APAE-29

REACTORS—POWER

UNITED STATES ATOMIC ENERGY COMMISSION

CORROSION PRODUCT ACTIVITY IN THE PRIMARY SYSTEM OF THE ARMY PACKAGE POWER REACTOR

April 15, 1958

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Schenectady, New York

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CORROSION PRODUCT ACTIVITY IN THE PRIMARY SYSTEM OF THE ARMY PACKAGE POWER REACTOR

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by

CHEMICAL TECHNOLOGY SECTION
ATOMIC ENERGY ENGINEERING

April 15, 1958

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ABSTRACT

Experimental work has been performed to determine the extent and mechanism of the buildup of activated corrosion products in the primary system of the Army Package Power Reactor. This report presents the results of radiochemical analyses of water and crud sampled from the primary system, and of deposits removed from the surface of metal test specimens exposed to the primary coolant. In addition, the dose rates measured during reactor shutdown at the external surfaces of primary system components are reported.

Water, crud, and deposits from the metal test samples were analyzed for long-lived gamma emitting nuclides only. Data are presented on the specific activity of these samples and the nuclide ratios of these specific activities. The buildup of activity on the surface of the metal specimens is shown to be related to time of exposure, temperature of the coolant, and the type of steel specimen used.

I INTRODUCTION

Alco Products, Inc., under contract with the Army Reactors Branch of the Atomic Energy Commission, has been investigating the extent of buildup of activated corrosion products at the Army Package Power Reactor (APPR-1). This reactor, located at Fort Belvoir, Virginia, is a 10 MW thermal reactor capable of producing 2,000 KW of electricity. The plate type fuel elements are fully enriched uranium clad with stainless steel. The plant went critical in April of 1957 and on June 2, 1957 began a 700 hour continuous test which was completed July 1, 1957.

In all pressurized water reactor operations as well as other types of reactors, activated corrosion products have been found to build up on primary system components. The corrosion products originate both in the reactor core and throughout the primary system. Persons concerned with the design, construction, and operation of pressurized water reactors are becoming aware of this problem. Theoretical calculations to predict the extent of buildup of radioactivity on the primary system components have not been sufficiently accurate, particularly for long lived nuclides. Experimental data is necessary to allow prediction of the future buildup on component parts. This experimental data is now being collected to determine the parameters and mechanisms contributing to this buildup.

The contract for the study of activity buildup includes the following:

1. A literature survey of the present state of knowledge of the field. A report on this work has been issued (1).

2. Design of the mechanisms for obtaining metal, crud, and water samples. A mechanism for the insertion and removal of test coupons from the steam generator has been designed and submitted to the Army Reactors Branch. Devices for collecting crud and exposing metal test coupons upstream and downstream of the purification system heat exchanger have already been installed.
3. Radiochemical analyses of water, crud, and metal samples. Previous reports(2, 3) indicated results of analyses of both primary system water and primary system crud during earlier operations.

This report gives results and the interpretation of data collected from the following sources during the period August 1, 1957 to February 7, 1958:

1. Radiochemical analysis of primary water sampled at two locations.
2. Radiochemical analysis of primary system crud sampled at two locations.
3. Measurement of dose rates emanating from the primary system after shutdown.
4. Gross activity of Type 304 stainless steel, Croloy 16-1 stainless steel, and carbon steel metal coupons and 304 pipe samples exposed to primary water.
5. Metallographic analysis of metal test samples.
6. Radiochemical analysis of loosely and tightly bound deposits on metal test samples.

7. Effect of different materials of construction on the activity buildup.

8. Effect of temperature on activity buildup.

II CONCLUSIONS

1. Radiochemical analyses of crud and water samples indicate there is no clear increase in the specific activity of long-lived gamma emitting nuclides with increased reactor operating time. However, the Co^{58}/Co^{60} ratio appears to be decreasing slowly, indicating that Co^{60} is still accumulating at a faster rate than Co^{58}.
2. Metal test specimens exposed to the primary coolant show that temperature has a marked effect both upon the total activity accumulated on the surface of the specimens and upon the adherence of the activity. Specimens exposed to 430-450° water were found to be from 2 to 10 times more radioactive than like specimens exposed to 90-110° water for the same periods of time.
3. The accumulation of activity on metal test specimens was found to be dependent on the type of material used. Of the three materials Type 304 stainless steel, Babcock & Wilcox Croloy 16-1 stainless steel and carbon steel, the Croloy 16-1 would be the least desirable material from the activity buildup and ease of decontamination viewpoint.
4. The experimental data show no clear relationship between circulating crud specific activity and the specific activity of the corrosion products deposited on metal test specimens. In general, the specific activity of the deposited material is less than that of the crud, but appears to have the same isotopic distribution of those

nuclides in the crud.

5. Dose rate measurements of primary system components at reactor shutdown indicate a buildup of long-lived activity with increasing reactor operating time. Because of variations in the data and unconfirmed assumptions, it is not possible at this time to accurately predict the future dose rates.

III SAMPLING PROCEDURES

The samples to be analyzed were obtained at the Army Package Power Reactor at predetermined intervals. They were then shipped directly to Alco's Schenectady laboratory where analysis was performed. The location of the sample points and sampling procedures followed for collecting water, crud and metal samples are described below.

