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FROM: L. F. Parsly, Jr., H. L. Falkenberry, and I. M. Miller

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Summary

Run SM-2 was an exploratory run to determine whether a sulfated thorium oxide slurry could be handled in a hydrodynamic system similar to the Homogeneous Reactor Test blanket. It was found that the thorium oxide concentration circulating in the pipes was consistently 50% or less of the expected concentration based on the quantity of oxide charged, and tended to decrease with time. Thus some modifications to the blanket itself are required to assure thorough mixing and a uniform slurry concentration.

The run lasted 1730 hours. It was terminated because of a slurry leak a few days before a shut-down had been scheduled. A heavy slurry bed was found in the bottom of the blanket at the end of the run, but this was easily removed by repeated rinses.

Severe erosion was found in the pump impeller and flow nozzle, with indications from the flow nozzle that the critical velocity for attack was 35 ft/sec. The generalized corrosion rate calculated from dissolved iron pick-up was 0.95 mil/year, but oxygen consumption during the run indicated a substantially higher attack rate. It is believed that the generalized corrosion rate figure has little meaning because of the heavy attack in localized areas.

Chloride concentration high enough to cause concern over possible stress corrosion cracking occurred on several occasions in the pressurizer, and indications of surface defects were found by dye-penetrant examination. Metallographic examination of the defects, however, indicated that these were the results of flaws in the ingot from which the pipes were formed.

The system is being reassembled for another exploratory run with slightly higher flows (300 vs 230 gpm) and cut-down blanket inlet nozzles to increase the velocity of the inlet jets.

Introduction

The slurry blanket test facility is a circulating loop designed to duplicate the HRT blanket system insofar as practicable. The pump is identical to the HRT blanket pump and the internal dimensions of the pressure vessel are the same. The core duplicates the HRT core dimensionally, but is made of stainless steel. The piping is of approximately the same complexity but is somewhat different geometrically. The system is limited to operating at pressures of 375 psi or less since the pressure vessel shell is only 1/2-in. thick, and the pressure was actually limited to about 275 psi for the present run by the rupture disc rating. The system is described in detail in Appendix B.

Run SM-2 is the first run made on the slurry blanket test facility with the dummy reactor included in the system. It was planned as an exploratory run with the hope that it would demonstrate that ThO_2 slurry containing about 3000 ppm sulfate, based on thorium, at concentrations up to at least 1000 g Th/kg H_2O could be used in the HRT blanket in its present form.

Description of the Run

After hydrostatic testing and repairing leaks until a leak-down rate of less than 10 psi per hour from a pressure of 360 psi was maintained for over 24 hours, the system was brought to 230 psi and started up on water on November 19, 1956. It was then brought to 170°C. Figures 1, 2 and 3 show the behavior of significant operating variables during the run.

After 44 hours running time on water, loading of oxygen was started and a total of 700 liters (stp) was loaded between 44 and 76 hr running time. After 300 liters had been loaded, events occurred which are not recognized as indicative of saturation; however it was felt on the basis of available solubility data[4] that the system should be capable of dissolving 720 liters, which represents 500 ppm based on water, so this much was charged. A check of other solubility data[5] indicated that at 170°C and 230 psig the solubility limit is 406 ppm and the maximum which can be dissolved in the loop is approximately 485 liters.

The excessive oxygen in the system complicated operations considerably during the succeeding 100 hours. Bubbles of oxygen worked their way into the back of the pump, causing gas binding, and a sizable gas pocket collected in the spool piece on the top of the pressure vessel. These accumulations were vented out of the system as necessary and after the 100 hours stable operation was re-established.

Meantime, slurry charging was started at 92 hr. The acid egg system (see appendix) was used to feed slurry into the main circulating loop downstream of the pressurizer, and a corresponding quantity of water was withdrawn from the top of the pressurizer.

Slurry loading was continued to give a calculated thorium concentration of 200 g Th/kg H_2O by 255 hr. At that point the seal on the slurry transfer pump failed and the feed system was down until 535 hr, when spare parts were obtained from the manufacturer and installed. Loading was resumed and sufficient additional slurry to bring the charge to 498 g Th/kg H_2O was charged to the system by 687 hr.

As the charge was increased, analytical results consistently indicated that the concentration circulating through the piping was only about 50% of the calculated charge. Samples from the bottom of the blanket were consistently higher in concentration, but below the charged concentration; e.g., at 730 hr the circulating concentration was approximately 250 g Th/kg H_2O while the lower blanket sample was 340 g Th/kg H_2O. Samples taken from the top of the blanket ran consistently about half the concentration of the samples from the bottom of the blanket. At first it was felt that the discrepancy might be accounted for by slurry coatings forming on the surfaces in the loop and by deposits in various pockets. However, the mass of slurry which was un-accounted-for eventually became so great that obviously most of it had to be in the blanket and the concentration in the blanket could not be uniform. With the sampling and gamma survey facilities available, this was as much as could be determined.

Since the Pressure Products valve in the feed line had started to leak across the seat near the end of the charging, it was decided to replace the valve and the loop conditions were reduced to below 100°C and 50 psi between 800 and 900 hr. On depressuring, difficulty was experienced after the pressure was dropped to 100 psi, due to evolution of dissolved gas. The balance of the pressure reduction had to be made very slowly, with venting of the dissolved gas from time to time.

Flowmeter and power readings increased during the period of low temperature and pressure operation to a greater extent than would be accounted for by the density change due to cooling.* Analyses showed that the circulating concentration increased by approximately 50%. The flow and power readings indicate that the increase in circulating concentration was associated with the de-pressuring operation rather than cooling and actually occurred at the time the pressure decreased below that necessary to maintain the gas in solution.

The valve replacement was completed on December 27 and the loop was brought back to operating conditions of 220 psi and 180°C at 930 hr. The circulating concentration dropped and by 1070 hr it was definitely below that obtained immediately after charging the loop.

During the period 950 to 1240 hr, efforts were concentrated on building up the oxygen concentration. It was discovered that saturation could be detected by a rise in pressurizer level and a procedure of dropping the blanket pressure 20 psi, adding oxygen until the rise was seen, and returning to the original operating pressure was adopted. Unfortunately, it appears that when the pressure was reduced, nitrogen leaked into the blanket from the core and the observed saturation was probably with respect to nitrogen rather than oxygen.

At 1142 hr, with the system temperature at 182.5°C, a sudden drop in pump power and flowmeter reading occurred. It was inferred that this was due to a loss of slurry from the circulating stream since settling rate studies on slurry taken from the loop had indicated that there was a marked increase in settling rate between 150° and

* Since the flowmeter reads in inches of water, the reading changes with density.

200°C.[3] Conversely, on dropping the temperature to 175°C the power and flow readings returned to their original values. The same phenomenon was repeated on several other occasions. It is interesting to note, however, that this sensitivity to temperatures above 180°C did not appear during the first half of the run.

At 1230 hr the pump sounded particularly noisy. Since gas binding might be involved, the pump was stopped and vented, but a negligible quantity of gas was removed. When slowing down, the pump sounded as though the bearings were rubbing. It was observed that the armored rotameter metering the process fluid circulating in the back of the pump did not respond properly and the pipes connected to the rotameter were hammered to try to free the rotameter bob. Unexpectedly, the pump quieted down, and the temperature at the Kingsbury bearing level dropped from 125°F to 105°F. The quiet operation continued for only about two hours, and the temperature at the Kingsbury bearing level started to increase. For the balance of the run, the hammering on the pipes connecting to the armored rotameter was done at intervals of two to four hours. By this means, it was possible to maintain the bearing temperature below 110°F and to minimize the vibration of the pump although the procedure became less effective toward the end of the run.

At 1237 hr, the pump was stopped for 5 minutes and a sample taken from the lower sphere sample point in an effort to determine the bed density in the blanket. The sample concentration with the pump stopped was 1070 g Th/kg H_2O compared to 480 g Th/kg H_2O at this point with the pump running. At 1256 hr, a similar experiment was run, except that samples were taken continuously for 5 minutes after stopping and for 4-1/2 minutes after restarting. The results are shown in Fig. 4.

To investigate the decrease in slurry concentration which occurred with a temperature increase above 180°C, the loop temperature was increased to 200°C between 1300 and 1400 hr. The results are shown in Fig. 3. The period of 1310 to 1350 hours is the operation at 185°, 1360 to 1380 hours at 193°, and 1380 to 1400 hours at 200°. The greatest change in the operating variables obviously occurred as the temperature was raised from 175 to 185°, and lesser, but definite effects are apparent up to 200°. Figure 5 shows the loop flowmeter reading and thorium concentrations from the pipeline, top of the blanket and bottom of the blanket during this period. While at 200°, the experiment of stopping the pump and observing the slurry concentration change was repeated. The results are shown in Fig. 6. It will be noted that the maximum concentration obtained is appreciably higher (1420 vs 1160 g Th/kg H_2O) than in the earlier experiment at 175°C, and also that the concentration apparently had not reached its maximum value in the 200° experiment after 5 minutes, although it appeared to have done so before.

At 1567 and 1590 hr, 270 and 135 liters of oxygen were fed without reducing system pressure. This was rapidly consumed since samples taken very shortly after the oxygen additions showed 193 and 135 liters in solution, respectively.

At 1650 hr, a leak to atmosphere was found in the core-to-blanket relief valve of the pressure balancing system. This resulted in a continuous loss of water inventory and it became necessary to feed makeup water periodically to maintain the temperature in the desired range.

At 1730 hr, a leak was found in one of the observation port flanges on the pressure vessel. During the subsequent shutdown it was found that the flange surface was not flat, the leak area being approximately 1/32" low. Since slurry was being discharged through this leak, it was necessary to stop the run. Initially, an attempt was made to use the let-down valve to release the charge to the storage tanks. This initially worked but plugged in a short time. The dump valve was then tried. Some difficulty was experienced in getting the circuit to function and an excessive amount of cooling water was run into the tanks prior to actually starting the dump. As a result, only about half of the charge could be dumped before the storage tank high level interlock closed the dump valve.

The excess water was decanted from the tanks, the cooling water interlock was shorted out so that the dump could be finished without using cooling water, (since the temperature had fallen to 125°C) and dumping was completed approximately 5 hours after the initial shutdown.

After cleaning up the spilled slurry and stripping off all of the insulation, the ports on the blanket were opened. A bed of slurry remained in the bottom of the sphere about 11 to 13 inches deep and it had a concentration of 1970 g Th/kg H_2O. It is estimated to have contained approximately 300 kg of Th or almost 50% of the charge to the loop. Figure 7 is a photograph of this slurry bed, taken through an inspection port directly above the east inlet. The hole in the bed is at the east inlet. The west inlet was completely covered. The craters in the bed surface are probably due to escaping bubbles of steam or gas.

Figure 8 shows the top of the core and the exit pipe assembly. The core was slightly off center so that the annular opening is greatest at the southwest and least at the northeast. (The pipe to the outlet nozzle on the outer shell runs south.) Some of the dry lumps which show in this photograph were examined for disintegration characteristics. It was concluded that these were simply thick slurry which had dried out. Larger lumps were piled on top of the horizontal pipe at the left in the photograph.

After examining the interior of the blanket, the inspection ports were closed with lucite covers and the blanket was filled. During the filling it was noted that the meniscus of the water rising along the metal surfaces covered with dried slurry film was of the mercury-in-glass type rather than the water-in-glass type. Water flowed into the blanket through the east inlet only.

Circulation was maintained for five hours and the system was dumped and inspected. Figures 9 and 10 show the slurry in the bottom after the first rinse. It will be noted that the slurry was well suspended in front of the nozzle over an arc of about 90° but that the original bed is untouched in the section behind the nozzle (extreme right of Fig. 9) and in the sector 90° to 135° in front of the nozzle (left of Fig. 10). During the rinse run the circulating concentration was approximately 65 g Th/kg H_2O.

A second rinse was then made, which removed a good deal more slurry but did not affect the big pile-ups in the northeast and southwest. This material was then manually spread out into the areas where the nozzles appeared to be effective in dispersing the slurry and a third rinse was made. This successfully suspended the remaining thorium, except for a few pockets such as observation ports. After digging the slurry out of the ports and breaking up adhering slurry along the walls, a fourth rinse completed removal of the solids from the blanket to the point where rinsing down with distilled water and siphoning the liquid below the inlets was all that was required to complete cleaning the blanket.

Corrosion and Erosion

The corrosion and erosion in the system experienced in the run have been followed in three different ways: by following the increase in the iron associated with the thorium as the run progressed, by oxygen consumption, and by examination of the system after shutdown. The first two methods permit calculation of generalized attack rates, which probably do not have much meaning since the attack obviously occurred in certain specific areas and the balance of the system appears quite untouched.

Figure 11 is a plot of the iron-to-thorium ratios and sulfate-to-thorium ratios found in the loop by analysis of the samples taken periodically. During the period up to 600 hours the loop was being charged and the iron-to-thorium ratio decreased due to the addition of large quantities of relatively pure ThO_2. The generalized corrosion rate has been calculated from the increase in iron content beyond 600 hours and is found to be 0.95 mils per year. If the corrosion is estimated from the oxygen consumed, assuming conversion of iron to Fe_2O_3, a generalized corrosion rate higher by a factor of at least 5 is estimated. Because the oxygen concentration level was not maintained during the run, this must be taken as a minimum figure.

From examination of the system at the end of the run the following conclusions are drawn:

The attack on stainless steel is concentrated in high velocity areas. Only the flow nozzle and the pump have been visibly corroded. A section of pipe taken out for installation of a corrosion sample holder appeared exactly as it was when initially installed.

The pressure vessel, which is carbon steel-spray coated with stainless, has probably accounted for the balance of the corrosion products. The surface is rusty in appearance, indicating porosity in the protective lining and defective areas in the coating, particularly in the vicinity of the girth joint, had been found previously. It seems likely that a good deal of the corrosion products have remained on the surface of the vessel; this would account for the discrepancy between the corrosion rates estimated from iron pick-up and from oxygen consumption.

Chloride build-up near the vapor-liquid interface in the pressurizer indicated the possibility of stress-corrosion cracking. Because of the constant evaporation of water, dissolved chlorides became concentrated just below the interface. This effect was first discovered after approximately 500 hr and the chlorides were displaced from the pressurizer at 515 hr by pumping 50 liters of distilled water into the blanket. Figure 12 shows the variation of chloride content of samples taken from the displaced supernate with time. The sharp chloride concentration gradient is obvious.

After the shut-down, the pressurizer was washed and then inspected down as far as 6" below the liquid interface by means of a borescope and with dye penetrant. No cracks were indicated by these methods. The oxide film was then removed with grit cloth and the dye penetrant examination was repeated. This time defects were found in the pipe wall a few inches below the stub end weld. Accordingly, the upper 7 ft of the pressurizer were removed to permit more detailed examination. The dye-penetrant examination, after sectioning the pipe longitudinally, showed a number of large areas with rough surface imperfections running generally longitudinally and extending down to the approximate liquid level. However metallographic examination indicates that these are relatively shallow, blunt-ended pits presumably resulting from blowholes in the billet from which the pipe was made. No transgranular cracking was observed, and it is concluded that stress-corrosion cracking did not occur.

Equipment Performance

230A Pump

The circulating pump used in the slurry blanket test is a Westinghouse type 230A, serial No. 1-80F-455. The pump was installed initially in the 230A test loop of the Engineering Development Section and operated in that loop during the period April 1955 to August 1955. It was run 1142 hours on water and 322 hours on slurry.

It was transferred to the Slurry Blanket Test in September 1955 and was operated on water during the period February 1956 to May 1956 accumulating a total of 729 hours. In May 1956 the pump was seal-welded. Since seal-welding it has run successively 236 hours on water, 126 hours on 1000 g Th/kg H_2O slurry in run SM-1, 1356 hours on low-pressure system shakedown runs on water, 1650 hours on slurry in run SM-2, and 16 hours on rinse runs following the shut-down of run SM-2. Altogether the pump has been operated 5578 hours since being received, of which 2114 hours have been in slurry service. Up to the end of the present run none of the original parts have been replaced.

In operation the pump was relatively quiet compared to similar pumps in use and ran smoothly up to the last three weeks of run SM-2. In this period it began to vibrate very noticeably and a rattling noise was heard from the sound pick-up. The condition at first could be alleviated somewhat by hammering the lines going to the armored rotameter used to measure the flow of liquid circulating in the motor and bearing cooling loop. As the end of the run approached, less was achieved by the hammering procedure, although this still proved helpful in reducing the temperature in the motor end of the pump.

During run SM-2 the pump was gas-bound on a number of occasions, the condition being easily detected on the sound pick-up. This occurred on November 22 to 26 due to excessive oxygen feed, on December 24 to 27 when the loop pressure was reduced to 50 psi in order to permit maintenance work to be done on a valve and dissolved gas came out of solution, and on December 29 when the condensate tank ran dry. Whenever gas binding was detected, the pump was stopped immediately and vented. When this was done, slurry from the loop was, of course, sucked up into the pump motor end.

The condensate purge flow through the pump motor was kept relatively high throughout run SM-2, normally about 120 cc/min.

