) in that loop will be required to clean up all the oxygen and hydrogen contamination caused by the leak before the loop is put back in operation. In the case of emergency dump most of the reaction products will precipitate at the bottom of the dump tank, and the cold trap(s) will only be required to reduce the concentrations of oxygen and hydrogen from a saturated condition of 400°F to their normal concentrations for operation (2 ppm for O_2, and .1 ppm for H_2). This turns out to be only a small fraction of the total leak.

2. Cleanup Requirements

Table A-I describes the specific leaks of Figure A-1, which were considered to effect the cold trap requirements for steam generator leaks, and gives the trap volume consumed per year on the average and the trapping time required for cleanup. The leaks were further divided from that in Figure A-1 in the intermediate size because of the possibility(18) of emergency dump due to a leak in the upper intermediate range. The frequency for these three leaks was assumed to be each one-third of the overall frequency(18) for intermediate leaks.

FIGURE A-1

CRBRP STEAM GENERATOR LEAK CLASSIFICATION
(REF.: GE LTR. D590-74-155, 6-18-74)



LEAK FREQUENCY PER LOOP

SIZE	NO./YR
SMALL	1/5
INTERMEDIATE	1/18
LARGE	1/18

NLS, 8-1-74

Capacity requirements are given in Table A-I in terms of pounds (O_2 or H_2) and cubic feet of crystallizer consumed (by oxide or hydride) per year on the average according to the indicated frequencies of these leaks. It is seen that the total volume consumed by O_2 and H_2 is 3.89 ~~1.60~~ ft^3/yr.

The lifetime of a first-in-plant IHTS loop cold trap will potentially be reduced to 3.46 ~~10.7~~ years from 4.33 ~~12.4~~ years because of the probability of steam generator leaks. Of course, use of the standby trap in each loop, or distributing the cleanup from steam generator leak which involves emergency dump, can extend the change-out time for the first trap beyond 3.46 ~~10.7~~ years.

The time required for cleanup after all steam generator leaks is well within the time needed to repair the leak for subsequent operation (several weeks(18)). Table A-I shows a maximum cleanup time of 223 hours (1.33 weeks) for leaks that do not involve emergency dump. In the event of emergency dump, the time required to reduce the oxygen concentration in the dump tank from saturation concentration at 400°F to 2 ppm is about 4 days. During this time the hydrogen concentration will be reduced to $< .1$ ppm. Of course, there are other time consuming cleanup operations that will be required as a result of emergency dump, which have not been considered here. This might involve removal of sodium-water reaction products from the dump tank, which are expected(18) to precipitate from the sodium following dump and cooling to 350-400°F.

3. Calculations

a. Loop Size

The largest of the 3 IHTS loops was chosen for the analysis because it would take the largest cleanup time although the maximum

TABLE A-I

IHTS LOOP COLD TRAP REQUIREMENTS FOR S. G. LEAK AND EMERGENCY DUMP

Leak Type[(a)]	Emergency Dump	Leak Rate lb/sec	Leak Amount lb	Frequency no. /yr	Cold Trap Capacity Required				Leak Time hr	Trapping Characteristics			
					Oxygen		Hydrogen			Oxygen		Hydrogen	
					lb/yr	ft^3/yr	lb/yr	ft^3/yr		Max Conc. ppm	Cleanup Time hr	Max Conc. ppm	Cleanup Time hr
Small	No	10^{-3}	5	1/5	.89	.099	.111	.511 ~~.234~~	1.4	12.77	93.8	1.446	92.9
Intermediate:													
Lower	No	10^{-3}	100	1/54[(b)]	1.65	.445 ~~.183~~	.206	.948 ~~.434~~	28	158	199	20.4	209
Ave.	No	10^{-2}	100	1/54	1.65	.445 ~~.183~~	.206	.945 ~~.434~~	2.8	218	213	27.0	223
Upper	Yes[(c)]	10^{-1}-1.	100	1/54	.084	.025 ~~.0093~~	.0067	.031 ~~.014~~	≤ .28	13.0	94.4	.973	78.0
Large	Yes[(c)]	1.	500	1/18	.253	.076 ~~.0281~~	.0200	.072 ~~.042~~	≤ .14	13.0	94.4	.973	78.0
				Totals	4.53	1.358 ~~.502~~	.550	2.55 ~~1.16~~					

(a) Definition of leaks in accordance with GE Ltr. D590-74-155, June 18, 1974 (Ref. 18)

(b) Frequency of all intermediate leaks is one per 18 years.

(c) Emergency dump occurs for upper intermediate and large leaks (Ref. 18). Cleanup by cold trap consists of reducing concentration of O_2 and H_2 from saturation at 400°F to 2 ppm in the case of O_2 and .1 ppm in the case of H_2 for largest loop volume.

concentration of reaction products would occur in the smaller loops for a given size of leak. A longer trapping time is apparent in the case where the loop is dumped because the starting concentration for cold trap cleanup is the same for all loops (saturation concentration at 400°F), independent of volume. Hence, the larger volume takes longer to purify for a constant cold trap flow. Therefore, from Table X, page 33, we have,