A. WATER

Primary water samples were taken upstream and downstream of the primary system purification demineralizer. One liter samples were taken from the upstream sample point, and following the addition of standardized carriers, the sample was concentrated and shipped to Schenectady for analysis. Since the samples downstream of the demineralizer had very little activity, it was necessary to take four liter samples from this point. This sample was then treated in the same manner as the upstream sample. Samples withdrawn upstream of the demineralizer were designated AU-1, AU-2, etc. Those taken downstream of the demineralizer were labeled RX-1, RX-2, etc.

B. CRUD

Crud samples were taken upstream and downstream of the blowdown cooler. The downstream sampling system is shown schematically in Figure 1.

The downstream sampling unit is a 4-1/2 inch long by 1-1/2 inch diameter micrometallic "PSS" Type 316 stainless steel, hollow cylindrical filter element, mounted within a 2 inch diameter stainless steel housing. The element is attached to the filter housing by means of a screw type insertion. Flow passes

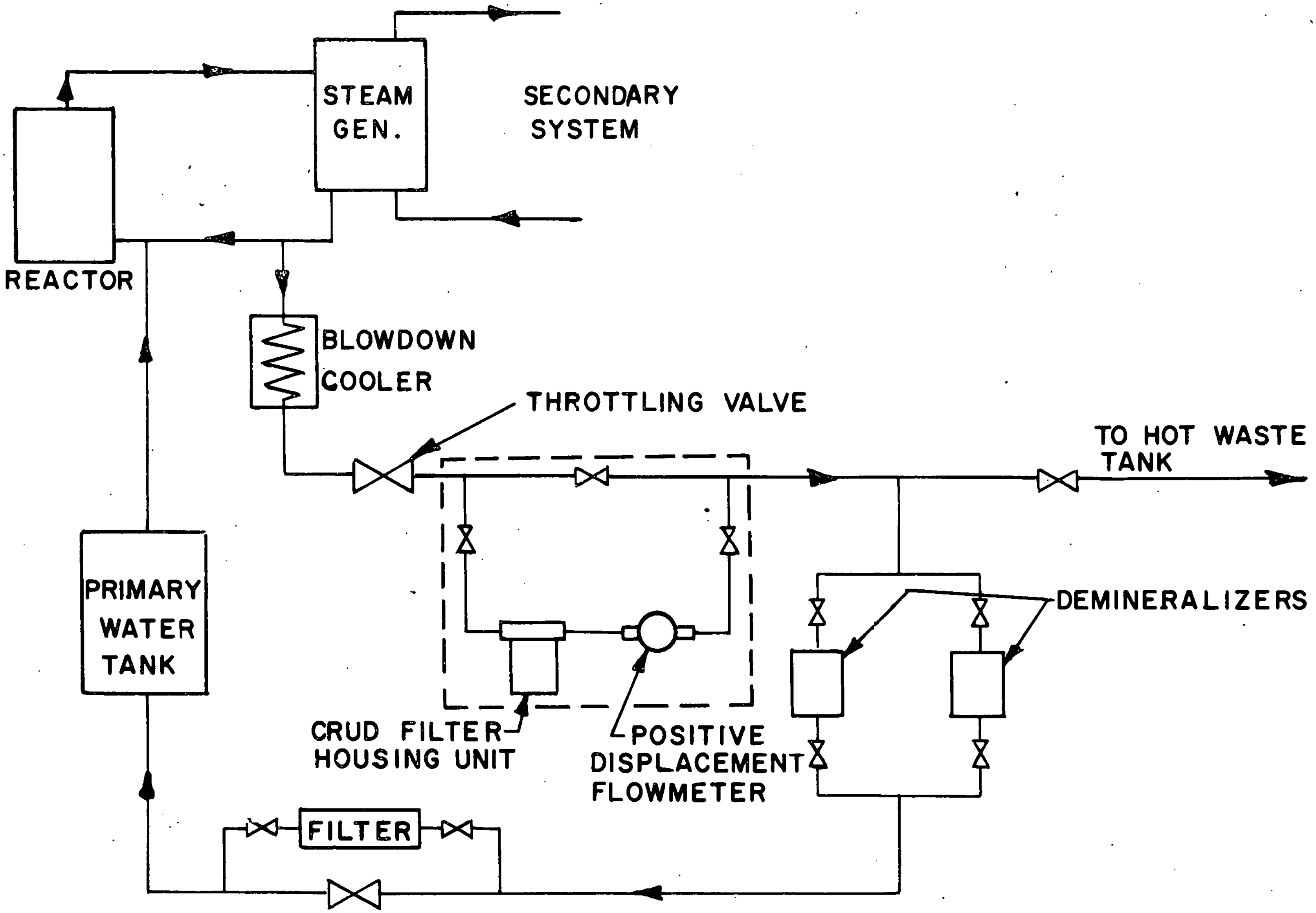

FIG. 1 CRUD SAMPLING SYSTEM

from the outside surface through the porous stainless steel into the hollow center, and out through the threaded connection. The element is rated to retain any particle larger than 2 microns. Flow through the filter was regulated by means of three needle valves. A positive displacement flowmeter with an accuracy of 2 percent was used to measure flow. Upon removal of the filter element from the housing, the filter plus the water and crud contained in the housing were placed in a polyethylene container and shipped to Schenectady for radiochemical analysis.