On disassembly, it appeared that the purge had been quite effective in removing slurry from the working parts. There was considerable slurry in the stagnant region behind the thermal barrier, but the parts which are flushed by the secondary flow were practically clean.

At the end of run SM-2 the pump was cut out of the loop for examination and repairs. The impeller was found to be severely eroded and as shown in Table I had a weight loss of approximately 10%. Figures 13 and 14 show the appearance of the impeller. The most severe attack occurred on the inner edges of the impeller vanes. The vanes throughout their length were attacked severely, also both shrouds and the bottom hub. The top hub was less severely attacked. The casing wear rings opposite the bottom impeller hub also show heavy attack, while the labyrinth rings in the thermal barrier opposite the impeller top hub and the rotor shaft were less severely attacked.

None of the bearing parts showed evidence of cracking or scoring although all bearings had worn sufficiently to warrant their replacement before returning the pump to service. The leading edges of the Kingsbury shoes show nicks; these shoes are stainless steel with stellite overlay. All of the pins in the Kingsbury bearing were worn measurably and this bearing will be rebuilt completely during the shutdown. Approximately 80% of the graphitar on the thrust runner had worn

TABLE I

SUMMARY OF SIGNIFICANT MEASUREMENTS TAKEN ON WESTINGHOUSE

TYPE 230A PUMP, SERIAL NO. 1-80F-455

Date	1-27-55	8-30-55	5-14-56	2-18-57
Operating hours on water	0	1142	1871	3464
Operating hours on slurry	0	322	322	2114
Total operating hours	0	1464	2193	5578
End play	0.032	.040"	.039"	0.091"
Height of graphitar on thrust runner	.057"	.054"	.056"	0.012"
O.D. of stellite on lower radial bearing	1.500"	1.500"	1.500"	1.497"*
I.D. of graphitar on lower radial bearing	1.504"	1.505"	1.502"	1.536"-1.544"
O.D. of stellite on upper radial bearing	1.500"	1.500"	1.500"	1.499"
I.D. of graphitar on upper radial bearing	1.503"	1.503"	1.503"	1.506"-1.508"
O.D. of shaft sleeve at labyrinth	1.500"	--	1.495"	1.501"
I.D. of labyrinth	--	--	1.511"	1.531"-1.538"
O.D. of top impeller hub	2.875"	--	2.873"	2.869"
I.D. of labyrinth	--	--	2.888"	2.916"
O.D. of bottom impeller hub	3.250"	--	3.248"	3.220"
I.D. of labyrinth	--	--	3.266"	3.302"-3.348"
Wt of impeller	--	--	1432 g	1299 g

*Surface rough, probably at least 0.010" less at bottom of grooves.

off. The lower radial bearing had worn approximately 0.040" and the lower journal surface was quite rough. The upper radial bearing and journal were in excellent condition; the bearing had worn only 0.005" and the journal not at all.

The measurements taken of the pump components from time to time during its service are shown in Table I. This shows that little wear occurred prior to May 14, 1956 when the pump was last inspected.

Figure 15 is a cutaway drawing of the pump which will assist in identifying the components and also shows the special features of this pump. These are the following:

1. The shaft opening into the thermal cavity has been plugged.

2. A thermowell is drilled in the stator flange to measure the temperature opposite the Kingsbury bearing.

3. The opening of the secondary cooling circuit into the cavity between the top plug and the upper bearing assembly has been closed and a hole has been drilled through the pump body to permit routing this flow outside the pump, through a rotameter and back into the top cap.

4. The bolt holes in the thermal barrier have been plugged and the thermal barrier is welded in place.

Pressurizer

The pressurizer performance was highly satisfactory throughout the run. On a few occasions it would have been convenient to have more heat available than the 10 kw which are installed, but this is not a serious limitation. Condensate production was easily maintained at 125 cc/min except when extra thermal loads, for example withdrawal of hot supernate during feeding or flushing operations, were applied.

Practically no slurry got into the upper part of the pressurizer during most of the run. Samples taken 18 in. above the slurry inlet and approximately 3 in. below the liquid surface consistently showed negligible slurry concentration.

Gamma Ray Surveys

Since some success had been achieved in detecting slurry stratification in the piping of the 200A loop by gamma ray absorption,[1] this technique was attempted to map thorium oxide distribution in the blanket. Arrangements were made so that a source could be placed at the center of the core and a track was installed on the northeast meridian of the pressure vessel with 28 positions at which a counting head could be positioned. The output from the head was fed to a Hewlett-Packard counter.

Prior to the run start-up, blank surveys were made both with the blanket empty and filled with water, using a 60 millicurie cobalt-60 source. Typical scans obtained are shown in Fig. 16. Scans were made during the first three weeks after thorium had been added, but attempts to interpret these indicated the need for refinements in the technique. Comparison of scans with and without the source showed that radiation from the thorium represented a high percentage of the total radiation picked up by the counter.

Further investigation of this technique on the 200A loop by A. S. Kitzes and M. Richardson revealed that the correct amplification settings on the counter had not been used in the early work. After the scanning technique was improved the equipment was again set up on the slurry blanket test using a 180 milicurie Co^{60} source.

This series of scans seemed to indicate the presence of highly concentrated slurry near the top of the blanket under the survey track, as well as in the bottom of the vessel. This is seen by comparing the two scans shown in Fig. 16. It will be recalled that the discharge collar was found to be slightly offcenter and closest to the core in this general area.

A test was made where the pump was stopped for 43 minutes. One counting head feeding a single channel analyzer was positioned on the highest usable position on the track and a second feeding a Hewlett-Packard counter, just above the equator. During the entire time the pump was off, the transmission at the top position increased less than 5%. Within 60 seconds after the pump stopped, the gamma transmission to the head near the equator increased by 50% and then decreased gradually for 17 minutes with frequent, irregular, momentary increases in transmission. When the pump was restarted, the original transmission readings were restored within a few minutes.

Slurry Characteristics and Behavior

The slurry charged for run SM-2 was made from a mixture of the following batches of ThO_2 produced in the pilot plant at Oak Ridge National Laboratory: LO-1, LO-2, LO-3, LO-6, LO-7, LO-9, LO-10, LO-11, LO-12 and LO-13. This material was prepared from specially purified thorium nitrate by precipitation with reagent grade oxalic acid at 70°C, followed by calcination for 2 hours at 370°C, 2 hours at 520°C and finally 2 hours at 800°C.

This oxide meets the specifications shown in Table II.

The slurry was prepared by dispersion of the oxide in distilled water. Sulfuric acid was added to give a calculated sulfate concentration of 3000 ppm, based on the thorium content.

On the basis of previous experience in handling thorium oxide slurries in the test loops at ORNL three aspects of the slurry behavior are of interest. These are: cake formation, formation of large spheroidal aggregates, and particle degradation.

From inspection of the loop since the end of run SM-2, no evidence of cake formation has been found.

Samples taken from the loop at various times have been examined microscopically for evidence of the formation of spheroidal particles. None have been found.

Particle size measurements have been made on slurry samples obtained during the run and are summarized in Table III. These indicated that the particles degraded to a mean particle size of 0.7 to 0.9 micron after a few hundred hours' pumping and that the size did not change thereafter.

Samples were obtained from the loop for hindered settling experiments after 800 hours and after 1160 hours. No significant difference was found between the two samples.

Instrument Performance

In general the instrument performance was excellent throughout the run. All pressure instruments measuring pressures or differential pressures in the slurry lines were connected into the process lines

TABLE II

THORIUM OXIDE SPECIFICATIONS LO-SERIES

Chemical Analyses

Th	87.2% min.	Si	10 ppm max.
CO_3	0.3% max.	Al	10 ppm max.
SO_4	100 ppm max.	PO_4	50 ppm max.
NO_3	10 ppm max.	Alkali Metals	100 ppm max.
Halides	10 ppm max.	Alkaline Earths	1000 ppm max.
Fe-Cr-Ni (total)	50 ppm max.	Rare Earths	50 ppm max.

Particle Size Analysis

100% through 200 mesh screen

Size distribution from sedimentation analysis of dispersion in 0.005 N $Na_4P_2O_7$

80% less than 10 microns

60% less than 4 microns

50% less than 2 microns

30% less than 1 micron

Nitrogen surface area 15 to 20 m^2/g

Crystallite size by X-ray 200 to 250 Å

TABLE III

PARTICLE SIZE DATA

Run Hours	Mean particle size from log-probability plot, microns: Circulating Loop Samples: Top of Pipe	1" Below Top of Pipe	2" Below Top of Pipe	Blanket Samples: Upper Sample Point	Lower Sample Point
324	--	3.0	1.5	0.6	1.2
417	--	1.7	0.8	1.0	0.8
491	0.7	0.7	0.7	0.7	0.7
519	0.9	--	--	--	--
519	1.0	--	--	--	--
586	1.0	1.0	1.0	0.8	0.9
661	0.9	--	--	--	--
773	0.9	--	--	--	--
873	0.8	0.8	0.8	0.9	0.8
1067	0.7	0.7	0.7	0.8	0.8
1212	1.1	0.8	1.8	1.8	0.8
1231	0.8	--	--	--	0.7
1233	0.8	--	--	--	0.8
1328	0.8	1.0	1.0	--	0.7
1376	0.5	0.7	1.0	--	0.7
1400	--	--	--	--	0.8
1425	--	--	--	--	0.9
1497	0.7	0.7	0.8	0.7	0.9
1688	0.7	0.7	0.7	0.7	0.6

through slurry traps in the manner shown in Fig. 17. No purge is used. No evidence of plugging was experienced and the three instruments having this type of connection worked very well.

The flow of condensate to the back of the pump was measured by a thermal flowmeter. Several thermocouples connected in series at the ends of a heated section of line supplied a signal to a Westronics miniature potentiometer recorder. The thermal flowmeter has one drawback; it does not give reliable readings while the temperature of the fluid being measured is increasing or decreasing.

The armored rotameter on the pump secondary flow circuit was sluggish during the latter part of the run. On disassembly, a heavy slurry accumulation was found in the dirt leg at the bottom of this instrument, which probably accounts for the trouble. A sample connection is to be added to the secondary flow circuit during the present shutdown. The takeoff will be made at the bottom of the rotameter dirt leg so that this will serve to remove slurry from the dirt leg as well as to sample the secondary flow.

The Swartwout d/P cell measuring the condensate tank level proved sensitive to venting the condensate tank, adding water to the condensate with the Sprague pump, or any other upset that might occur in flow in or out of the condensate tank. As originally installed, the reference leg was tied to the condensate tank inlet and the variable leg to the bottom of the condensate tank. On disassembly of the system at the end of the run, it was found that the bottom of the condensate tank was full of heavy slurry, which had of course gotten into the cell. In spite of this, the cell had continued to operate. The zero setting did shift on at least two occasions during the run; this is understandable in view of the slurry accumulation.

During the shutdown, the reference leg is being relocated so that the sensitivity to flow through the tank will be eliminated, and the variable leg tap is being moved from the bottom to the side of the condensate tank to reduce the chance of getting slurry in it.

Two pressurizer level instruments were utilized during the run. One is a d/P cell connected to the pressurizer through slurry traps and the second is a displacement instrument with magnetic damping of the type developed for the HRT. The instruments were calibrated together prior to start-up. The d/P cell instrument has generally worked very well. During oxygen additions, it had a downward zero shift of approximately 7 in. which occurred within 5 minutes or less after the oxygen feed started and persisted for three or four hours after the oxygen was turned off. This is probably due to the fact that the oxygen has been fed into the top of the slurry trap connected to the high pressure (reference) side of the cell. The oxygen feed point will be relocated before the next run. The d/P cell instrument is used to control the loop heaters and in normal operation the level is held within $\pm$ 0.25 in. of the set point.

The displacement instrument in general has functioned very well. Assuming that the true level can be determined by correcting the d/P cell instrument reading for density, the displacement instrument has a downward zero shift of 10.5 in. in going from ambient conditions to operating temperature and pressure. The instrument, with the magnetic damping, has a noise band width of 1 to 1.25 in., but probably could be adapted to control fairly readily. Because of the noisy trace, it uses a tremendous amount of ink and requires inking every two to four hours.

APPENDIX A

Run History

11-19-56 Run started at 1310. Pump time 2355 hours.

11-20-56 Gamma survey made.

11-21-56 Checked out slurry feed system on water. Calibrated O_2 feed system in place. Fed O_2 for 420 minutes at 1 liter/minute; then for 20 minutes at 0.5 liter/minute. Total fed-430 liters. Signs later recognized as signifying saturation observed after 385 liters had been added.

11-22-56 Fed O_2 for 540 minutes at 0.5 liter/minute. Total fed 270 liters. Pump started acting as though it were pumping undissolved gas about 1530 (1 hour before O_2 cut off). This continued until 0430 on November 23. Low pump power alarm sounded every 15 minutes during this period. The back of the pump was vented a few times during this period.

11-23-56 Loaded 83.3 kg Th as 600 g Th/kg H_2O slurry. Pump gas-bound and it was necessary to stop and vent several times.

11-24-56 Leakage found between the core and blanket through the pressure balancing valves. Gas found in the top of the sphere. Removed by venting. Pump again required venting. Considerable trouble with condensate system due to excessive gas.

11-27-56 Loaded 96.5 kg Th.

11-28-56 Loaded 50.8 kg Th. Some erratic pump operation observed.

11-29-56 Loaded 85 kg Th.

11-30-56 Charged an estimated 40 kg of Th. Charged interrupted when gross slurry leak from the Wilfley pump was discovered. This ultimately proved to be a broken seal.

12-1-56 12-11-56 incl. Steady operation with estimated charge of 244 g Th/kg H_2O. Samples indicated about 130 g Th/kg H_2O actually circulating. Added 120 liters of O_2 during this period. Displaced 50 liters from pressurizer to remove Cl^- on 12/11.

12-12-56 Charged 74 kg Th.

12-13-56 Charged 93.4 kg Th. Added 50 liters O_2.

12-17-56 Charged 110.7 kg Th.

12-18-56 Charged 68 kg Th and 50 liters O_2. Wilfley pump seal failed again. Calculated charge 498 g Th/kg H_2O.

12-23-56 Cooled loop to 90°C.

12-24-56 Reduced pressure to 50 psi. Difficulty encountered below 100 psi due to evolution of dissolved gas.

12-27-56 Completed replacing Pressure Products valve in feed line. Raised pressure to 210 psi.

12-28-56 Completed reheating loop to 180°C. Loaded 50 liters O_2.

12-29-56 Gas bound pump due to condensate tank running dry. After venting pump and re-establishing normal operation, loaded 200 liters O_2.

1-3-57 Approximately 43 liters of O_2 slugged into loop due to failure to close flowmeter by-pass tight. Additional O_2 relieved into core. Indications that pressure balancing valves leaked.

1-4-57 Added 18 liters O_2. Apparently 48 liters N_2 leaked in from blanket.

1-5-57 Flushed pressurizer by displacing 48 liters to remove Cl^-.

1-6-57 Sudden drop in power and flow after 20 hours at 182.5°C. Corrected by reducing temperature to 175°C.

1-7-57 Added 8 liters of O_2. Loop appeared saturated.

1-8-57 Added 15 liters of O_2. Temperature again rose to 182° and sudden drop in pressure and flow was again observed. Cooling to 177° restored original readings.

1-10-57 Pump sounded as though there was rubbing. Plans made to shut down. However in trying to un-stick the secondary cooling water rotameter by beating on the connecting lines, the noise was made to disappear. Also found that the internal cooling water temperature had been rising since 1/1 and dropped some as a result of the hammer treatment. Stopped pump for 12 minutes to get samples of settled material.

1-11-57 Stopped pump for 5 minutes to follow concentration at bottom of sphere.

1-13-57 Temperature raised to 185°C. Drop in power and flow were repeated.

1-15-57 Increased temperature to 193°C.

1-16-57 Increased temperature to 200°C.

1-17-57 Stopped pump for 5 minutes to collect samples under static conditions from bottom of blanket.

1-18-57 Cooled down to 177°C. Flowmeter reading increased from 57.5 to 68%.

1-21-57 Flushed pressurizer again.

1-23-57 Loaded 10 liters of O_2.

1-24-57 Loaded 270 liters of O_2.

1-25-57 Loaded 135 liters of O_2. Gamma surveys made utilizing improved technique. These indicated slurry concentrated in the upper hemisphere.

1-28-57 Leak to atmospheric developed in core to blanket pressure balancing valve. This makes temperature control difficult.

1-29-57 Stopped pump for 43 minutes for gamma survey study of settling.

1-31-57 A leak developed in an inspection port on the blanket. Run terminated at 1730 hour.

APPENDIX B

DESCRIPTION OF SYSTEM

I. Main Circulating Loop

   A. Equipment

   B. Instrumentation and Control

II. Condensate System

   A. Equipment

   B. Instrumentation and Control

III. Slurry Feed System

IV. Let-down and Dump System

V. Sampling Facilities

VI. Miscellaneous Auxiliaries

I. Main Circulating Loop

A. Equipment and Piping

The high pressure circulating loop is illustrated in Fig. 18. The piping is partly 3-1/2" ips x 0.469" wall and partly 3" ips sch 40, depending on whether the particular part of the system is to be used in an alternative 2000 psi arrangement of the system. Both sizes have essentially the same cross-section and the line velocity is 10 ft/sec at the nominal pump capacity of 230 gpm.