Volume = 7543 ft^3

At 600°F, sodium density = 54.7 lb/ft^3 and

Mass = 412,600 lb

b. Small Leak

At the rate of 10^{-3} lb/sec, 5 lb of water will leak in 1.39 hours. The concentration of oxygen in the 412,600 lb of sodium will increase by,

$$\frac{5 \text{ lb } H_2O}{.4126 \text{ million lb Na}} \times \frac{16 \text{ lb } O_2}{18 \text{ lb } H_2O} = 10.77 \text{ ppm}$$

The hydrogen concentration will increase by,

$$\frac{5 \text{ lb } H_2O}{.4126 \text{ million lb Na}} \times \frac{2 \text{ lb } H_2}{18 \text{ lb } H_2O} = 1.346 \text{ ppm}$$

The trapping time required for a 60-gpm cold trap to restore the oxygen concentration to 2 ppm after the addition of 10.77 ppm was determined by timesharing computer program C0TRAP(19). The minimum cold trap temperature was set at 250°F; however, with the 50°F temperature margin requirement, the initial minimum cold trap temperature for 12.77 ppm system oxygen concentration is 369°F. As the system is purified the minimum cold trap temperature is dropped until it hits the 250°F minimum.

The trapping time required for the hydrogen (i. e., to reduce its concentration from 1.446 to .1 ppm) was determined with program H2CLUP(19), which is basically the same as C0TRAP with the same minimum temperature restrictions, except that it incorporates the solubility of hydrogen in sodium.

c. Minimum Intermediate Leak

The rate of leak is the same as the small leak (10^{-3} lb/sec), but the amount of leak is 20 times larger or 100 lb of water. The duration of the leak becomes 28 hours. To handle the situation where contamination is added to a system while it is being cold trapped, timesharing program REFUEL(19) was written. In this particular case oxygen is added at the rate of 7.7 ppm/hr for 28 hours. The oxygen concentration increases from 2 to 158 ppm at 28 hours, then is restored to 2 ppm in an additional 199 hours.

Program HTCT(19) was used to evaluate the hydrogen transient. The concentration increases from 0.1 to 20.4 ppm in 28 hours, then decreases to 0.1 ppm in an additional 209 hours.

Comparing the oxygen and hydrogen transients, it takes 10 hours more to restore the hydrogen concentration to its original level.

d. Average Intermediate Leak

This leak is the same as the minimum intermediate leak except that it is 10 times faster. The 10^{-2} lb/sec leak of 100 lb of water takes 2.8 hours. This time is short compared to cleanup time so it was assumed the 100 lb leak occurs instantaneously. Therefore, program C0TRAP could be used. The cleanup time obtained is 213 hours, when starting with an oxygen concentration of 217 ppm.

Program H2CLUP was used to calculate the cleanup time for hydrogen. This time is 6 hours longer than for oxygen, or 223 hours. The initial hydrogen concentration in this case is 27 ppm.

e. Upper Intermediate and Large Leaks

These leaks cause system relief and emergency dump. Both result in the same cleanup problem from the standpoint of the cold trap(s). This consists of reducing the concentrations of oxygen and hydrogen from their saturated condition at 400°F to 2 ppm in the case of oxygen and 0.1 ppm in the case of hydrogen. The mass of sodium to be purified is the contents of the largest IHTS loop or 412,600 lb.

The saturation concentration of oxygen in sodium at 400°F is 13.02 ppm. Then, the amount of oxygen to be removed is,

$$w(O_2) = (13.02 - 2.0)\ 10^{-6} \times .4126 \times 10^{6}$$
$$= 4.55 \text{ lb } O_2$$

The saturation concentration of hydrogen in sodium at 400°F is .973 ppm. Then, the amount of hydrogen to be removed is,

$$w(H_2) = (.973 - .1)\ 10^{-6} \times .4126 \times 10^{6}$$
$$= .360 \text{ lb } H_2$$

The times required to remove this oxygen and hydrogen were determined by timesharing programs COTRAP and H2CLUP, to be 94.4 and 78.0 hours, respectively.

f. Cold Trap Lifetime

The lifetime of the first IHTS cold trap when steam generator leaks are neglected was estimated to be 13.4 years (Table IV, p. 15).

Including the accumulation rates of oxygen and hydrogen in the cold trap due to leaks (Table A-I) together with the rates of Table IV, we have,

$$\dot{w}(O_2) = .27 + 1.0 + 4.53 = 5.8 \text{ lb } O_2/\text{yr}$$
$$\dot{w}(H_2) = 3.2 + .55 = 3.75 \text{ lb } H_2/\text{yr}$$

The trap capacity for oxygen is ~~900~~ 333 lb or the capacity for hydrogen is ~~47~~ 21.74 lb (see p. 8). Initial cleanup of the IHTS consumes ~~8~~ 17.9% of the trap, leaving ~~92~~ 82.1% for subsequent operations. Letting t_c equal trap lifetime in the sum of the trap volume fractions consumed by oxygen and hydrogen:

$$\xcancel{\frac{5.8\, t_c}{900} + \frac{3.75\, t_c}{47} = .92}$$

$$\xcancel{t_c = 10.67 \text{ years.}}$$

$$\frac{3.6}{21.74} + \frac{3.75\left(t_c - \frac{1000}{24 \times 365}\right)}{21.74} + \frac{5.8\, t_c}{333} = .8212$$

$$t_c = 3.56 \text{ years}$$

([illegible] initial high H_2 flux and steam generator leak probability.)