The crud sampling unit upstream of the blowdown cooler is nearly identical to the downstream filter, except that it is longer - 12 inches long by 1 inch diameter, with 45 square inches filter of surface area. The unit is rated to withstand a differential pressure of 1500 psi. Particle retention size and other features are the same as the downstream unit. This filter is also located on a bypass line of the 1 inch purification system blowdown line similar to the downstream filter. Figure 3 is a photograph of this crud filter as it is installed within the vapor container. A turbine type flowmeter and remotely operated (from the control room) solenoid valve are employed to regulate the amount of flow through the filter.

The crud filter is removed during plant shutdown when access can be had to the vapor container. Handling procedure upon removal is similar to that for the downstream filter. Since upstream crud sampling periods were over a longer time interval than that for the downstream filter (due to inaccessibility in the vapor container), flow through the filter was for a 15 minute period each day. This allowed a convenient amount of crud to be collected, and it was considered that a more representative sample could be collected in this manner.

Crud samples collected upstream of the blowdown cooler are designated CU-1, CU-2, etc.

Crud samples collected downstream of the cooler are labeled CD-1, CD-2, etc.

C. METAL SAMPLES

To measure the activity buildup on metal surfaces, metal test specimens were inserted in the primary purification blowdown line both upstream and downstream of the blowdown cooler. These test specimens were fabricated in the shape of individual flat coupons 3-1/2" x 1/2" x 1/16", and 1 inch segments of Type 304 stainless steel 1 inch Schedule 80 pipe.

The metal coupons were fabricated from flat mill-rolled stock of Type 304 stainless steel, Babcock and Wilcox stainless steel Croloy 16-1 (a Type 430 - modified stainless steel), and carbon steel. These coupons were held in special specimen holders, which in turn were located inside a special 1-1/2 inch flanged pipe holder inserted in the purification blowdown line. Figure 2 illustrates a typical coupon specimen holder, and Figure 3 illustrates the flanged pipe holder into which the specimen holder is placed. The one inch segment pipe samples were placed in a similar type flanged holder. These pipe specimens were so positioned that flow passed only over the inner surface of the pipe sample.

The Type 304 stainless steel coupons were fabricated from 1/16 inch thick flat stock. No surface machining or grinding was performed as it was desired that the surface finish of the specimens be in the "as-rolled" condition.