The circulating pump is a Westinghouse type 230A canned motor pump having a design point of 230 gpm at 50 ft head and a working pressure of 2000 psi. Essentially, this is the type 300A pump with a cut-down impeller.

The pressurizer is a 6" sch 160 vertical pipe with an overall height of 14'0" above the inlet. It is closed at the top with a 6" 1500 lb blind flange mating to a 6"-1500 lb lap-joint flange.

The flow enters through a 6"x3-1/2" reducer and a 6" tee, turns down and out through a second 6"x3-1/2" reducer and 3-1/2" elbow. The center line of the outlet is 1'3-7/8" below the inlet center line. Baffles are installed to damp out the vortex which would exist above the inlet.

The liquid level is ordinarily carried 39" below the top flange. Two liquid level instruments span the range of 30" to 60" below the flange to sense the level. One, of the displacement type, is located in an auxiliary shell located east of the pressurizer itself and connected by a 1" line at the bottom and a 1/2" line at the top. The second is a differential pressure cell which compares the level in the pressurizer with that in a fixed reference leg.

Vapor is taken off through a 1/2" line connected to the blind flange at the top of the pressurizer. Ten inches of Yorkmesh are located in a can on the underside of the flange to minimize entrainment through this line.

Heat for maintaining pressure is provided by four 2500 watt strip heaters 5 ft long mounted just below the zero point of the level instruments.

From the bottom of the pressurizer the slurry stream flows to the dummy reactor vessel. It splits into two parts and enters through two inlet nozzles arranged to give rotational flow in the dummy reactor. Figure 19 illustrates this arrangement, which was selected on the basis of experimental work done by C. G. Lawson on an 18 in. vessel.[2] The dummy reactor vessel is a spherical tank, 60 in. ID containing a stainless steel replica of the homogeneous reactor test core. This is illustrated in Fig. 20. Slurry leaves from the dummy reactor through the collar around the core illustrated in Fig. 20 which is arranged to minimize dead space at the top of the blanket and settling on the top of the core and then returns to the pump through a flow element.

B. Instrumentation and Control

1. Pressure Control

Core Pressure.--The core may be pressurized either with steam using the plant 250 psi steam supply or with nitrogen. When on steam, a Foxboro dynalog recorder-controller (PRCA-36) controls the pressure. On nitrogen, a standard N_2 regulator suitable for dead-end service is used and PRCA-36 acts as a recorder and alarm only. Since heat transfer data are not desired at present, and since it was desired to operate with the core empty, nitrogen was used during run SM-2.

Blanket Pressure.--This may be controlled either directly, using PRCAX-2, a Honeywell strip chart recorder-controller, or the core-to-blanket differential pressure may be controlled with PdRCA-3, a Foxboro Dynalog circular chart recorder-controller. Successful operation can be obtained either way. A toggle switch on the front of the panel transfers control to one instrument or the other.

2. Temperature Control

Temperature control is maintained by varying the input to four sets of line heaters totalling 30 kw. Either TRCAX-8, a Honeywell circular chart temperature recorder-controller obtaining its signal from a thermocouple in a well in the circulating stream, or LRCAX-1, the d/P cell level recorder-controller, may be used to control temperature. The level instrument is now normally used since it gives far more precise control than the temperature instrument. It is estimated that the temperature is controlled within better than $\pm$ 0.1°C by this instrument, compared with $\pm$ 1°C by the temperature instrument.

3. System Level

Two instruments are provided. LRCAX-1 consists of a Foxboro type 5E electric d/P cell feeding a Foxboro Dynalog circular chart recorder-controller, and LR-7 is an experimental magnetically damped displacement element feeding a Foxboro dynalog recorder.

4. Pump Instrumentation

a. Power is measured by a 110v, 1000w thermal converter supplied by suitable current and potential transformers in the pump power supply and feeding the red pen of an L and N two pen miniature recorder. The effective instrument range is 20 kw.

b. Voltage is measured by an Arga suppressed range voltmeter supplied by the same 440:110 volt potential transformer which feeds the power recorder. This indicates the voltage above the suppression setting and also records it on the blue pen of the L and N mentioned above. Since voltage normally runs around 450, the 110 volt suppression setting is usually used.

c. Cooling water is measured by a rotameter in the supply line and the pump is automatically shut down by a flow switch if it is less than a predetermined value (about 1.8 gpm).

d. Internal cooling water flow is measured by an armored transmitting rotameter and recorded by a Foxboro dynalog recorder.

e. The temperature in the motor cavity is measured by a thermocouple located immediately behind the thermal barrier and by a second thermocouple located in the top cap of the motor cavity. The former is more valuable in determining overheating of the bearings.

II. Condensate System

A. Equipment

The pump purge system consists of the purge condenser, condensate tank, and associated piping. The system is shown schematically in Fig. 18. The condenser consists of four parallel

18 in. lengths of 1/4 in. sch 80 stainless pipe with cooling jackets. The condensate tank is made of 4 in. sch 80 pipe and provides a surge volume of approximately 3 liters. A line taken off near the bottom of the tank leads to the top of the motor cavity. A second line is taken from the top of the tank and enters the main circulating loop just upstream of the pump suction. The latter is provided to enable gas accumulating in the condenser to be vented into the circulating loop.

B. Instrumentation and Control

1. Flow Regulation

Fifteen-turn needle valves are provided to regulate flow from the condensate tank to the pump and to the loop.

2. Temperature Measurement

The temperatures of the following are measured on the panel instruments:

a. Condenser cooling water exit temperature - pt 9 on 12 point recorder.

b. By-pass stream to pump suction - pt 11 on 12 point recorder.

c. Condensate to pump - pt 13 on 18 point indicator.

3. Condensate Flow Measurement

The flow of condensate is measured by a thermal flowmeter located in the line from the condensate tank to the pump. This consists of a heated section of line with thermopiles at the ends connected in opposition and feeding a 5 millivolt Westronics recorder.

4. Condensate Tank Level

This is measured by a 20 in. Swartwout d/P cell feeding an indicator on the panel.

III. Slurry Feed System

The slurry feed system consists of three slurry storage tanks designated 11A, 11B and 11C, the slurry transfer pump and the acid egg feed system, with associated piping and valves.

The tanks are as follows: 11A is a horizontal cylindrical tank with flat heads having a capacity of approximately 450 gallons. 11B is a vertical tank with dished heads having a capacity of approximately 500 gallons, and 11C is a vertical tank with a cone bottom and having a capacity of approximately 90 gallons. All three tanks are equipped with agitators. All tanks are equipped with side outlets and top inlets. Each tank has a bottom connection piped for use either as an outlet or an inlet. An overflow connection on tank 11B is piped to 11A.

Tank 11C is equipped with a float type level indicator. Tank 11B has a gage glass (which has proved useless in slurry service) and will be replaced with a float as soon as this can be done. Tank 11A has a d/P cell level transmitter and a capacitance probe level alarm. Tank 11C has a series of valves spaced along the wall for decanting to concentrate slurry and the other tanks are to be similarly equipped.

For slurry transfer a Wilfley 3"x2" stainless steel centrifugal pump with a 15 HP direct-connected motor and mechanical shaft seal is used. This pump can take suction from the side or bottom of any of the three tanks and can discharge to the top or bottom of any of the tanks.

It can also discharge into the loop and the acid egg feed system is on a branch of the line running from the pump to the top of the three tanks.

The acid egg system is illustrated in Fig. 21. In operation, the high and low air tank pressure switches PX-61-A and PX-61-B are set at predetermined pressures above the loop pressure, these being set so that in expanding from the higher to the lower pressure the air displaces the contents of the slurry tank into the loop. The high pressure air compressor is operated to furnish air at approximately 400 psi. The cycle is started with the slurry tank empty and vented by pressing the button marked "charge". This automatically closes vent valve V-6 and opens valve V-4 to admit air to the air tank and valve V-42 to admit slurry to the slurry tank. When the air pressure increases to the desired value, PX-61-A closes V-4 and lamp L-3 lights on the panel. When the slurry tank is full, LX-63, a conductance probe, closes V-42 and causes lamp L-2 to light on the panel. Once these events have occurred, the button marked "feed" may be pushed. This causes valve V-5 between the air tank and the feed tank to open and also valve V-12 between the feed tank and the loop, so that the charge is forced into the loop. When the pressure in the air tank drops to the PX-61-B setting, the two valves close automatically and lamp L-4 lights. Then the slurry tank is vented by pushing the button marked "vent". When the pressure drops to essentially atmospheric, lamp L-1 comes on and the cycle may be repeated. All of the control valves are air-operated with the air supply being controlled by solenoid valves in the air lines. The system is interlocked so that the steps must be carried out in proper sequence and so that it is impossible to proceed to any step until the previous step has been completed, including closing of critical valves.

IV. Let-down and Dump System

The let-down and dump systems are shown on Fig. 22. These are both provided for the purpose of removing slurry from the loop. The let-down system consists of the let-down heat exchanger and the let-down valve and is intended primarily for removal of small quantities of slurry from the system. It was sized initially for operation at 2000 psi.

The let-down heat exchanger is a double pipe heat exchanger consisting of 16 ft of 1/2-in. sch 80 stainless pipe jacketed with 1 in. sch 40 steel pipe. The valve is a 1/2 in. Annin Fig. 3461 control valve with C_v 0.063 trim. The slurry exit temperature from the let-down heat exchanger can be monitored from the panel, and the valve is likewise operated from the panel so that it is possible to control the let-down rate to prevent discharging excessively hot slurry to the storage tanks. The slurry can be discharged either to tank 11B or 11C by opening the appropriate hand valves in the tank room. A relief valve is provided on the line downstream of the let-down valve, discharging into tank 11B to protect low-pressure piping in case by some oversight neither tank valve is opened.

The dump system is designed to empty the entire loop from 300 psi, 200°C into the storage tank in approximately 10 minutes. It consists of the dump valve (a 1 in. Annin control valve C_v 2.5), dump cooler, tanks 11B and 11A, dump cooling water pump, dump cooling water tank, and an electrical interlock system to assure proper operation.

The dump cooler is of the contact type. It consists of a spray chamber in which slurry is sprayed out from a center pipe while cooling water is introduced through spray nozzles around the periphery of the cooler. This type of cooler was selected when preliminary calculations for a heat exchanger indicated that several hundred feet of jacketed pipe would be needed to cool the slurry to 100°C.

The dump cooler is mounted on a large nozzle on tank 11B and an overflow line is provided from 11B to 11A. The two tanks together contain sufficient volume to hold the loop inventory and sufficient water to cool it to 100°C.

The cooling water is stored in a tank located in the basement and is transferred to the dump cooler by a centrifugal pump.

The interlock system is provided to minimize the operator's problems during the dump, to prevent dumping without having cooling water and to prevent overfilling the storage tanks. Before a dump can be initiated, the cooling water must be turned on and brought up to a minimum value and loading air must be applied to the dump valve. Then, pressing the "start" button on the dump control panel will energize a solenoid valve in the air supply line to the valve and apply air to open the valve. Simultaneously a normally-closed contact in the 110v control circuit is opened which interrupts control power to the pump and heater contactors and thus stops the circulating pump and heaters. Also a solenoid valve in the core steam supply line is energized, interrupting air to this valve and shutting off the steam. The dump may be interrupted manually by actuating the "stop" button on the dump control panel. If the level in tank 11A rises to the alarm point, the alarm on this tank will automatically de-energize the dump circuit and terminate the dump. Before the core steam can be turned on again, it is necessary to operate the "reset" button on the dump control panel to de-energize the solenoid valve in the air supply to the steam valve.

V. Sampling Facilities

As of the start of this run, seven sample locations were provided on the circulating pump and pressurizer. These points, with their original intended uses are listed below.

A. For slurry and gas samples from the circulating stream. This is located in the south-north run between the blanket and the pump, upstream of the loop flow element. The inlet is flush with the top of the pipe. The sampler is of the bomb type, with provision for mounting up to four bombs in series.

For slurry samples from the pressurizer.

Point B. The inlet is located 1-3/4 in. in from the west wall of the pressurizer 18 in. above the center-line of the slurry inlet. The sampler is of the bomb type, with provision for one bomb only.

Point C. The inlet is located 54 in. below the top flange or 12 in. below the normal liquid level, 1-3/4 in. in from the west wall. Prior to this run, this sampler was converted to a continuous type. A cooling jacket is provided and a 15-turn needle valve for regulating the flow rate.

For slurry samples from the pressure vessel.

Point G. This sampler is located on a porthole 30° below the top of the sphere and on the west side of the vessel. This sampler and "H" are of the continuous type and use the same cooler. The inlet is flush with the inside of the porthole cover.

Point H. This is located on a porthole 30° above the bottom of the sphere on the west side. The installation is otherwise similar to "G".

For slurry samples from the circulating stream.

Point J. This is located on the east-west run from the pressure vessel to the pump with the inlet placed 1 in. below the top of the pipe. The sampler is of the bomb type.

Point K. Identical to "J" and in the same location. However, the inlet is 2 in. below the top of the pipe.

VI. Miscellaneous Auxiliaries

Sprague Pump. A Sprague air driven piston pump has been installed permanently next to the sample station at the northeast corner of the loop shield. This is used for a variety of purposes including hydrostatic testing, refilling the condensate tank, adding makeup water to the loop and clearing plugged sample lines. By making minor changes in tubing connections it can discharge into the sample line coming from samplers G and H, simultaneously into samplers G and H and the core, or into the condensate line between the condensate tank and 230A pump.

Oxygen Feed Station. This consists of an oxygen cylinder with regulator, a pressure gage, an intregral orifice d/P cell, a needle valve and suitable block valves. The regulator is used to supply oxygen at a suitable upstream pressure for metering. Then the flow is measured by the d/P cell which is calibrated to give flows of 0.5-1 liter/min. and the feed rate is controlled by the needle valve.

Air Compressor. A Norwalk 5-stage air compressor rated 30 scfm at 2000 psi is used to supply air for the acid egg system. While the compressor has far more capacity and discharge pressure than needed, it was already installed in a convenient location and can be controlled to supply air for this service.

APPENDIX C

SUMMARY OF ANALYTICAL RESULTS

TABLE IV

SUMMARY OF ANALYTICAL RESULTS

Sample No.	Description	Run Hr	SLURRY ANALYSIS: Th g/kg H_2O	Fe ppm	Cr ppm	Ni ppm	SO_4/Th ppm	Cl ppm	pH	SUPERNATE ANALYSIS: pH	Cond. mhox10^5	SO_4 ppm	Cl ppm
F-45	Slurry charge	93	330	45			5750	<10	4.9				
A-51	Circulating loop - top of pipe	112	30	14					4.8				
F-62	Slurry charge	160	463				1360						
A-61	Circulating loop - top of pipe	161	29	27				<10	4.9	4.9			
F-63	Slurry charge after adjusting conc. and SO_4	165	700				3500						
C-64	Top of pressurizer	184	0.81										
G-65	Top of blanket	187	60	35	<5	<5			5.2			6	
H-66	Bottom of blanket	187	60	35	<5	<5			5.3			6	
J-69	Circulating loop - 2" below top of pipe	188	55	40	<5	<5			5.3			6	
K-70	Circulating loop - 1" below top of pipe	188	52	37	<5	<5			5.4			6	
F-72	Slurry charge	189	525				2110	10	7.5				
A-73	Circulating loop - top of pipe	189	90	59					5.7	6.3		8	
G-74	Top of blanket	212	62	32			7000	<10	5.1	5.6		6	1
H-75	Bottom of blanket	212	130	69			9600	<10	5.8			6	2
A-76	Circulating loop - top of pipe	212	87	40	<5	6	5200	<10	5.4	4.9		<5	4
F-77	Slurry charge	212	510				4620						
F-84	Slurry charge	226	505				2955		8.3				
G-86	Top of blanket	249	70	30			6100		5.2	5.2			
H-87	Bottom of blanket	249	154	45			4450		5.9	5.9			
B-88	Bottom of pressurizer	250	4.0						4.9				
C-89	Top of pressurizer	250	<.02	10				2	5.2	5.2			
A-92	Circulating loop - top of pipe	254	103	43			6400		5.6				
J-93	Circulating loop - 2" below top of pipe	254	107	48			6000		5.6				
K-94	Circulating loop - 1" below top of pipe	254	107	42			5900		5.5				
F-95	Slurry charge	255	570	25			3340		8.1				

TABLE IV. SUMMARY OF ANALYTICAL RESULTS (continued)