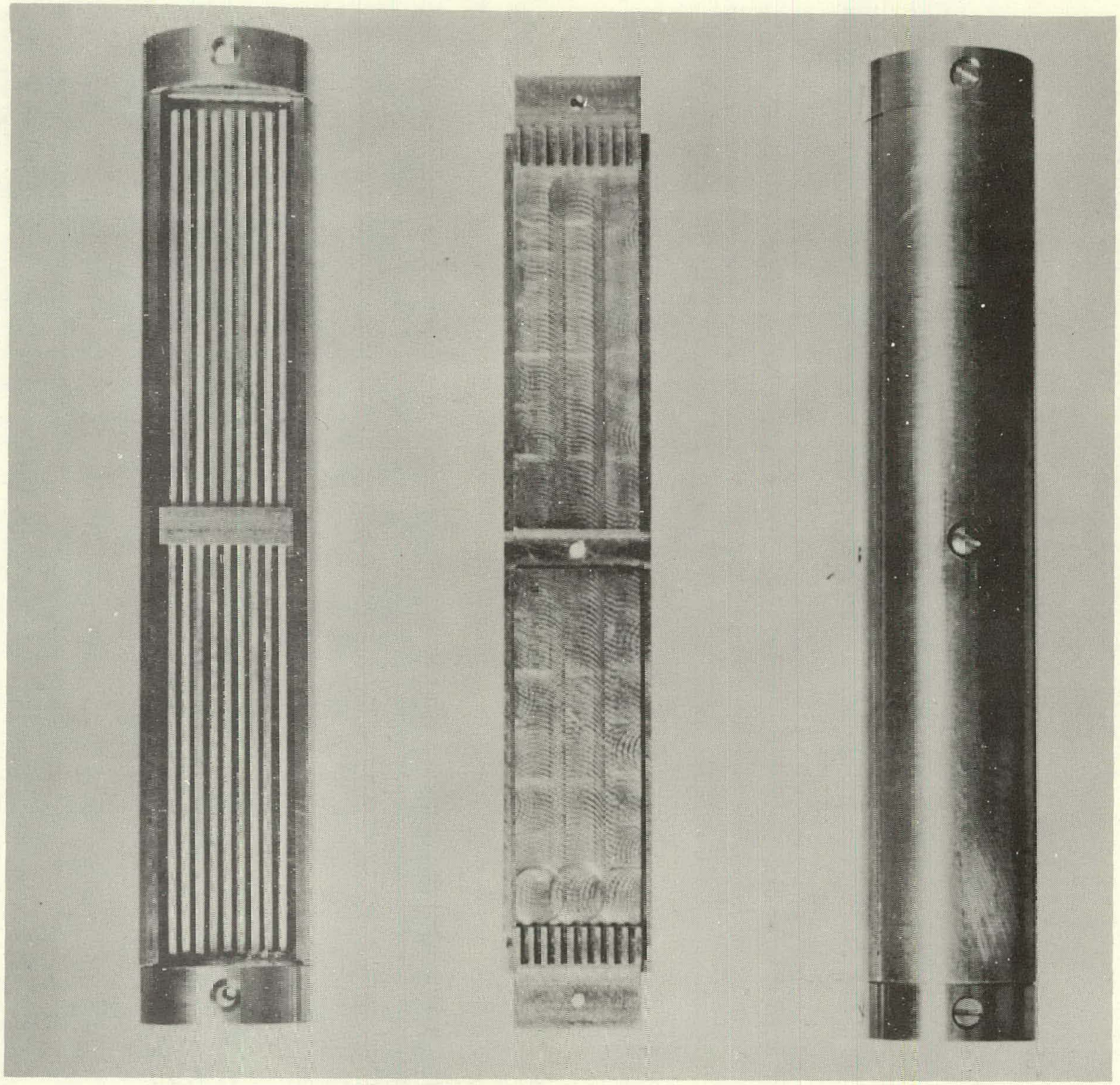

FIG. 2 COUPON SPECIMEN HOLDER

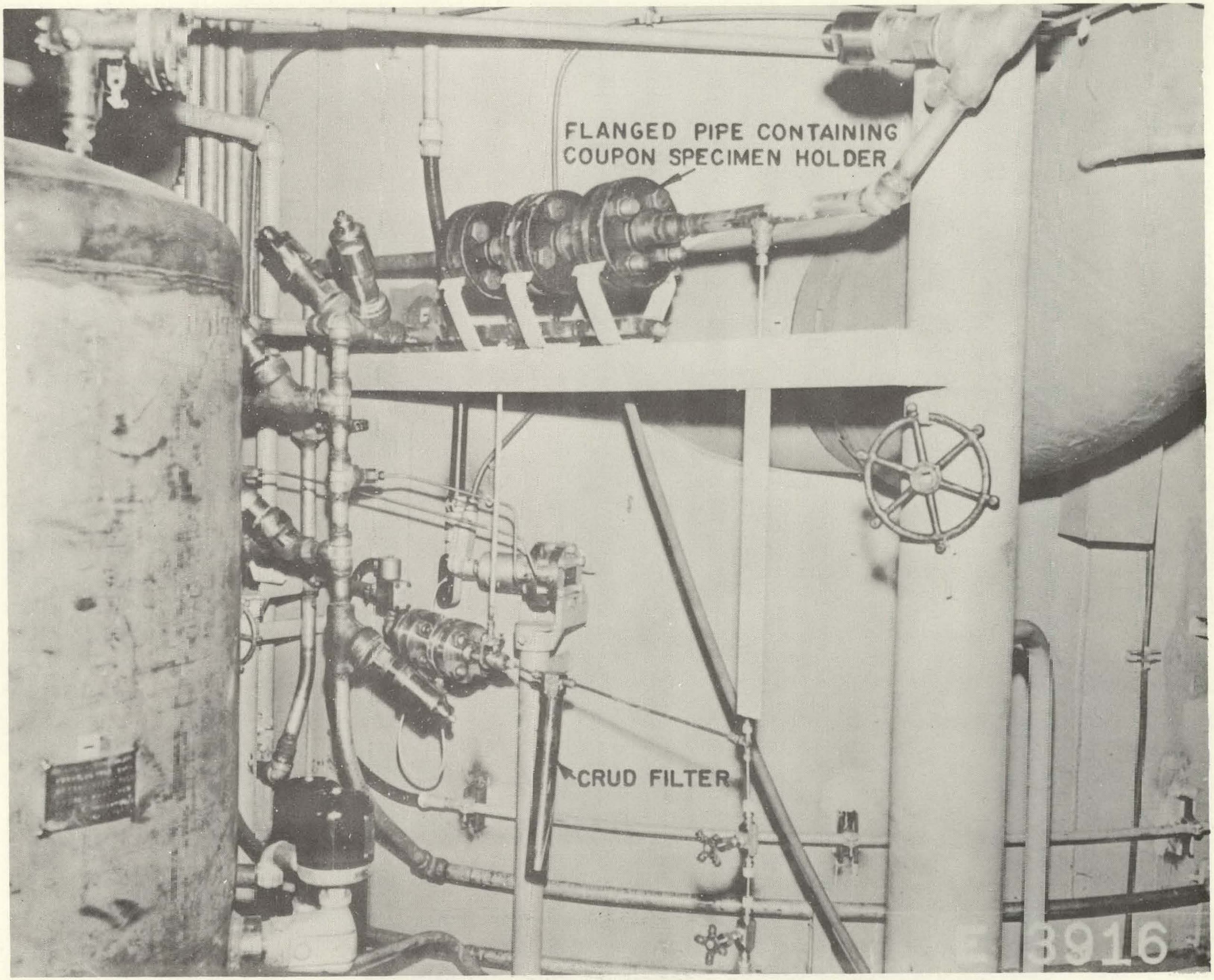

FIG. 3 TEST SPECIMENS AND CRUD FILTER EXPOSED TO REACTOR WATER

The Croloy 16-1 specimens were fabricated from a 3/32 inch thick stock that was not heat treated by the vendor. This stock was machined down to slightly greater than 1/16 inch thick, the specimens then heat treated, and the oxidation film removed by machining to about a 60 RMS surface finish. Heat treatment was at 1700° F. for one hour and air cooled, followed by reheating at 1300° F. for one hour with a slow furnace cool to below 600° F. The carbon steel coupons were fabricated from 1/8 inch thick stock carbon tool steel in the "as-rolled" condition. The pipe specimens were segments cut from the original 1 inch blowdown piping that was removed to accommodate the 1-1/2 inch flanged pipe holder.

Specimens were removed from the holders for analysis during plant shutdown when access could be had to the vapor container. One coupon of each type material and one pipe sample each were removed from the holders both upstream and downstream of the blowdown coolers. Specimens were handled gently with tweezers to distrub as little of the material on the surface as possible. Each specimen was wrapped individually in ashless filter paper, placed in a polyethylene bag and shipped to Schenectady for analysis.

IV EXPERIMENTAL TECHNIQUE

A. WATER AND CRUD SAMPLES

The radiochemical methods employed for the analysis of crud and water samples have been previously described (2, 3). Techniques employed for other samples are discussed below.

B. METAL SPECIMENS

A summary of the method of analyses performed on the metal coupons and pipe samples upon their receipt at Schenectady is outlined below. The detailed methods of examination are described.

The samples are weighed as received and visually inspected under a microscope.

A gross beta-gamma measurement is performed.

A wipe sample is taken and radiochemically analyzed.

The samples are weighed and another gross beta-gamma measurement made.

The test coupons and pipe samples are cut; a small portion is metallographically inspected, and the remainder is descaled.

The sample is reweighed after descaling.

Another gross beta-gamma measurement is performed.

The descaled solution is radiochemically analyzed.

1. Wiping Techniques

The loosely bound deposited material was removed from the samples by an empirical wipe technique. Samples were received from Fort

Belvoir individually wrapped in Whatman #42 filter paper to collect any deposit loss resulting from handling and shipment. After microscopic examination and B-γ assay for gross activity, the samples were wiped with the original filter paper by hand pressure. The filter paper was ashed and an effort was made to determine the amount of material removed by direct weight. This was unsuccessful because insufficient material was removed to allow accurate weighing. The oxide residue after ignition of filter paper was dissolved by a wet chemical technique consisting of treatment with HNO_3-$HClO_4$-HF. The solutions were made to volume and analyzed radiochemically. The weight of material removed was determined by analyzing for iron colorimetrically. To avoid making an assumption on the percent iron in the material removed, results are expressed on the basis of the amount of iron removed rather than total material removed.

2. Descaling Technique

Following the wiping, the samples were descaled electrolytically. The sample was made the cathode to a lead anode in a solution of 5 percent H_2SO_4 containing 1.0 g/1 of thiourea as a corrosion inhibitor. A curent density of 1.3 amperes/in^2 was used for 3 minutes. The descaling solution was held at a temperature of 140° F. in a water bath. The solution was contained in a 50 ml test tube with a plexiglass separator between the anode and cathode. The test tube was used so that the entire sample could be immersed in the solution. Earlier experiments had shown that if only half the sample was immersed, the acid fumes and spatter attacked the unimmersed part of the sample. This attack was particularly serious in the case of the carbon steel.

The quantity of deposit and amount of activity removed from the test coupon was determined by difference. Samples were weighed and assayed for B-γ activity both before and after descaling. The removed deposits were filtered from the descaling solution and dissolved by the same wet chemical method as employed on the wipe sample residues. The resulting solution was added to the filtrate descaling solution and made to volume for radiochemical analysis.

3. Beta-gamma Counting

The B-γ activity deposited on the coupons was measured with a G-M tube on the "as received" basis and following wiping and descaling. A plexiglass shelf was made to fit the shelf grooves of a NRD Instrument Company 2 inch lead shield and sample holder. This method gave relative rather than absolute measurements since the G-M tube only saw one segment of the coupon. Since the coupon was inserted the same way each time and at the same distance from the tube, it saw the same segment each time. Thus, if the removal techniques (wipe and descaling) removed activity from the coupon in a uniform manner, this counting technique would give a valid picture of the effectiveness of the treatment. It was necessary to resort to this type of assay because efforts to use a flow chamber were unsuccessful since the total amount of activity with this geometry was so great that the instrument jammed.

4. Metallographic Examination

All pipe samples and upstream Type 304 stainless steel coupons were examined metallographically for evidence of corrosion and buildup of deposits. This examination was made on a section cut from the pipe or coupon after the loose deposits had been removed by the wipe technique.

Specimens were mounted in either bakelite or lucite using heat and pressure during the mounting process. The samples were then prepared for examination by grinding and polishing using accepted metallographic techniques. Microscopic examination was made at 100X, 500X, and 1000X magnification on both the polished surface and after a 15 second electrolytic etching in 10 percent oxalic acid solution. Photomicrographs were made showing general views of the pipe sections, coupons, and control samples.