Sample No.	Description	Run Hr	SLURRY ANALYSIS Th g/kg H_2O	Fe ppm	Cr ppm	Ni ppm	SO_4/Th ppm	Cl ppm	pH	SUPERNATE ANALYSIS pH	Cond. mhox10^5	SO_4 ppm	Cl ppm
B-97	Bottom of pressurizer	323	0.10					10					
C-98	Top of pressurizer	323	<.01										
G-100	Top of blanket	324	90										
H-101	Bottom of Blanket	324	200										
J-102	Circulating loop - 2" below top of pipe	326	98										
K-103	Circulating loop - 1" below top of pipe	326	103										
A-104	Circulating loop - top of pipe	327	103						6.1		6.1		
A-105	Circulating loop - top of pipe	345	103						5.1		5.1		
B-106	Bottom of pressurizer	346	.04	<2	<2	<2			5.7		5.7		
C-107	Top of pressurizer	346	<.01	<2	<2	<2		12	5.6		5.6		
G-108	Top of blanket	347	101						5.6	5.8			
H-109	Bottom of blanket	347	235						6.1	6.2			
J-110	Circulating loop - 2" below top of pipe	345	140						5.8	5.9			
K-111	Circulating loop - 1" below top of pipe	345	142						5.9	5.9			
A-112	Circulating loop - top of pipe	418	150	26	5	6	4750	20	5.7	4.9		7	<1
B-113	Bottom of pressurizer	418	.027	<2	<2	<2		<2	4.9				
C-114	Top of pressurizer	418	.023	3	<2	7		19	5.9				
G-115	Top of blanket	418	75	25	<5	6	5700	20	5.3	5.3		<5	<1
H-116	Bottom of blanket	418	215	38	10	5	4100	20	5.9	6.1		<5	<1
J-117	Circulating loop - 2" below top of pipe	417	130	30	6	5	4280	10	5.8	5.8		<5	<1
K-118	Circulating loop - 1" below top of pipe	417	130	28	<5	6	4450	<10	5.6	5.8		<5	<1
A-121	Circulating loop - top of pipe	490	135	57	<5	<5	4300	10	5.2	5.6		<5	<2
B-122	Bottom of pressurizer	490	0.01	<2	<2	<2			4.5				
C-123	Top of pressurizer	490	<.01	<2	<2	<2		25	5.6				
G-124	Bottom of blanket	491	100	44	6	<5	4850	<10	4.9	5.6		<5	<2

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TABLE IV. SUMMARY OF ANALYTICAL RESULTS (continued)

Sample No.	Description	Run Hr	SLURRY ANALYSIS: Th g/kg H_2O	Fe ppm	Cr ppm	Ni ppm	SO_4/Th ppm	Cl ppm	pH	SUPERNATE ANALYSIS: pH	Cond. mhox10^5	SO_4 ppm	Cl ppm
H-125	Top of blanket	491	210	81	8	<5	3950	<10	5.4	5.9		<5	<2
J-126	Circulating loop - 2" below top of pipe	489	130	61	7	<5	4590	<10	5.1	5.7		<5	<2
K-127	Circulating loop - 1" below top of pipe	489	125	55	7	<5	4400	<10	5.1	5.6		<5	<2
F-143	Slurry charge	541	840				2100	<10	7.9				
A-147	Circulating loop - top of pipe	586	220	69	6	7	3310	<2	6.6	6.7	3.6	<5	<2
B-148	Bottom of pressurizer	586		<1	<1	<1		3	5.5	5.5	7.0		<3
C-149	Top of pressurizer	587		<1	<1	<1		<10	5.5	5.5	7.0		3
G-150	Top of blanket	587	170	51	5	6	3110	<10	6.4	6.4	3.2	<5	<2
H-151	Bottom of blanket	587	291	82	7	7	3440	<10	6.4	6.7	3.3	<5	<2
J-152	Circulating loop - 2" below top of pipe	585	203	65	5	8	3660	<10	6.2	6.5	2.4	<5	<2
K-153	Circulating loop - 1" below top of pipe	585	180	57	5	6	3380	<10	6.6	6.5	3.8	<5	<2
F-156	Slurry charge	660	855				1990	15	8.2				
F-161	Slurry charge	685	800				2470	<10	8.0				
A-165	Circulating loop - top of pipe	730	259	75	9	6	4670	8	6.3	6.4	2.7	<5	2
B-166	Bottom of pressurizer	730		<1	<1	<1		<2	4.9	4.9	2.3	<5	<2
C-167	Top of pressurizer	731		<1	<1	<1		<2	5.2	5.2	7.0	<5	<2
G-168	Top of blanket	731	203	61	7	7	4400	10	6.2	6.4	4.1		4
H-169	Bottom of blanket	732	340	88	13	8	3538	5	6.2	6.4	1.8		4
J-170	Circulating loop - 2" below top of pipe	732	255	76	11	7	3545	8	6.4	6.4	3.1		3
K-171	Circulating loop - 1" below top of pipe	732	220	68	9	6	3690	9	6.3	6.4	3.2	<5	2
A-174	Circulating loop - top of pipe	873	310	67	9	10	4360	6	6.4	7.3	2.8	<5	<2
B-175	Bottom of pressurizer	873								5.2	25.0	5	10
C-176	Top of pressurizer	873								5.7	2.2	<5	<2
G-177	Top of blanket	874	280	110	9	9	1610	7	6.4	6.1	2.5	<5	2
H-178	Bottom of blanket	874	330	97	10	10	3790	8	6.6	6.2	2.6	<5	<2

TABLE IV. SUMMARY OF ANALYTICAL RESULTS (continued)

Sample No.	Description	Run Hr	SLURRY ANALYSIS Th g/kg H_2O	Fe ppm	Cr ppm	Ni ppm	SO_4/Th ppm	Cl ppm	pH	SUPERNATE ANALYSIS pH	Cond. mhox10^5	SO_4 ppm	Cl ppm
J-179	Circulating loop - 2" below top of pipe	874	290	117	10	9	3360	14	6.7	6.3	2.7	<5	<2
K-180	Circulating loop - 1" below top of pipe	875	297	110	9	10	3420	11	6.6	6.1	2.7	<5	<2
A-195	Circulating loop - top of pipe	1069	200	91	<5	7	3110	<10	5.3	5.4	3.7		
B-196	Bottom of pressurizer	1070		<2	<2	<2				4.6		<20	<2
C-197	Top of pressurizer	1070		<2	<2	<2				5.3		<20	9
G-198	Top of blanket	1071	170	78	5	8	3750	<10	5.2	5.4	3.1	<5	2
H-199	Bottom of blanket	1071	420	144	16	6	2960	<10	5.6	5.7	3.7	<5	2
J-200	Circulating loop - 2" below top of pipe	1069	182	82	8	5	2970	<10	5.3	5.6	4.7	<5	3
K-201	Circulating loop - 1" below top of pipe	1069	188	87	10	5	3530	<10	5.1	5.4	3.3	<5	<2
A-224	Circulating loop - top of pipe	1212	168	79	7	7	3440	<10	5.0	5.8	4.9	<5	<2
G-225	Top of blanket	1213	120	47	6	<5	3490	<10	5.1	5.3	4.1	7	<2
H-226	Bottom of blanket	1212	285	123	11	10	2780	<10	5.4	5.5	4.0	7	<2
J-227	Circulating loop - 2" below top of pipe	1213	131	71	<5	7	3480	<10	5.2	5.5	4.0	5	<2
K-228	Circulating loop - 1" below top of pipe	1213	215	100	9	8	2330	<10	5.2	5.4	4.1	<5	<2
A-229	Circulating loop - top of pipe	1213	210	95	8	6	2750	<10	5.1	5.8	3.9	<5	<2
H-230	Bottom of blanket	1214	420	166	16	13	2880	<10	4.9	5.3	3.5	<5	
B-231	Bottom of pressurizer	1214		<2	<2	<2				4.6	7.8	20	<2
C-232	Top of pressurizer	1214		<2	<2	<2				5.0	11.0	50	3
A-256	Circulating loop - top of pipe	1328	71	36	5	6	3520	<10	4.7	5.2	3.1	<5	2
B-257	Bottom of pressurizer	1328	.04	<5	<5	<2		<2	4.6				
C-258	Top of pressurizer	1328	.09	<5	<5	<2		3	4.9				
G-259	Top of blanket	1328	2	<5	<5	<2		<2	4.7				
H-260	Bottom of blanket	1329	500	208	25	16	3035	<10	5.5	5.7	3.9	6	6
J-261	Circulating loop - 2" below top of pipe	1329	30	40	6	<5	3600	<10	4.9	5.2	3.3	<5	<2
K-262	Circulating loop - 1" below top of pipe	1329	80	35	<5	<5	5100	<10	5.1	5.5	3.2	<5	<2

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TABLE IV. SUMMARY OF ANALYTICAL RESULTS (continued)

Sample No.	Description	Run Hr.	SLURRY ANALYSIS Th g/kg H_2O	Fe ppm	Cr ppm	Ni ppm	SO_4/Th ppm	Cl ppm	pH	SUPERNATE ANALYSIS pH	Cond. mhox10^5	SO_4 ppm	Cl ppm
A-263	Circulating loop - top of pipe	1376	38	35	<5	<5	3640	12	4.4	4.9		<5	<2
H-267	Bottom of blanket	1376	529	205	32	18	3150	<10	5.3	5.7		<5	4
A-270	Circulating loop - top of pipe	1399	17	16	<5	<5	7500	<10	4.6	5.0	3.0	7	2
H-274	Bottom of blanket	1400	495	200	22	19	2510	<10	5.6	5.4	3.9	<5	<2
A-295	Circulating loop - top of loop	1424	26	20	<5	<5		<10	4.7	5.2	4.3	<5	2
B-296	Bottom of pressurizer	1425		<1	<1	<1				4.6	3.9	6	6
C-297	Top of pressurizer	1424		<1	<1	<1				4.8	8.6	10	4
G-298	Top of blanket	1425	1.0	<5	<5	<5		<10	4.7	4.7	4.0	<5	2
H-299	Bottom of blanket	1424	385	172	17	14	2070	13	5.6	5.7	3.4	<5	<2
J-300	Circulating loop - 2" below top of pipe	1425	24	<5	<5	<5		<10	4.9	5.1	3.1	<5	2
K-301	Circulating loop - 1" below top of pipe	1425	20	15	<5	<5	5500	<10	3.5	4.6	3.6	<5	2
A-302	Circulating loop - top of pipe	1497	230	133	14	<5	2630	<10	4.8	5.2	1.2	7	<2
B-303	Bottom of pressurizer	1497		<1	<1	<1				4.6	4.1	<5	7
C-304	Top of pressurizer	1497		<1	<1	<1				5.1	19	16	8
G-305	Top of blanket	1497	20	29	<5	<5	5550	<10	4.1	5.1	4.2	<5	<2
H-306	Bottom of blanket	1497	305	137	14	12	2030	<10	4.4	5.3	4.2	5	<2
J-307	Circulating loop - 2" below top of pipe	1497	197	111	11	11	2720	<10	4.5	5.1	6.1	5	<2
K-308	Circulating loop - 1" below top of pipe	1497	152	82	7	6	2850	<10	4.4	5.7	4.6	5	<2
A-316	Circulating loop - top of pipe	1688	188	123	11	<5	2690	<10	4.5	4.9	4.5	<5	<2
B-317	Bottom of pressurizer	1688		<1	<1	<1				4.6	5.6	<5	
C-318	Top of pressurizer	1688		<1	<1	<1				4.6	5.9	22	
G-319	Top of blanket	1688	13	13	<5	<5		<10	4.7	4.7	4.7	<5	<2
H-320	Bottom of blanket	1688	170	125	12	<5	3500	<10	4.5	5.1	4.6	6	<2
J-321	Circulating loop - 2" below top of pipe	1688	190	136	11	<5	2480	<10	4.4	4.9	4.9	11	<2
K-322	Circulating loop - 1" below top of pipe	1688	204	144	12	<5	2530	<10	4.4	4.6	5.9	<5	<2

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5. Zöss *et al.*, Trans ASME *76*, 69 (1954).

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Fig. 1

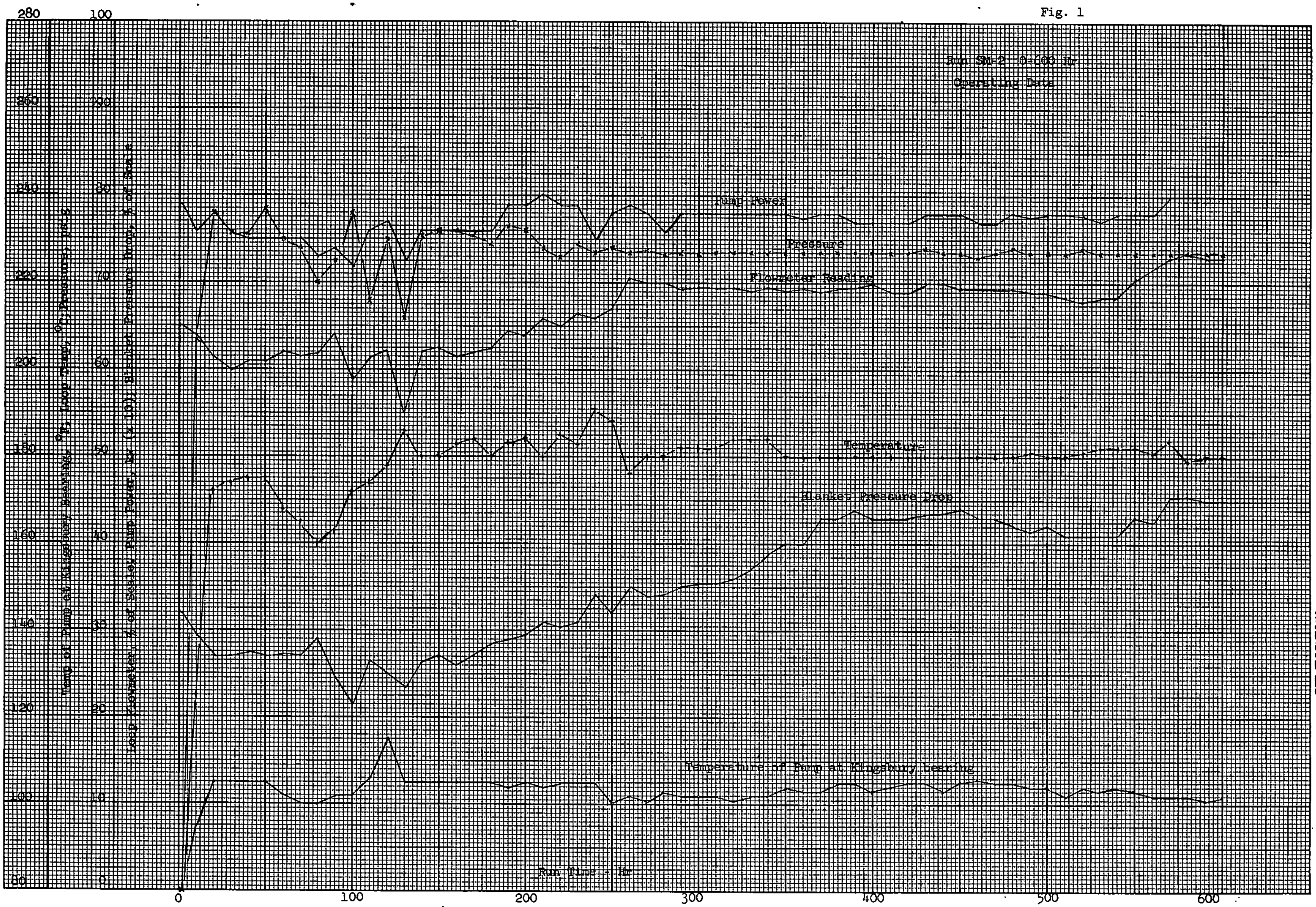

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Fig. 2

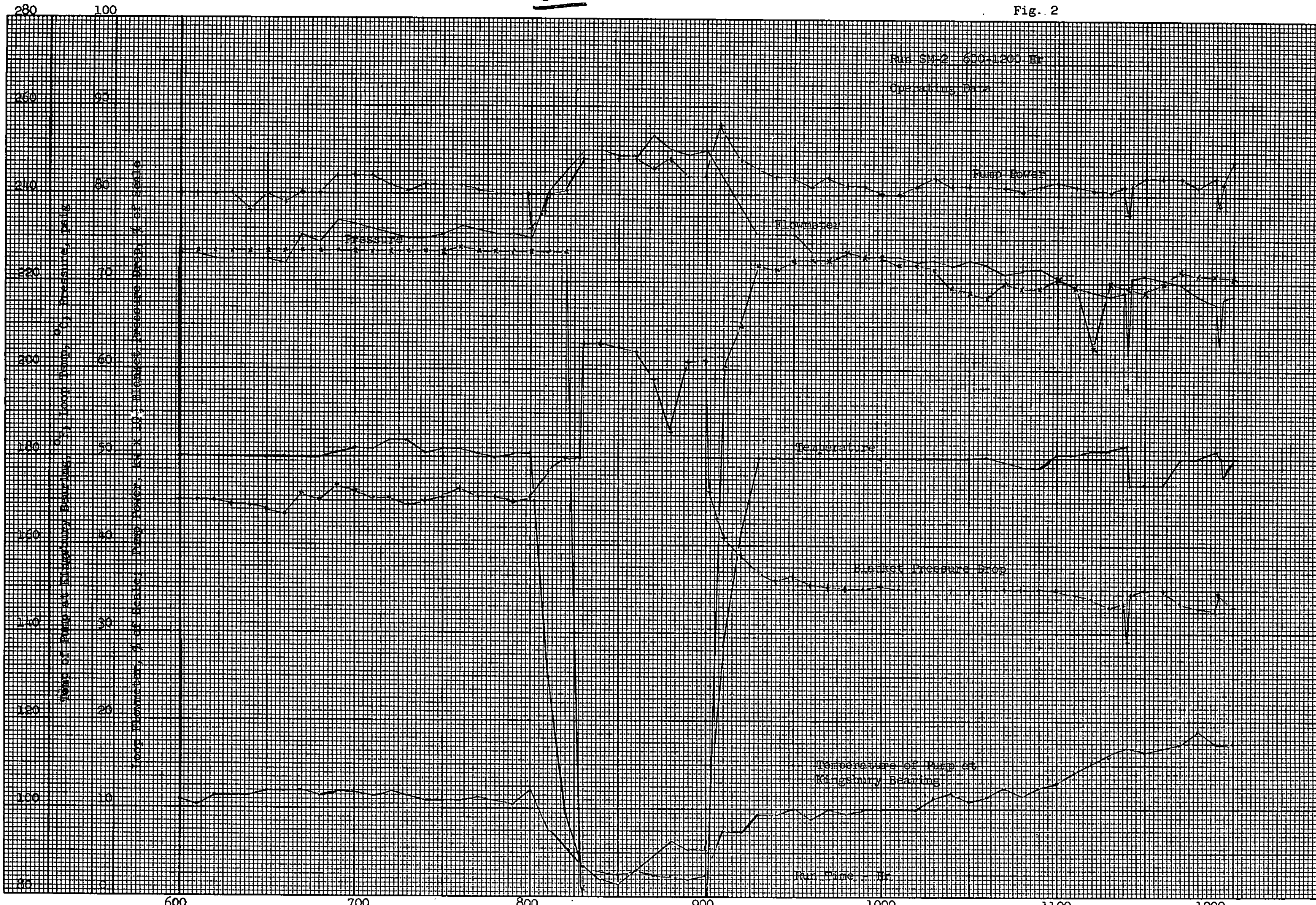

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Fig. 3

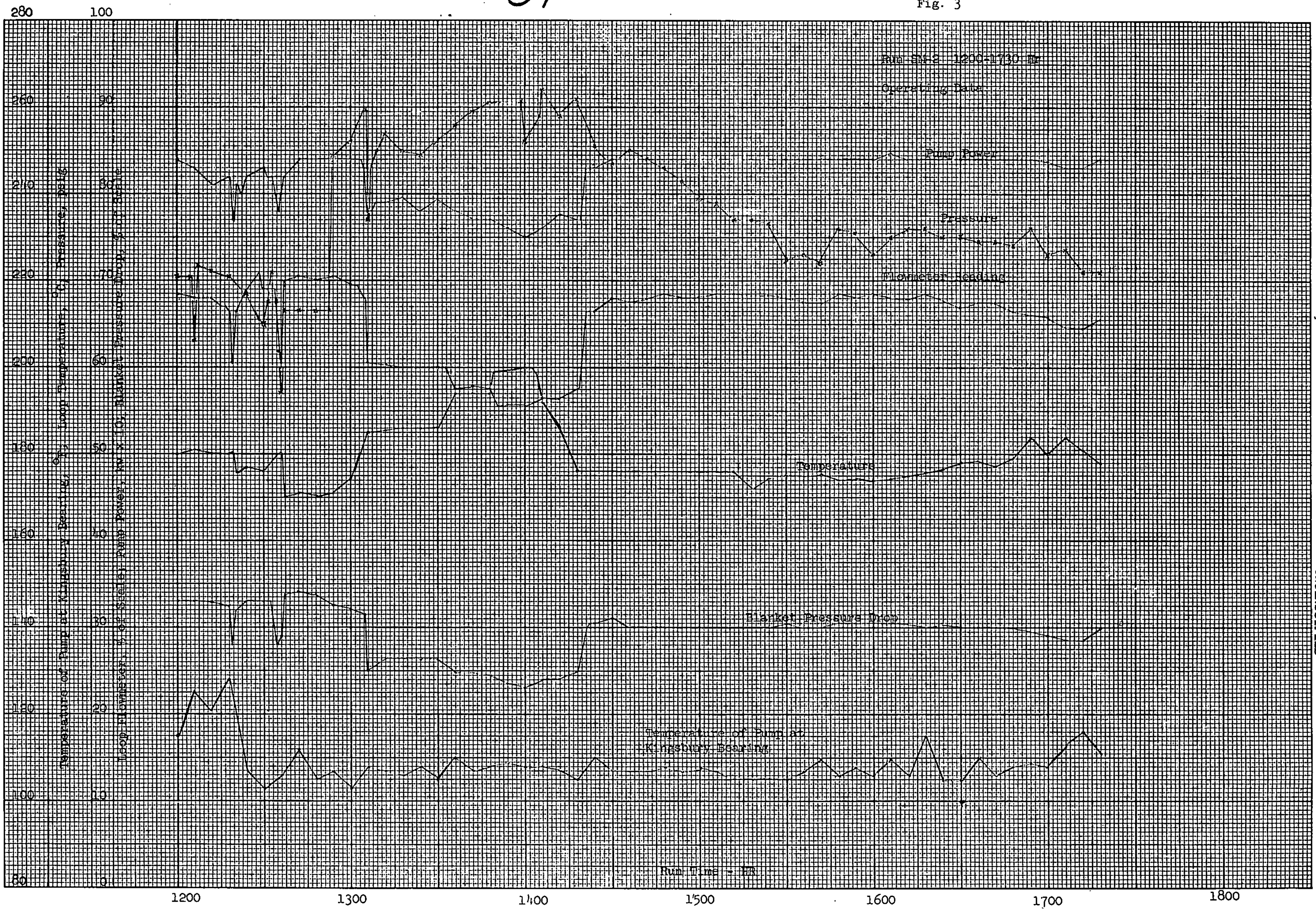

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Fig. 4

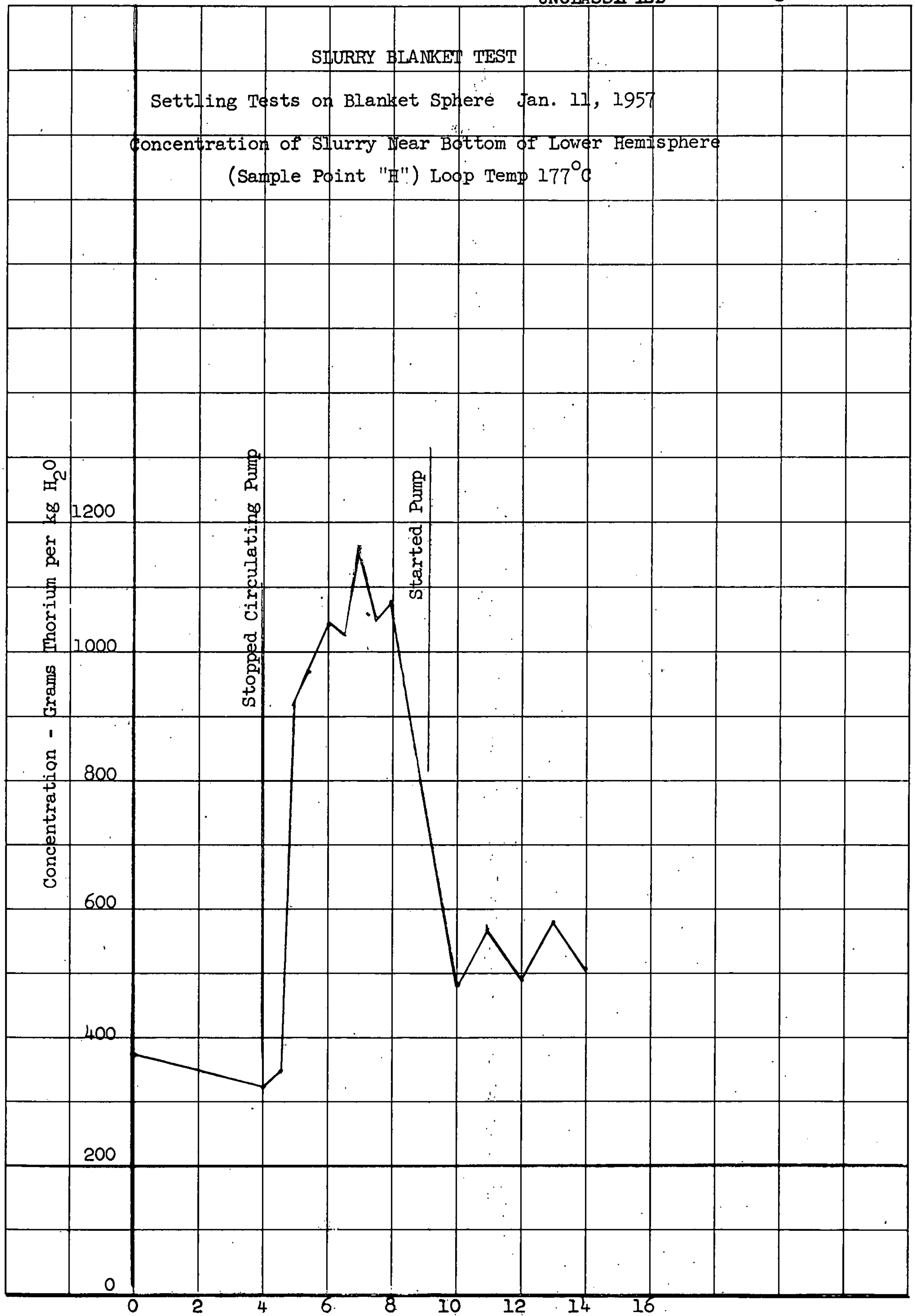
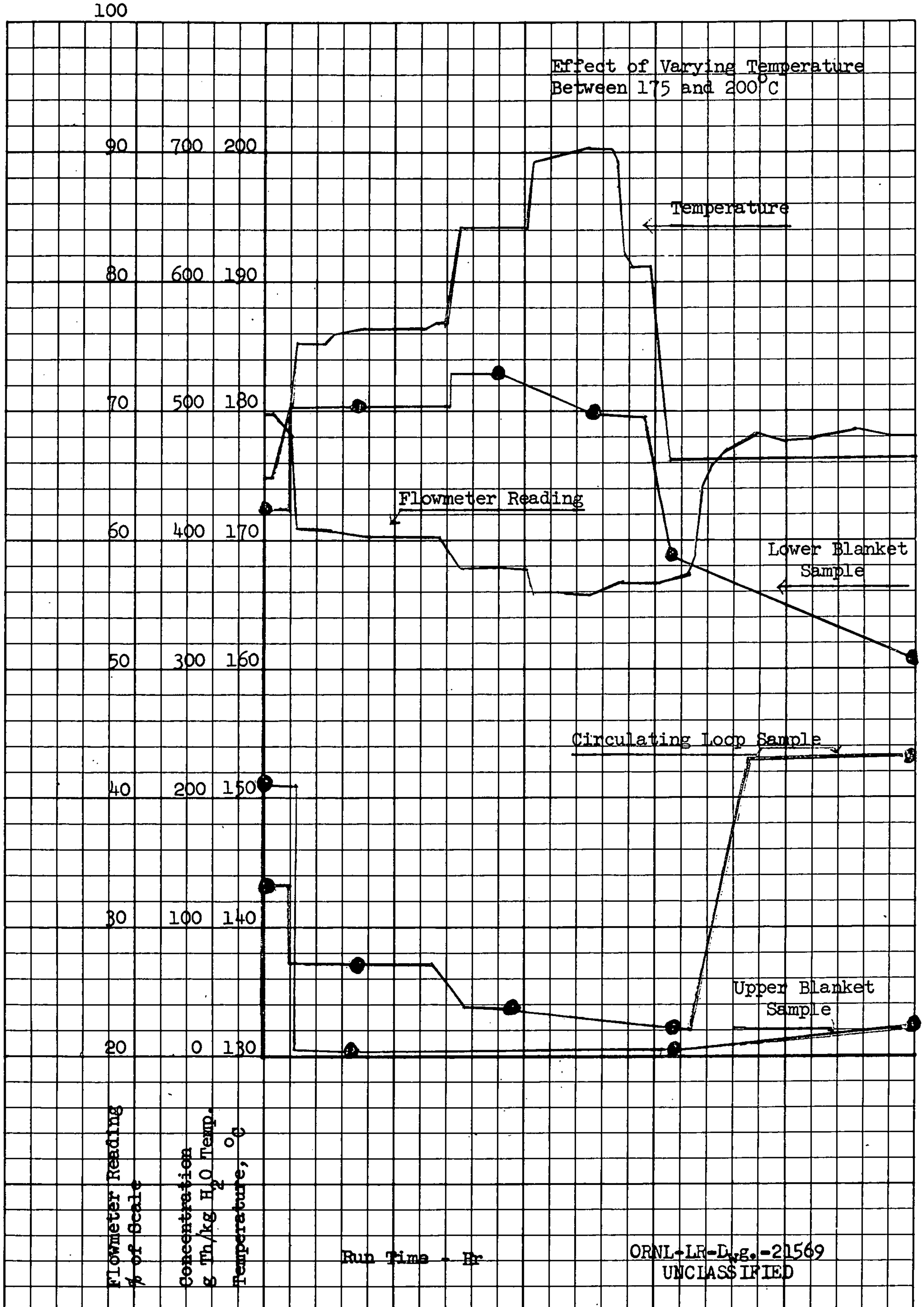


Fig. 5


Effect of Varying Temperature
Between 175 and 200°C
Temperature
Flowmeter Reading
Lower Blanket Sample
Circulating Loop Sample
Upper Blanket Sample
100
90 700 200
80 600 190
70 500 180
60 400 170
50 300 160
40 200 150
30 100 140
20 0 130
Flowmeter Reading % of Scale
Concentration g Th/kg H2O Temp.
Temperature, °C
Run Time - Hr
1300
1340
1380
1420
1460
1500
ORNL-LR-Dwg.-21569
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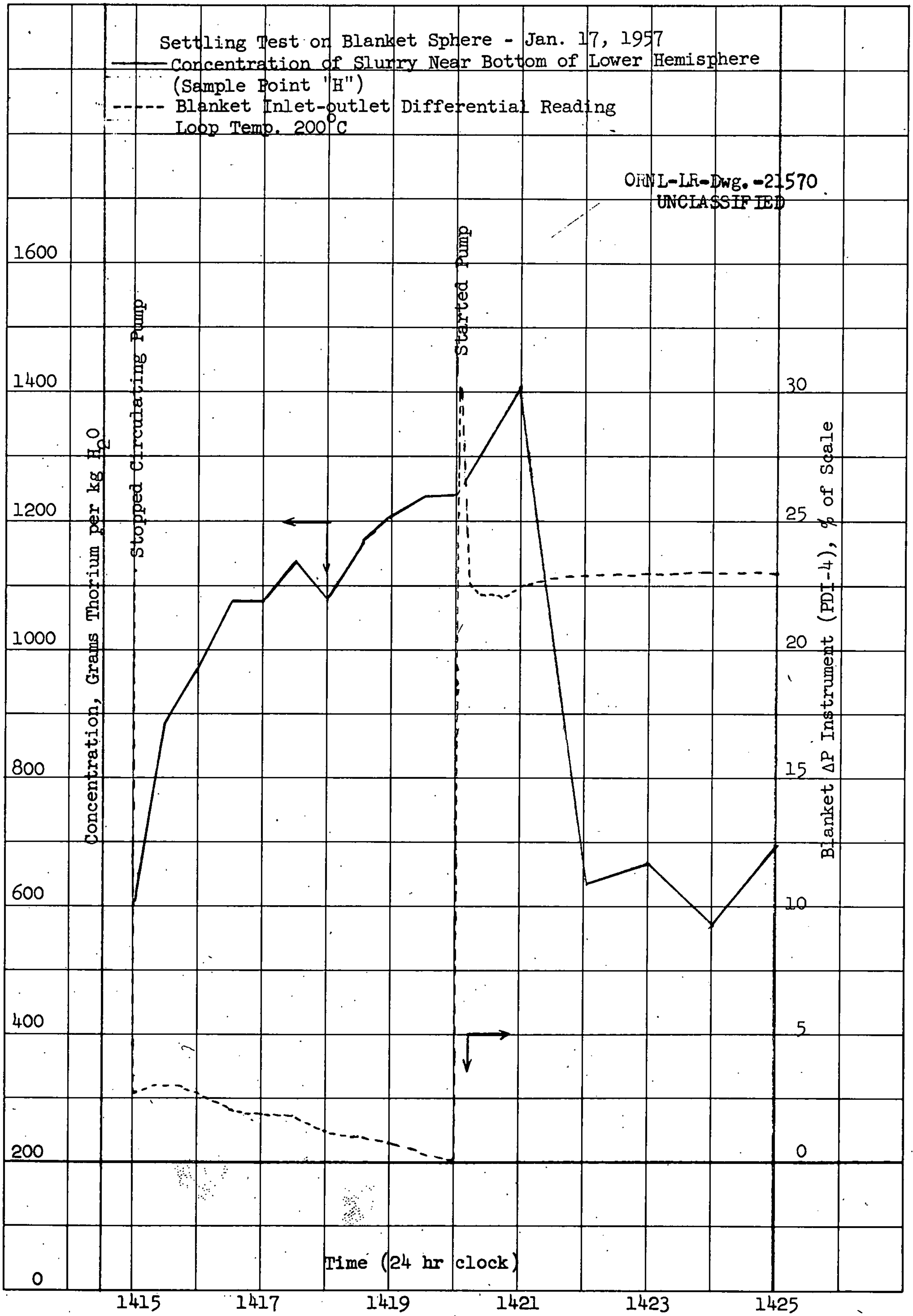
SLURRY BLANKET TEST