C. RADIATION SURVEY METHODS

Radiation levels, in mr/hr, emanating from primary system components were measured during plant shutdowns. Measurements were made using a "cutie pie" radiation detection instrument. The measurements were made at various locations, aligning up a marked part of the barrel of the chamber with marked spots on the primary system. The long-lived contribution at each point was obtained by extrapolating from decay measurements made during a 10 day shutdown (when the second set of metal samples was withdrawn from the system).

V DISCUSSION OF RESULTS

A. ACTIVITY OF THE PRIMARY COOLANT

The water samples removed from the purification blowdown line upstream of the demineralizer contain activity which may be associated with soluble, insoluble, or colloidal material. The activity of a sample of this water can be considered as representative of the total circulating activity of the coolant.

The results of radiochemical analysis of the primary coolant for long-lived nuclides are presented in Table I. It has been established in a previous study (2) that exchange of the radioactive atoms between the carrier and the total activity of the water is obtained using the radiochemical technique that we employ.

The total circulating activity does not show any definite trend of increase with equivalent full power hours with the possible exception of Mn^{54}. Mn^{54}, which is an n-p product, shows the largest variation, with an increase by a factor of about 20 over the five month sampling period.

The specific activity values (dpm/ml) are considerably lower than those observed at the end of the 700 hour test, with the exception of Mn^{54} (2). Since the volume specific activity is the product of crud level (mg/ml) and crud weight specific activity (dpm/mg), this decrease may be due to a reduction in either of these two factors. Since the crud specific activity is about the same or at best, very slightly increased over the last reported values (3), the decrease in volume specific activity is probably due to decreasing crud levels.

The nuclide ratios of the total circulating activity (upstream of demineralizer) are presented in Table II. It shows that the Co^{58}/Co^{60} ratio is still decreasing, but at a slower rate than was the case in previous studies(2, 3).

Table I

TOTAL CIRCULATING ACTIVITY OF PRIMARY COOLANT VS EQUIVALENT FULL POWER HOURS

Sample	Date	E. F. P. H.	Specific Activity (dpm/ml)					
			Co^{60}		Co^{58}	Fe^{59}	Mn^{54}	Cr^{51}
			1.33 Peak	1.17 Peak				
AU-1	6 Aug.	750	560	360	2400	290	69	610
AU-2	13 Aug.	915	320	220	1300	220	85	230
AU-3	21 Aug.	1110	320	200	1300	220	92	260
AU-4	3 Sept.	1220	310	320	1300	290	600	262
AU-5	19 Sept.	1240	1700	1200	8400	1300	818	1300
AU-6	3 Oct.	1550	320	310	1400	740	1500	2100
AU-7	22 Oct.	1715	430	410	1900	1400	230	470
AU-8	5 Nov.	2010	580	780	2900	570	1300	130
AU-9	23 Nov.	2175	730	770	3200	770	940	870
AU-10	3 Dec.	2390	1200	1100	5000	1200	1700	1300
AU-11	19 Dec.	2550	560	590	2300	920	1700	580
AU-12	30 Dec.	2740	780	800	2700	1200	1900	720

Table II

NUCLIDE RATIOS FOR

TOTAL CIRCULATING ACTIVITY OF PRIMARY COOLANT

Sample	E.F.P.H.	Co^{58}/Co^{60}	Fe^{59}/Co^{60}	Cr^{51}/Co^{60}	Mn^{54}/Co^{60}
AU-1	750	5.2	.63	1.3	.15
AU-2	915	4.8	.81	.85	.31
AU-3	1110	5.0	.85	1.0	.36
AU-4	1220	4.1	.92	.8	1.9
AU-5	1240	5.8	.90	.56	.90
AU-6	1550	4.4	2.4	6.7	4.8
AU-7	1715	4.5	3.3	1.1	.55
AU-8	2010	4.3	.84	.19	1.9
AU-9	2175	4.3	1.0	1.2	1.3
AU-10	2390	4.3	1.0	1.1	1.5
AU-11	2550	4.0	1.6	1.0	3.0
AU-12	2740	3.4	1.5	.91	2.4

B. WATER ACTIVITY DOWNSTREAM OF THE DEMINERALIZER

Samples of water collected from downstream of the demineralizer were analyzed for the same long-lived nuclides as found in the upstream samples. As might be expected, the amount of activity in these samples is small. Consequently, a 4 liter sample was collected and concentrated for analysis. Since the amount of activity was low, it was not feasible to run the analyses in duplicate as is the procedure for the upstream samples. Results of the analyses are shown in Table III.

The significance of these results is uncertain because the counting rates were so very low that it was difficult to obtain dependable values. The nuclide ratio data for the downstream samples is presented in Table IV. While there is a variation in values, the Co^{58}/Co^{60} ratios are about the same as the upstream values. Since the two nuclides should be removed in equal quantities when passing through the demineralizer, this result would be expected. The other ratios are based on such very low counting rates, particularly Cr^{51}, that no conclusions can be made.

Table V presents some demineralizer decontamination factors based upon specific nuclides. The data were obtained from the ratio of the specific activities of the demineralizer influent to that of the effluent for each nuclide from samples collected at the same time. Considerable variation exists for different nuclides on the same day. In addition, the decontamination factor for each nuclide shows no clear pattern with time. The inability to obtain accurate values from samples with a low level of activity probably accounts for the dispersion of the data.