Fig. 6



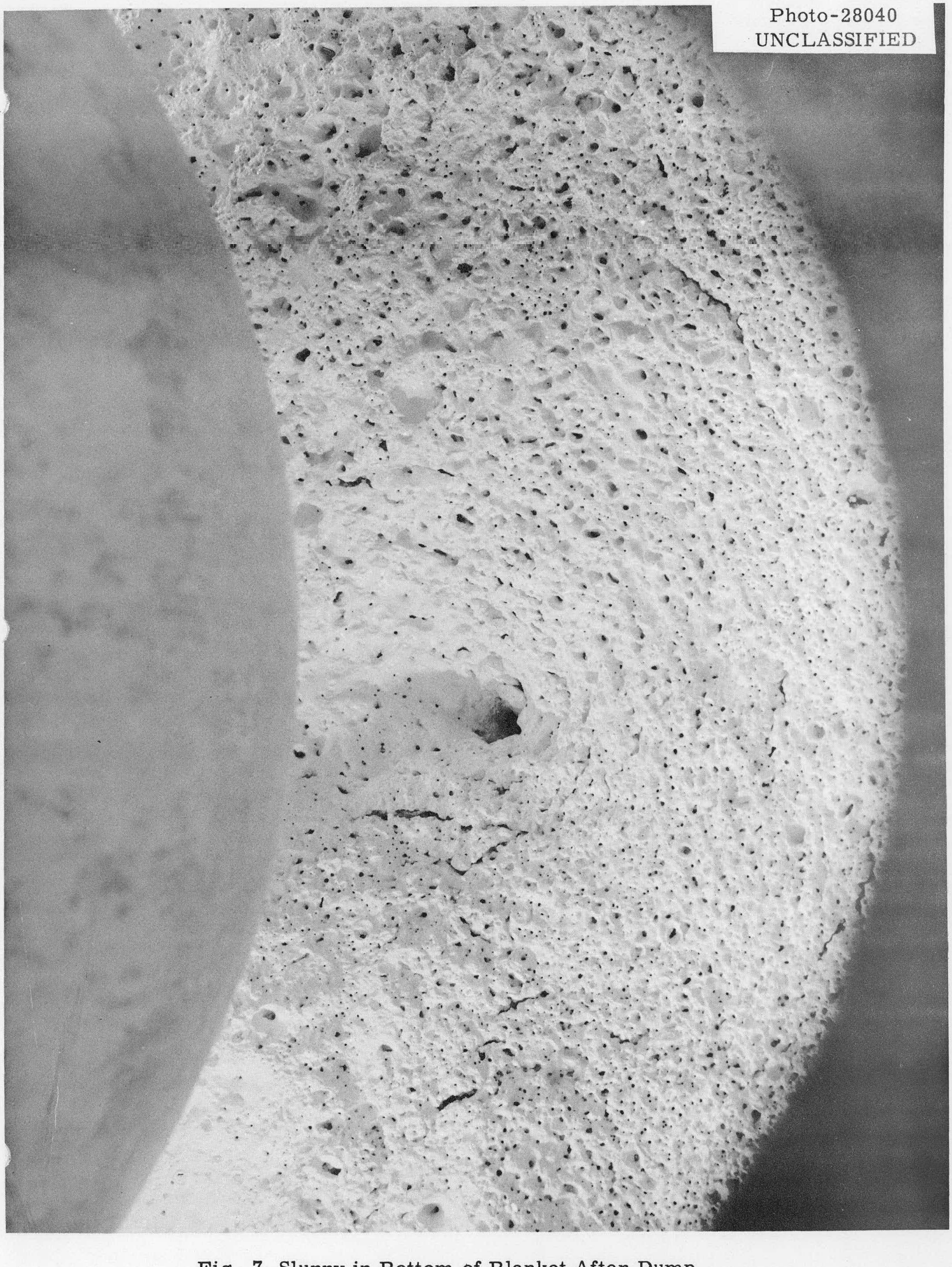


Fig. 7 Slurry in Bottom of Blanket After Dump

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Fig. 8 Top of Core After Dump

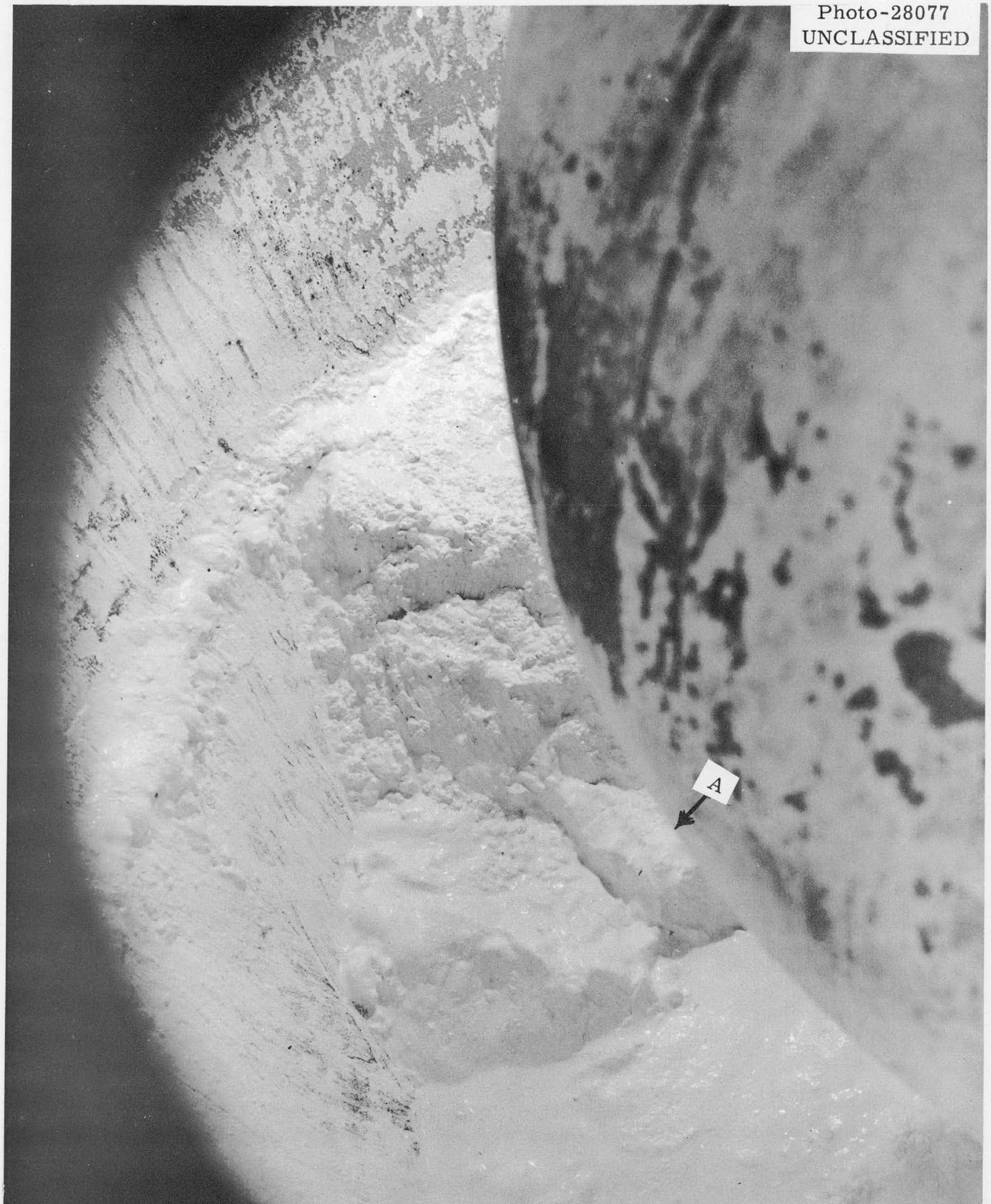

Fig. 10 View of Bottom of Blanket Looking Southwest Through East Porthole After First Rinse Run. Point "A" is Tie Point to Fig. 9.

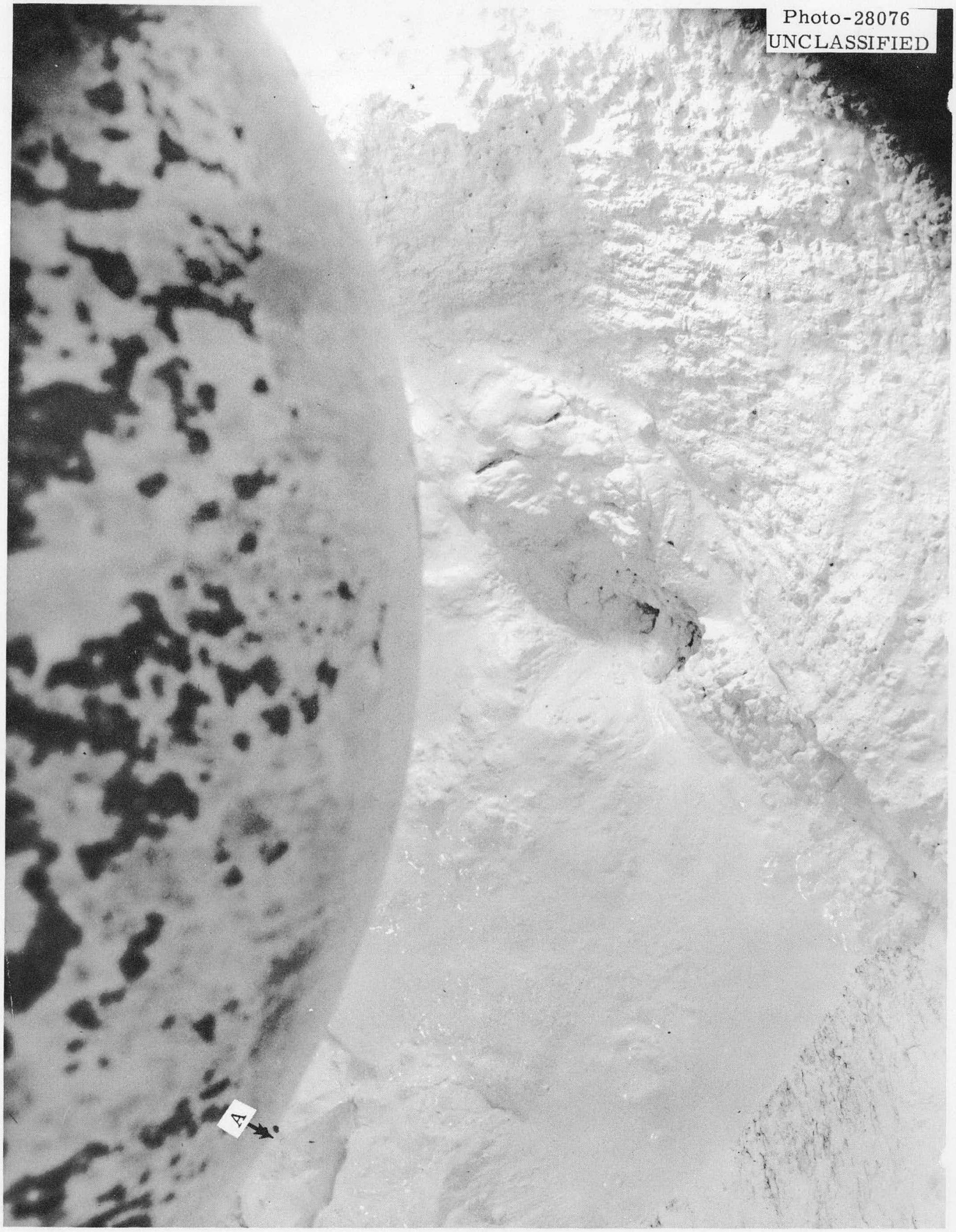

Fig. 9 Slurry in Bottom of Blanket After Refilling, Circulating 5 Hr. and Dumping. View Down Through East Porthole. Point "A" is Tie Point to Fig. 10.

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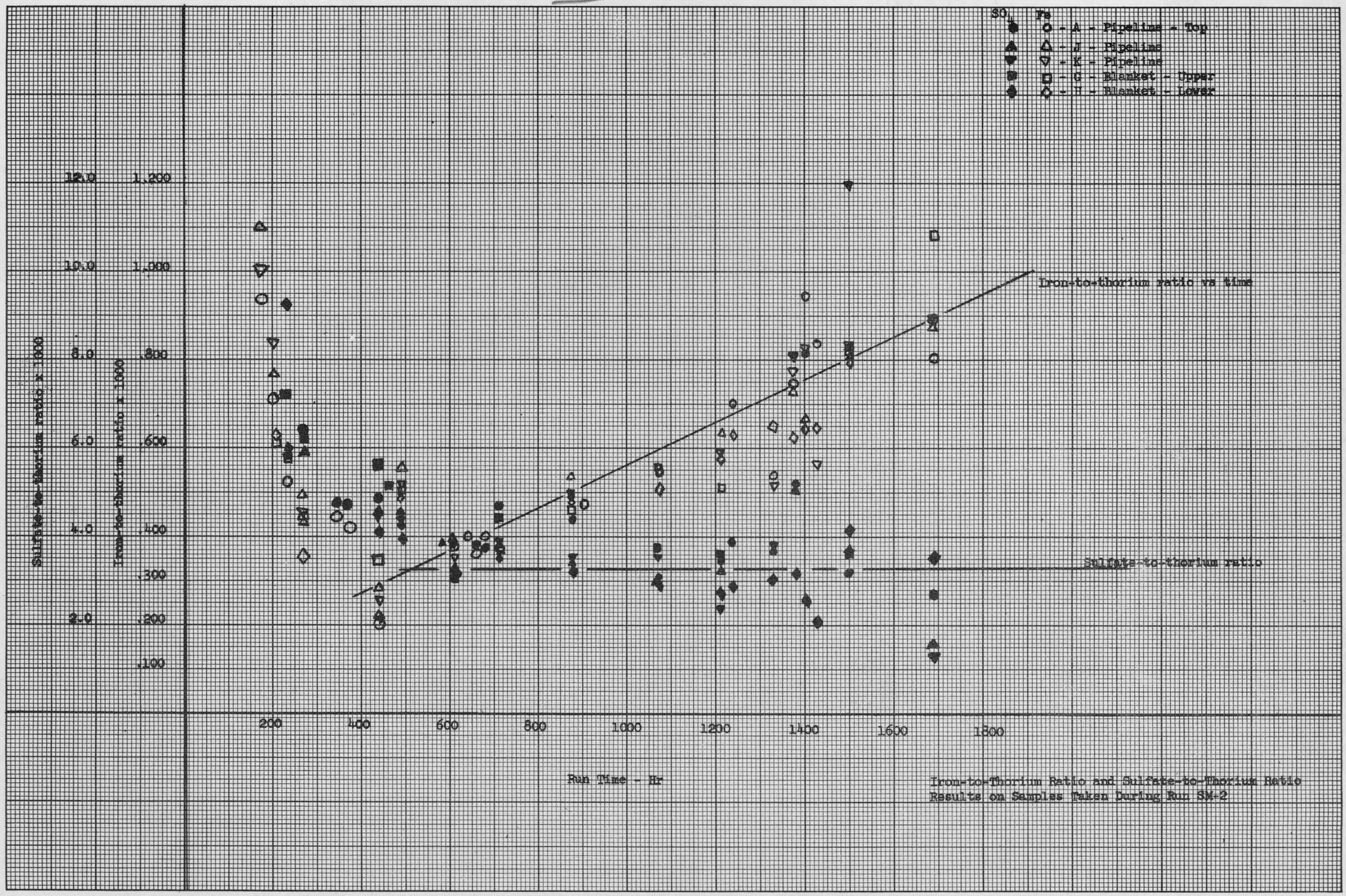
Fig. 11



Iron-to-Thorium Ratio and Sulfate-to-Thorium Ratio Results on Samples Taken During Run SM-2

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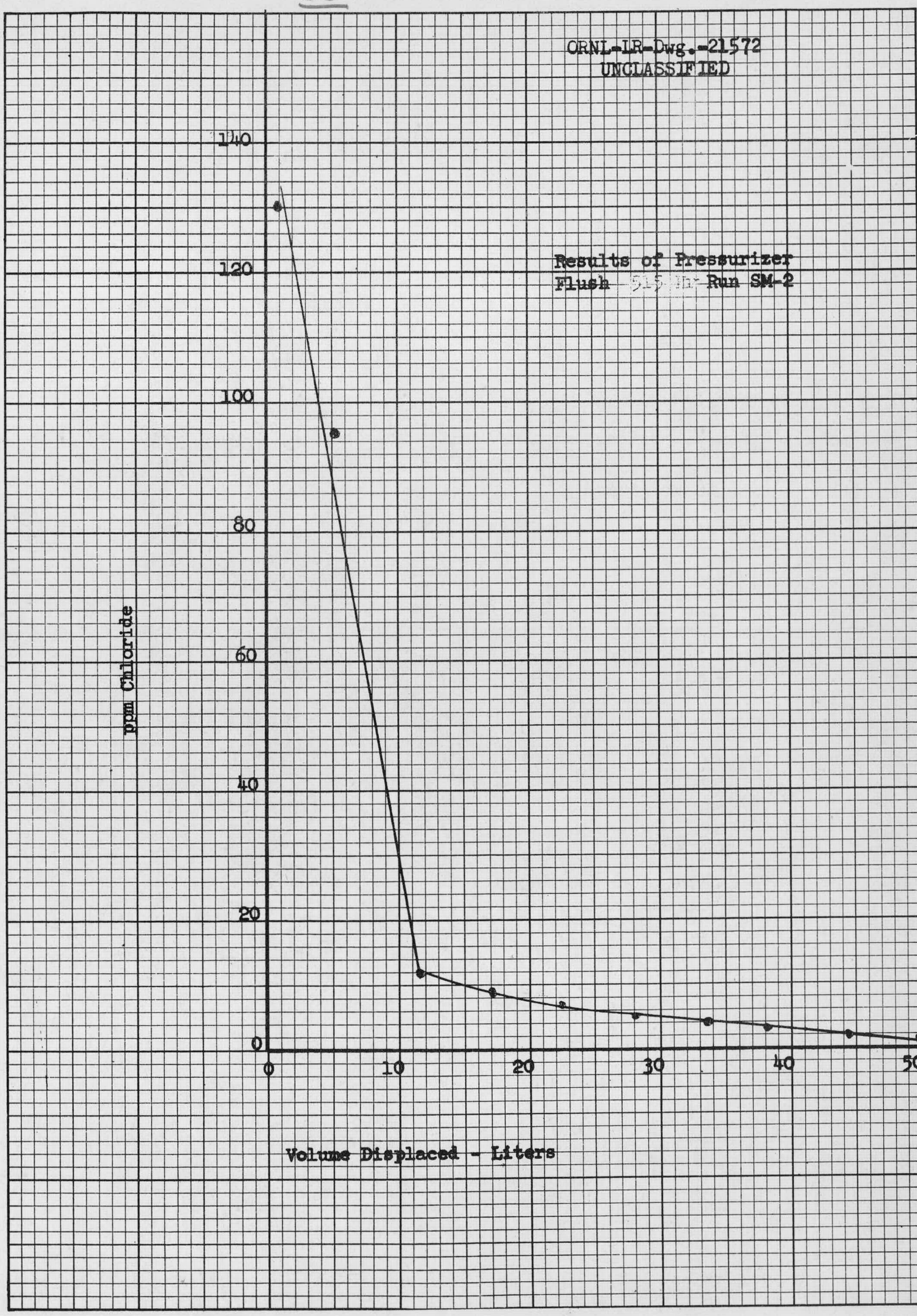
Fig. 12


ORNL-LR-Dwg.-21572
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Results of Pressurizer
Flush 515 Hr Run SM-2
ppm Chloride
140
120
100
80
60
40
20
0
0
10
20
30
40
50
Volume Displaced - Liters

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Fig. 13 Pump Impeller

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Fig. 14 Pump Impeller - Bottom View

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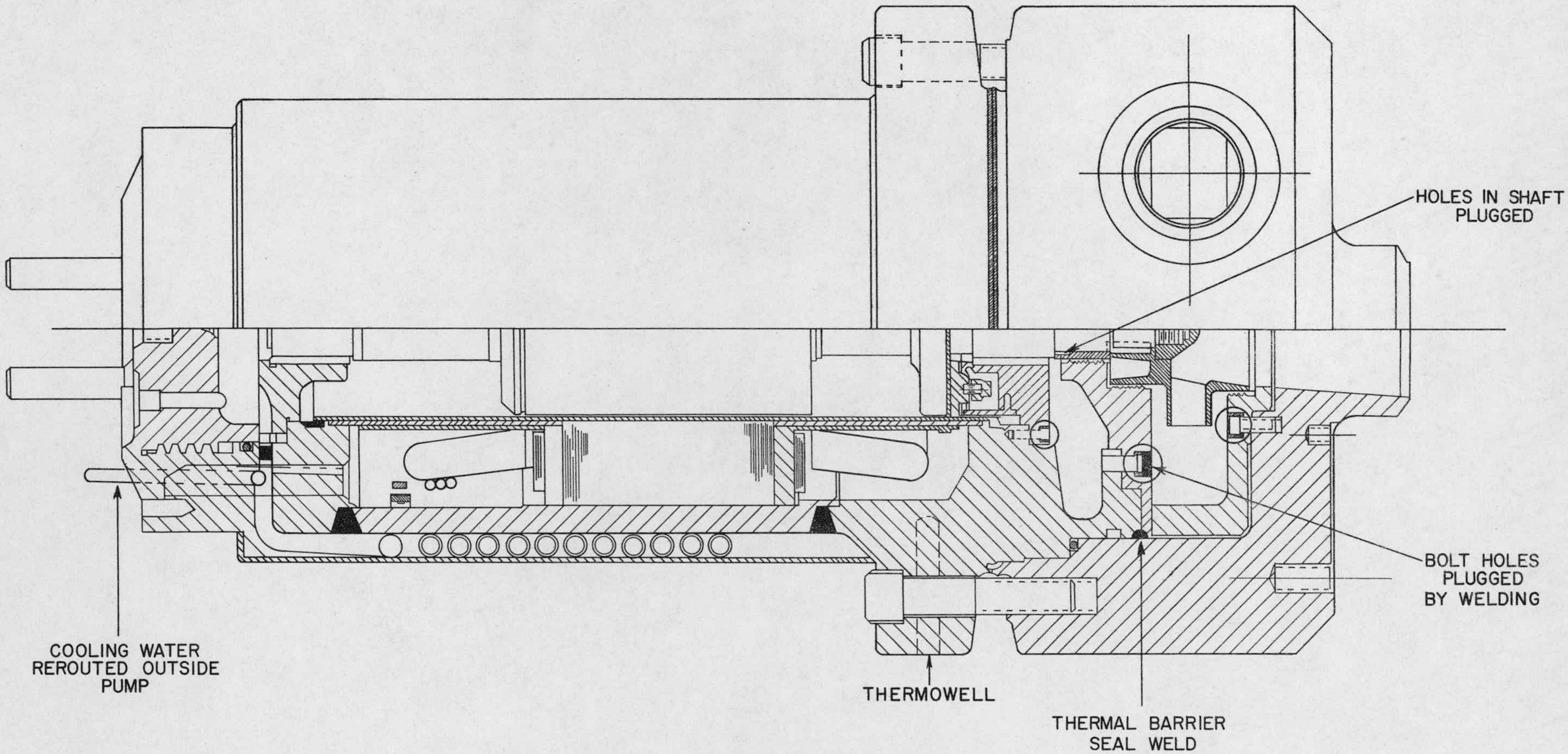

FIG. 15 MODEL 300A PUMP ASSEMBLY SHOWING MODIFICATIONS

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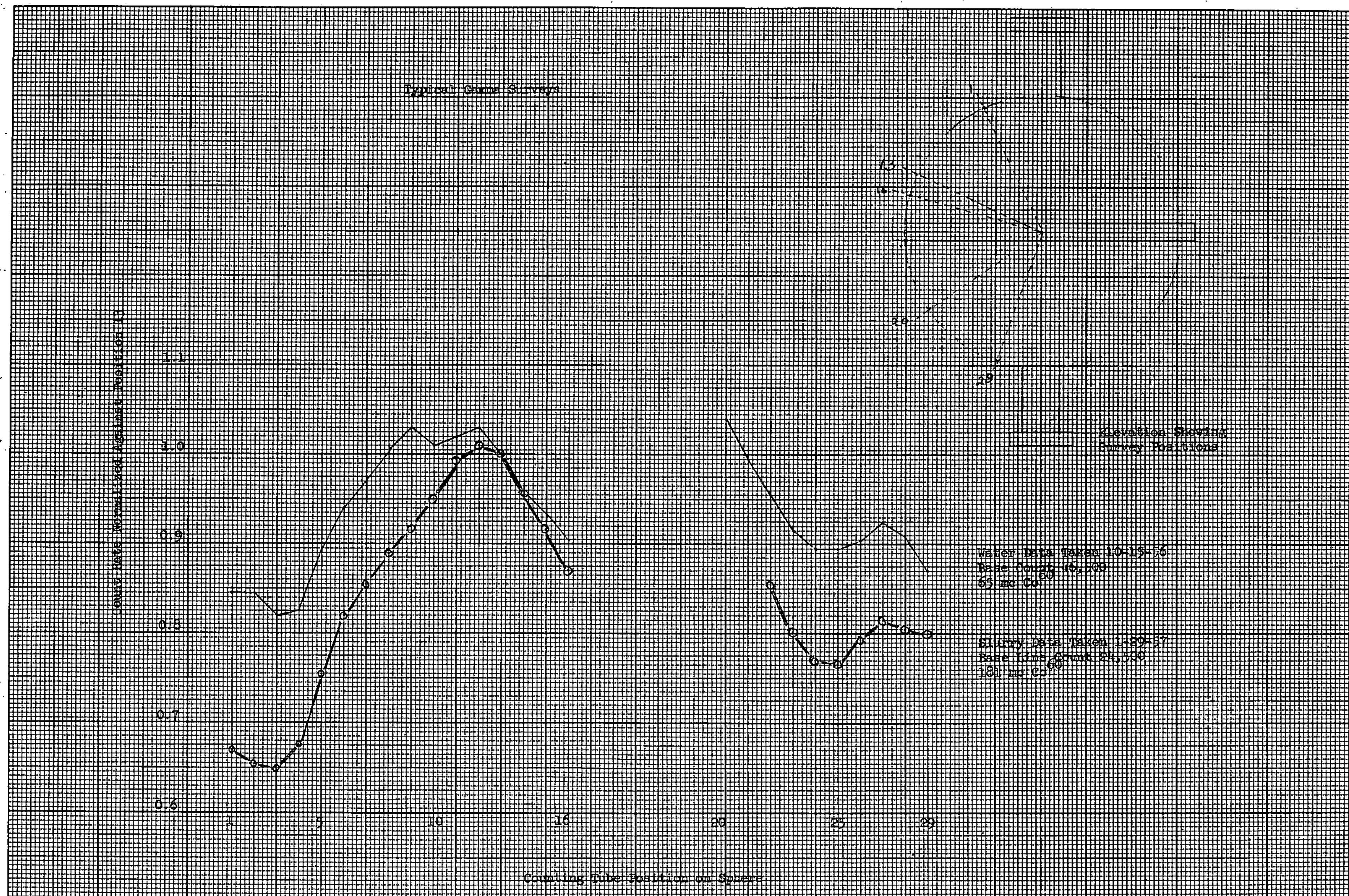
Fig. 16



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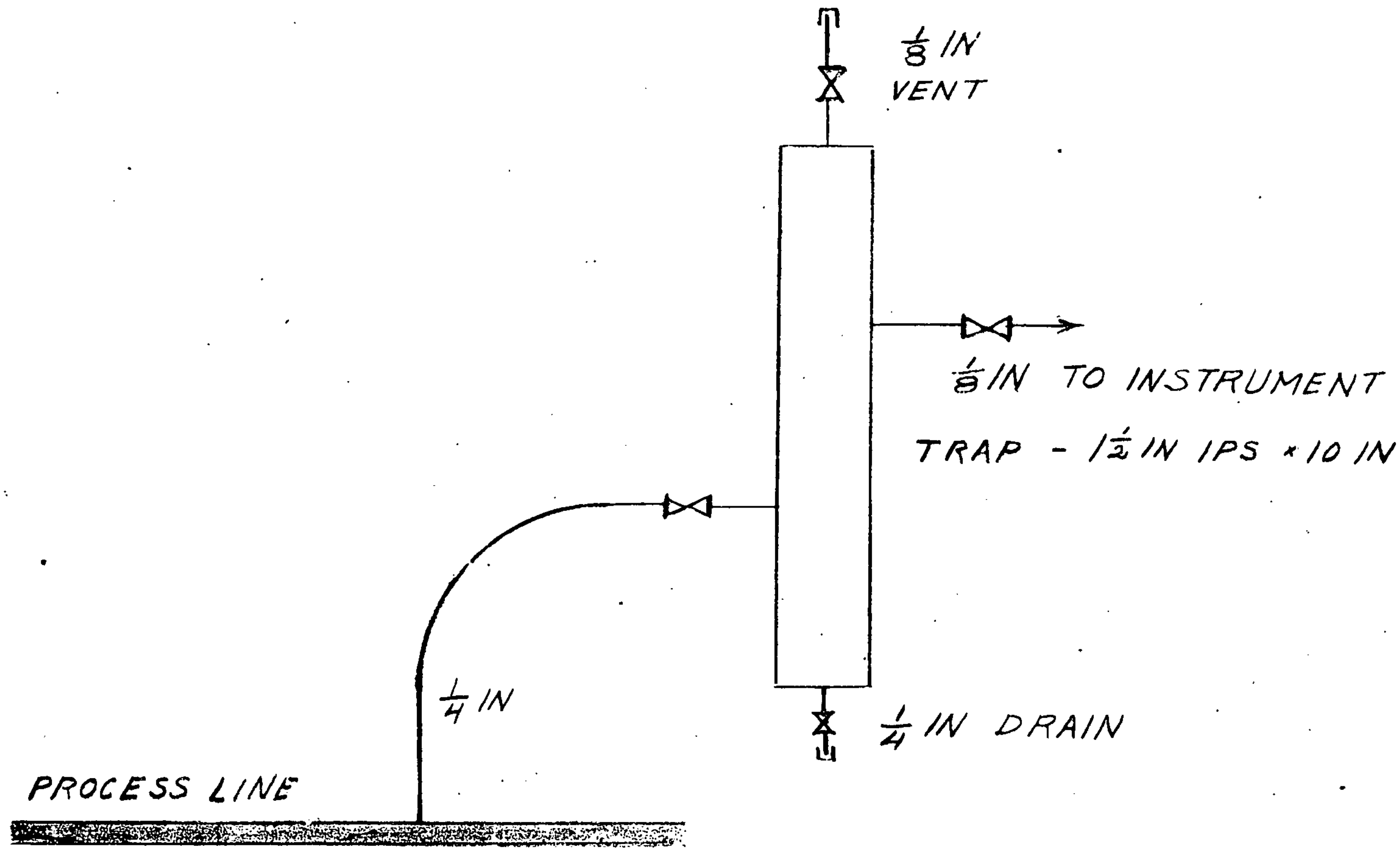