Table III

WATER ACTIVITY DOWNSTREAM OF DEMINERALIZER

Sample	Date	E. F. P. H.	Specific Activity (dpm/ml)					
			Co^{60}		Co^{58}	Fe^{59}	Mn^{54}	Cr^{51}
			1.33 Peak	1.17 Peak				
RX-1	19 Sept.	1240	3	3	17	0	0	24
RX-2	24 Sept.	1360	5	5	20	4	170	36
RX-3	3 Oct.	1550	6.5	6.8	30	5	34	8
RX-4	8 Oct.	1665	79	80	420	5.2	44	14
RX-5	22 Oct.	1720	11	11	53	5	27	25
RX-6	29 Oct.	1869	15	14	65	14	18	28
RX-7	5 Nov.	2016	16	16	61	10	11	33
RX-8	23 Nov.	2180	5	6	20	9	44	73
RX-9	3 Dec.	2396	5	6	20	5	9	98
RX-10	19 Dec.	2550	9	10	32	18	20	21
RX-11	30 Dec.	2740	10	11	30	6	8	18
RX-12	11 Jan.	2960	25	30	58	11	11	12

Table IV

DOWNSTREAM WATER ACTIVITY NUCLIDE RATIOS

Sample	E. F. P. H.	Co^{58}/Co^{60}	Fe^{59}/Co^{60}	Cr^{51}/Co^{60}	Mn^{54}/Co^{60}
RX-1	1240	5.7	---	8.0	---
RX-2	1360	4.0	.8	7.0	34.0
RX-3	1550	4.5	.75	1.2	5.1
RX-4	1665	5.3	.65	.18	.55
RX-5	1720	4.8	.45	2.3	2.5
RX-6	1869	4.5	.95	1.9	1.2
RX-7	2016	3.8	.63	2.1	.69
RX-8	2180	3.6	1.6	13.0	8.0
RX-9	2396	3.6	.91	18.0	1.6
RX-10	2550	3.4	1.9	2.2	2.1
RX-11	2740	2.9	.57	1.7	.76
RX-12	2960	2.1	.40	.44	.40

Table V

NUCLIDE DECONTAMINATION FACTORS

ACROSS DEMINERALIZER

Date	Co^{60}	Co^{58}	Fe^{59}	Mn^{54}	Cr^{51}
19 Sept.	570	140	-*-	-*-	250
3 Oct.	64	47	158	44	260
22 Oct.	43	36	280	8.5	19
5 Nov.	36	48	57	108	4
23 Nov.	146	160	86	21	12
3 Dec.	240	250	240	190	130
19 Dec.	56	72	51	85	29
30 Dec.	78	90	200	238	40

* Not detectable in demineralizer effluent

C. CIRCULATING CRUD SPECIFIC ACTIVITY

Table VI presents data on the specific activity of the circulating crud sampled upstream and downstream of the blowdown cooler as a function of reactor equivalent full power hours. Specific activities are reported as dpm/mg Fe contained in the crud. This allows direct comparison with the specific activity of the deposited material removed from the metal test specimens. To allow comparison with crud specific activities of a previous report(3) which were calculated on a dpm/mg of crud basis, the percent iron in each crud sample, as measured by chemical analysis, is also given in Table VI.

The data of Table VI indicate that temperature has a negligible effect on the specific activities of all nuclides. There does not appear to be as clear a trend of increasing specific activity with reactor operating time for the cobalt nuclides as with previous crud samples(3). This may be due to collection of non-representative samples or to other causes.

The nuclide ratio data for the insoluble material (crud) is presented in Table VII. There is no clear difference between the ratios of these samples taken upstream of the blowdown cooler and those sampled downstream of the cooler. In both cases, the Co^{58}/Co^{60} ratio seems to be decreasing as would be expected. More data are necessary before drawing conclusions from the other nuclide ratios.

Table VI

CIRCULATING CRUD SPECIFIC ACTIVITY

All values 10^6 dpm/mg Fe

		Co^{60}		Co^{58}	Fe^{59}	Cr^{51}	Mn^{54}	% Fe in Crud
Sample	efph	1.33 Peak	1.17 Peak					
			Downstream of Blowdown Cooler					
CD-1	2424	7.6	7.4	29.0	6.6	16.0	3.1	39.4
CD-2	2659	5.4	5.3	21.0	8.3	4.9	2.1	36.7
CD-3	2899	4.7	4.5	18.0	5.4	4.3	2.1	31.0
CD-4	3104	9.1	9.1	28.0	6.2	8.6	2.3	54.4
CD-5	3396	4.2	3.5	13.0	3.8	6.8	3.5	40.0
			Upstream of Blowdown Cooler					
CU-1	2352	7.1	7.1	29.0	8.7	1.4	1.9	40.3
CU-2	2659	3.5	3.5	14.0	6.8	3.6	1.8	39.6
CU-3	2899	7.5	7.4	29.0	5.6	11.0	2.6	39.5
CU-4	3104	10.0	9.9	35.0	8.3	32.0	3.0	49.7