TYPICAL INSTRUMENT CONNECTION THROUGH SLURRY TRAP

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Fig. 17

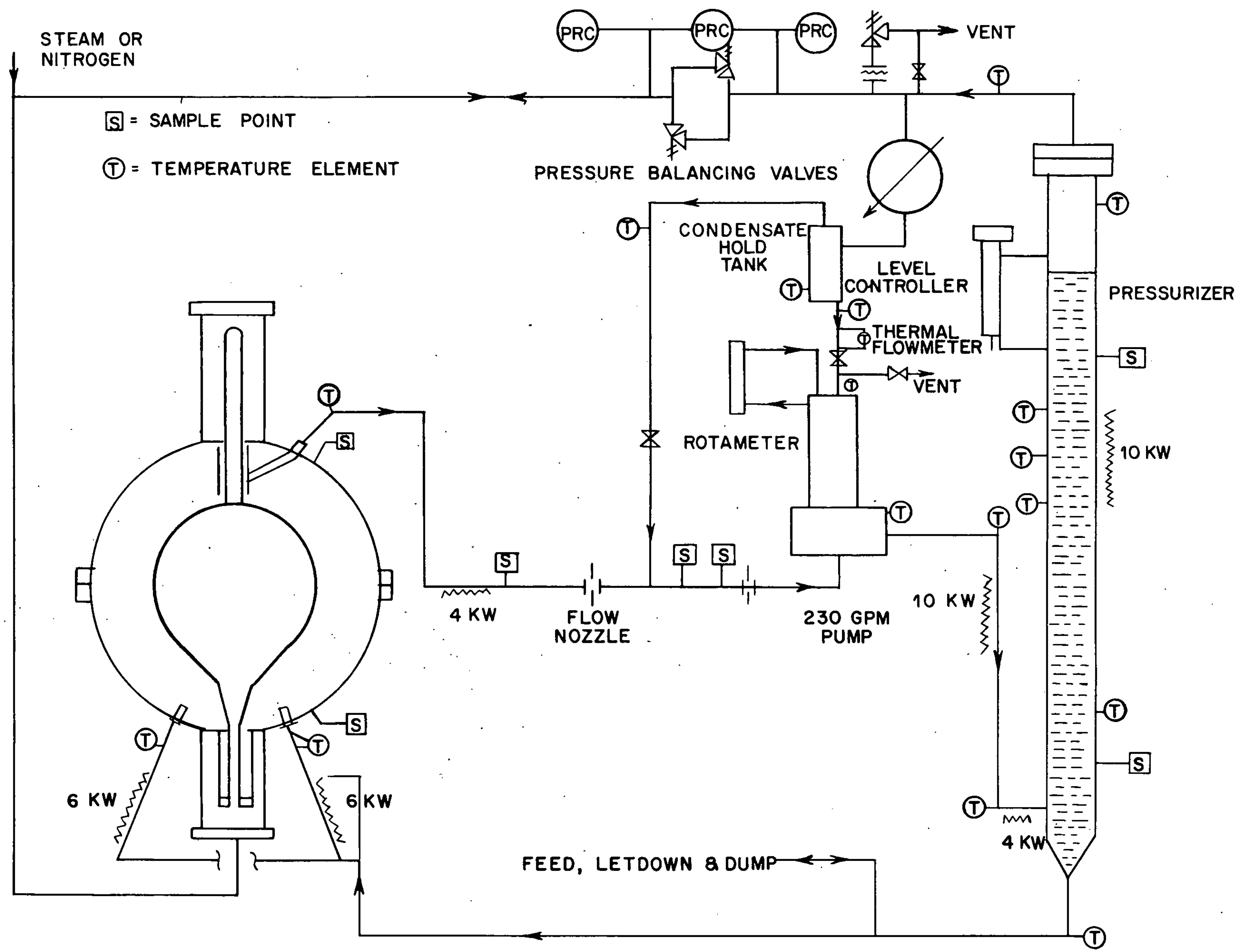

Fig. 18 Slurry Blanket Test System

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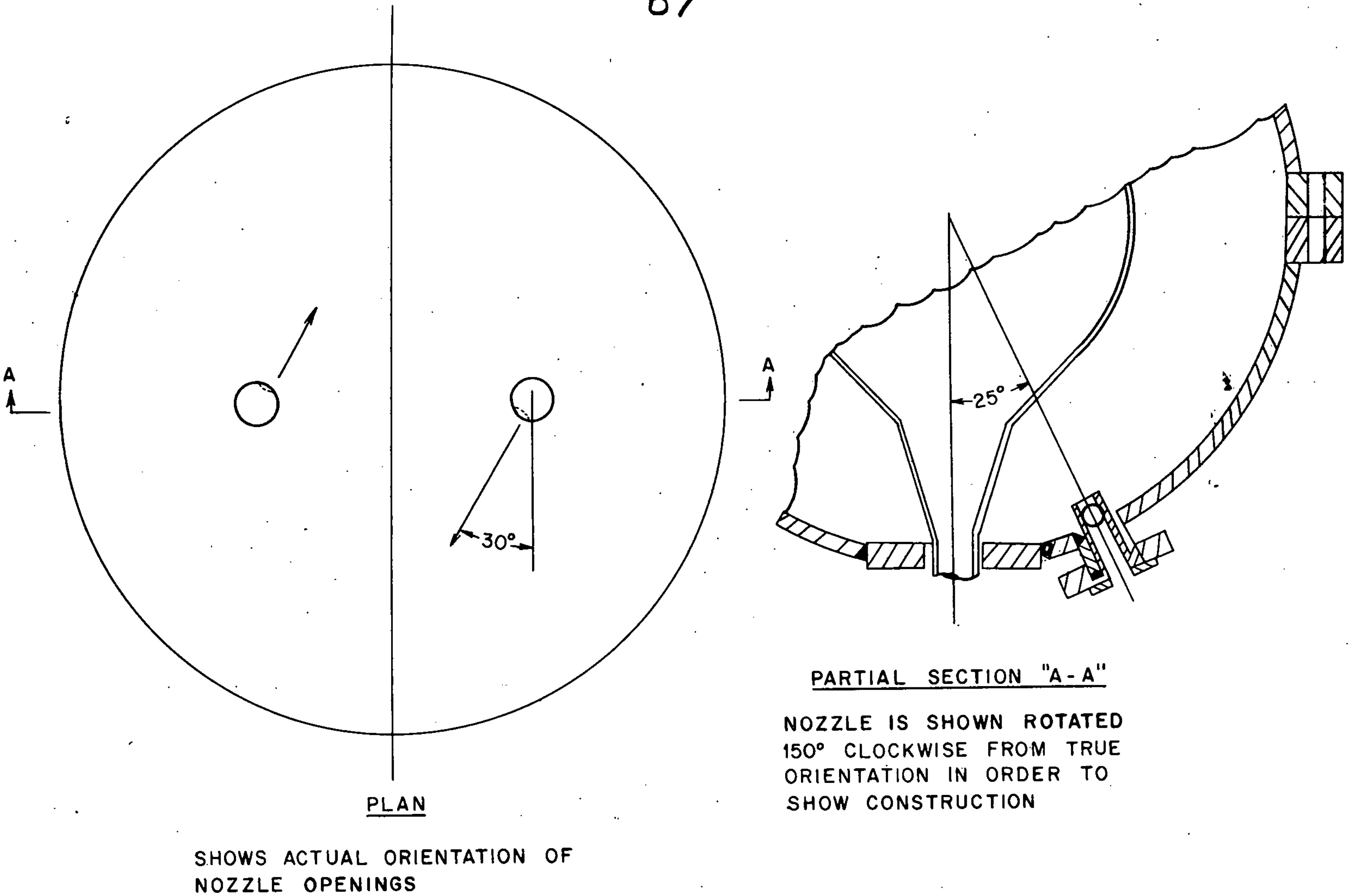

Fig. 19 Inlet Nozzle Arrangement

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ORNL-LR-DWG 18872

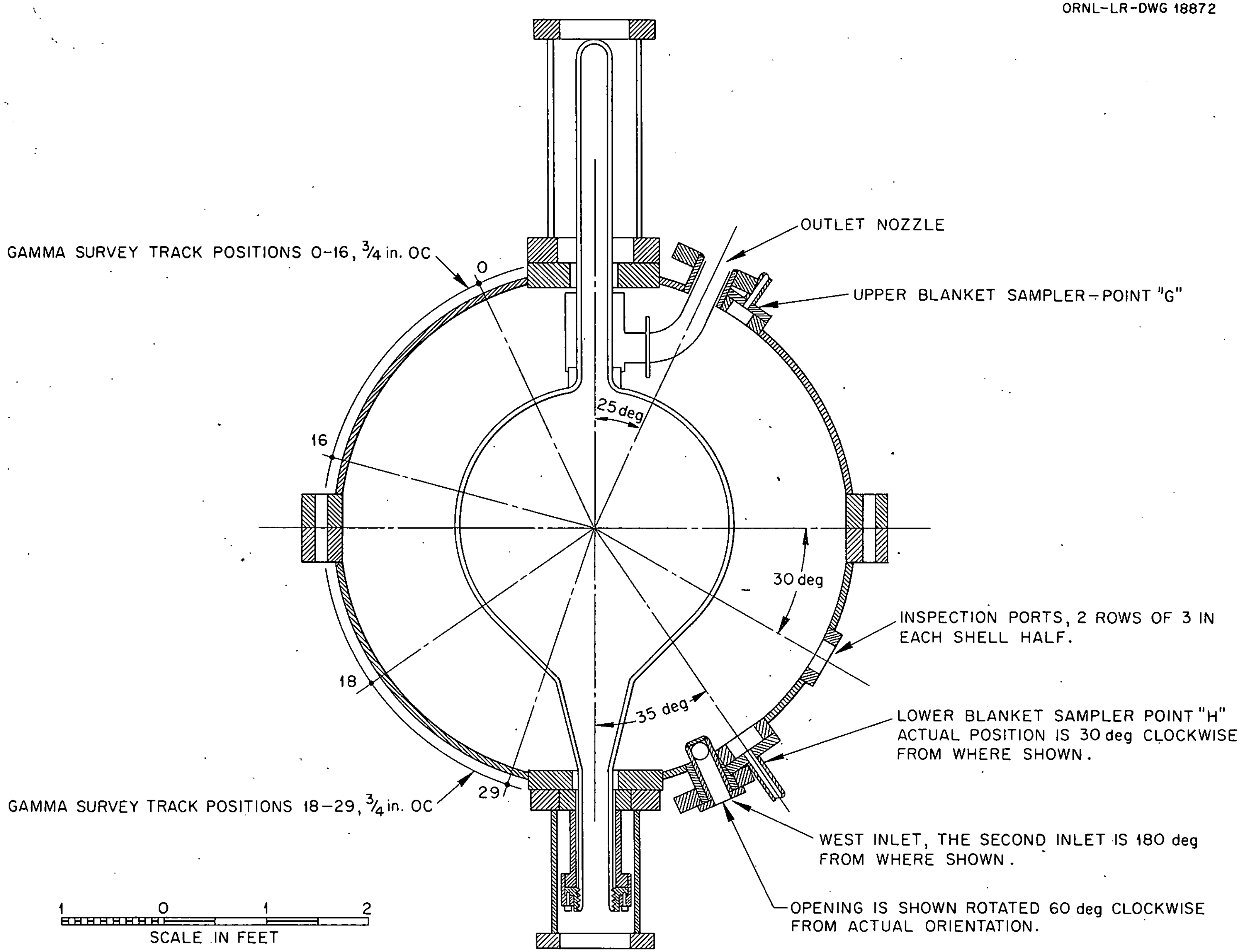

Fig. 20

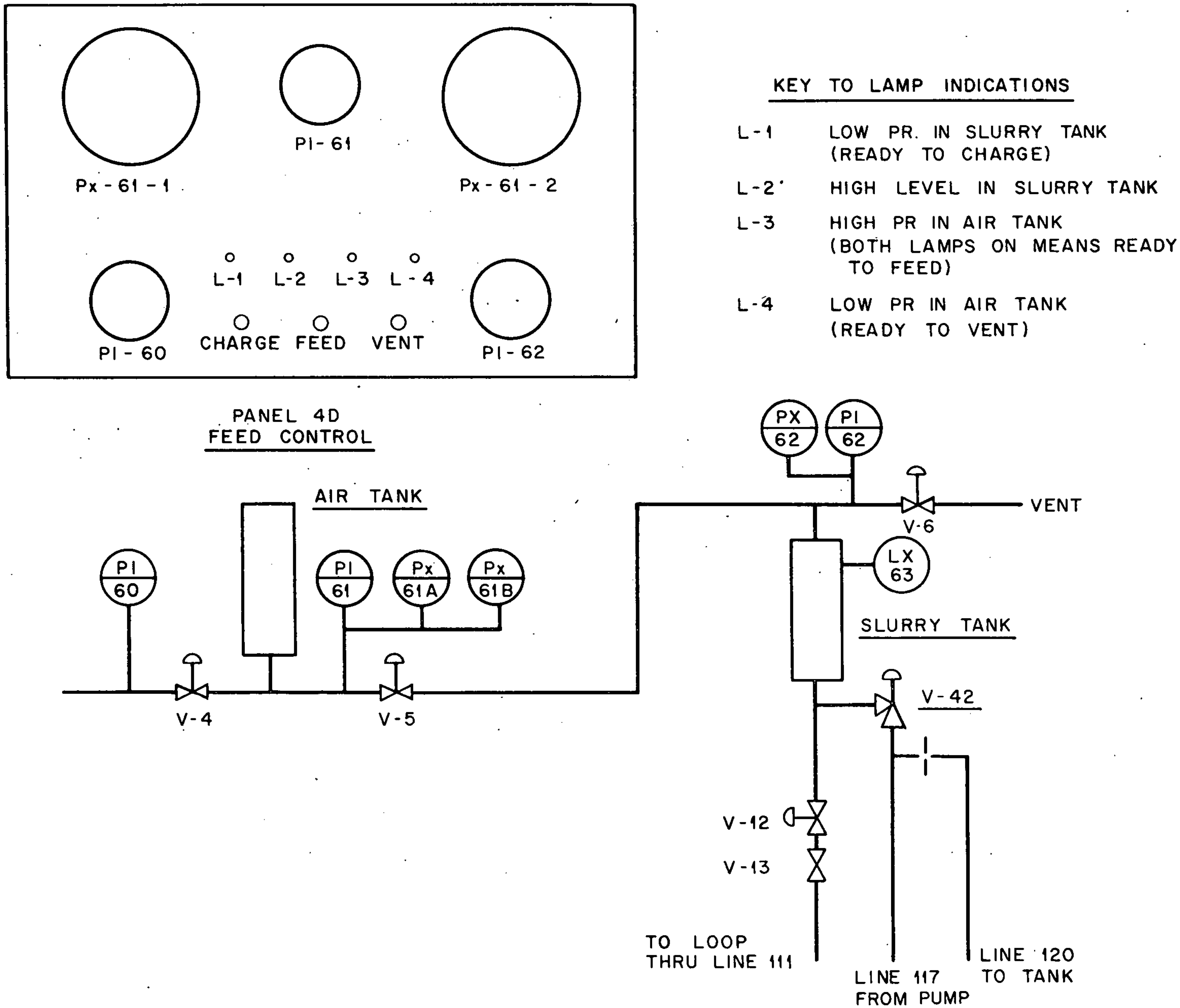

Fig. 21 Slurry Blanket Test High Pressure Feed System

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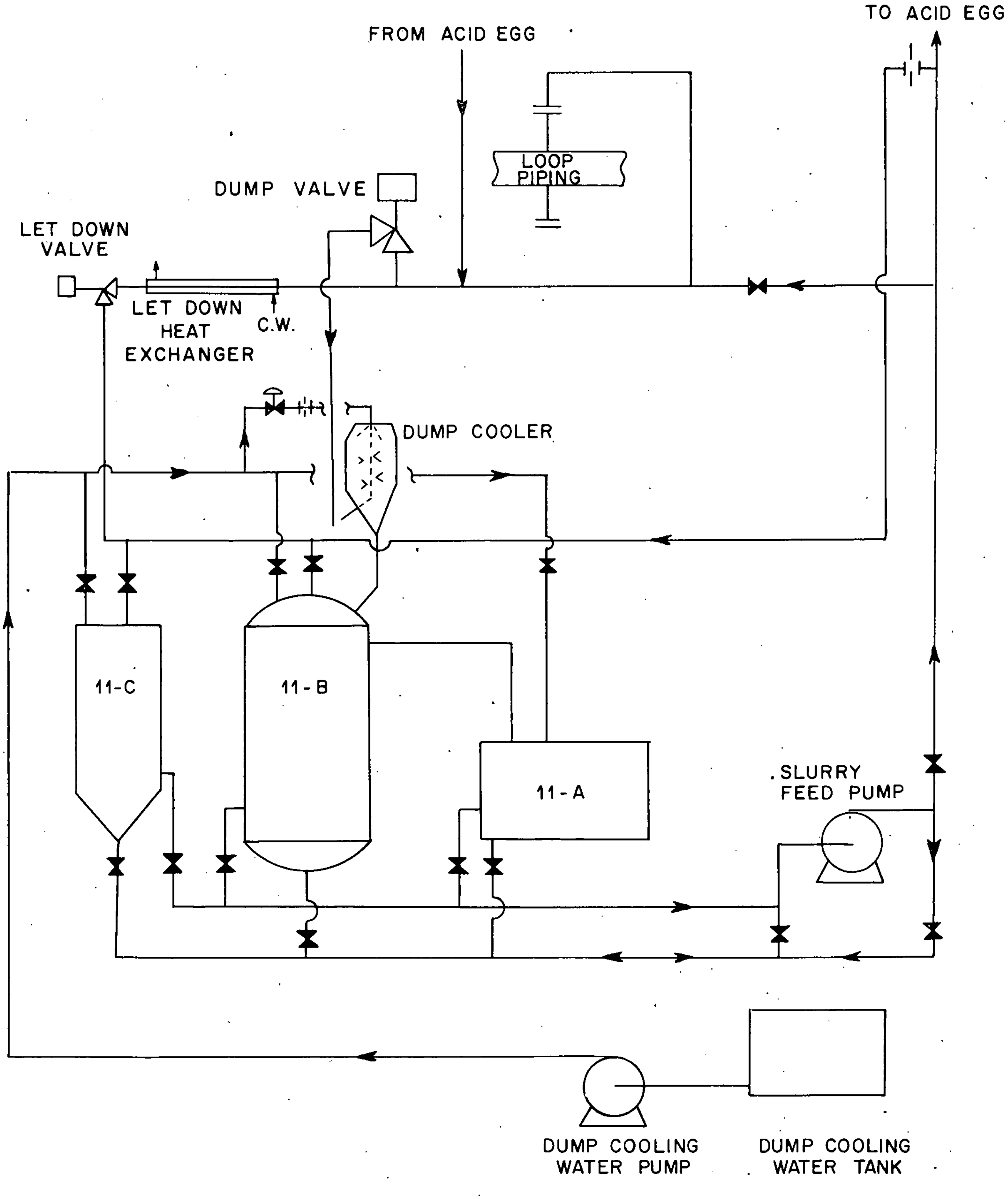

Fig. 22 Slurry Blanket Test Feed, Dump and Letdown Systems

I–III AND
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