Table VII

NUCLIDE RATIOS FOR CRUD

Sample	efph	Co^{58}/Co^{60}	Fe^{59}/Co^{60}	Cr^{51}/Co^{60}	Mn^{54}/Co^{60}
		Downstream of Blowdown Cooler			
CD-1	2424	3.9	0.89	2.1	.41
CD-2	2659	3.9	1.6	0.98	.42
CD-3	2899	3.8	1.2	.93	.45
CD-4	3104	3.1	.69	.95	.26
CD-5	3396	3.3	.99	1.8	.92
		Upstream of Blowdown Cooler			
CU-1	2352	4.2	1.2	.20	.26
CU-2	2659	3.9	2.0	1.0	.50
CU-3	2899	3.9	.75	1.5	.35
CU-4	3104	3.5	.83	3.2	.30

D. CRUD LEVELS

The concentration of crud in the circulating coolant, the "crud level", was determined for each sampling interval both upstream and downstream of the blowdown cooler. The crud samples were collected on the previously described porous stainless steel crud filters over intervals of about two weeks each during steady state reactor operations. Total flow through the crud filter during the collection period was measured by an integrating flow meter.

The crud was removed from the filter by backflushing with compressed air in a beaker of boiling distilled water. These washings were added to the crud collected from the housing of the crud filter. The water was removed by evaporation and the crud ignited in a tared platinum dish at about 700-800° C.

Survey measurements of the crud filter indicated that about 25 percent of the activity was removed by this backflushing technique. However, no crud particles were visible on the surface of the filter, and water flowed easily through the filter. The ignited weight of crud (in milligrams) divided by the volume of water (in liters) passed through the crud filter is the calculated crud level in parts per million.

Average crud levels for the various sampling periods are reported in Table VIII. The reactor equivalent full power hours given in this table are the mean values during the crud collection period. These data show a variation in crud levels, with a seemingly higher crud level upstream of the blowdown cooler. Whether these variations in crud level truly represent system conditions is not certain. The figures in Table VIII represent average crud level over intervals of about two weeks. The occurrence of so called "crud bursts" during the sample collection period could invalidate the average calculated crud level. Although the technique used for removal of crud from the filter did not quantitatively remove all activity, it is felt the variation in crud levels between the different samples is greater than can be attributed to incomplete removal of crud or inconsistent handling of the crud.

The variation in crud level between the samples upstream and the samples downstream of the blowdown cooler could possibly be due to a temperature effect. However, there is a difference in the instruments used to measure the flow through the two filters which could also contribute to this difference. The upstream instrument is operated remotely in conjunction with a solenoid operated valve. This flow measuring instrument is rated to be more accurate than that instrument used downstream of the blowdown cooler. However, a very slow leak through the solenoid operated valve, which is quite possible with this type equipment, would not register on the flow instrument. Over a 3-4 week period such leakage could contribute to apparently high crud levels.

E. CRUD LEVEL AND CIRCULATING CRUD ACTIVITY

The measurement of crud levels and crud specific activity during this program offers additional data to determine if a relationship exists between these two parameters. The crud levels and crud total specific activity for the samples analyzed are recorded in Table IX.

Table VIII

PRIMARY SYSTEM CRUD LEVELS

Sample No.	Reactor efph	Crud Weight Removed, mg.	Total Flow Through Filter, Liters	Crud Level ppm
		Upstream of Blowdown Cooler		
CD-1	2424	68.5	249.8	0.27
CD-2	2659	41.3	416.7	0.10
CD-3	2899	26.5	227.1	0.12
CD-4	3104	189.5	417.9	0.45
CD-5	3396	14.9	227.1	0.07
		Downstream of Blowdown Cooler		
CU-1	2352	144.0	96.1	1.50
CU-2	2659	92.2	265.3	0.35
CU-3	2899	87.4	147.6	0.59
CU-4	3104	43.5	439.7	0.10

Table IX

CRUD LEVEL VS CRUD TOTAL SPECIFIC ACTIVITY

Sample No.	Reactor efph	Crud Level ppm	Total Specific Activity, dpm/mg Fe
CD-1	2424	0.27	61.9×10^6
CD-2	2659	0.10	41.6
CD-3	2899	0.12	34.0
CD-4	3104	0.45	54.0
CD-5	3396	0.07	31.0
CU-1	2352	1.50	57.9
CU-2	2659	0.35	29.3
CU-3	2899	0.59	55.5
CU-4	3104	0.10	87.8

However, as pointed out in a preceding paragraph on Crud Levels, page 29, it is not certain that the calculated crud levels are indicative of the true crud concentration in the primary system. Modified crud sampling techniques are necessary and measurement of crud concentrations at daily intervals is desirable in order to definitely establish true system crud levels, and to determine what relationship exists between crud level and crud specific activity.

F. GROSS ACTIVITY OF METAL TEST SAMPLES

As described in a previous section, the coupons were examined visually upon receipt from the reactor site, and changes in their weights measured after wiping and descaling. These weight changes, and the visual appearance of the samples are shown in Table X. Figure 4 and Figure 5 are photographs of the specimens exposed upstream and downstream of the blowdown cooler. In general, the Type 304 stainless steel specimens displayed a very thin, if any, oxide film, whereas all the Croloy 16-1 specimens had a lustrous adherent film with the carbon steel specimens showing the heavier oxide films.

The gross activity of the coupons and pipe samples measured as received and after wiping and descaling are summarized in Table XI. This gross activity was measured as described on page 15. The fractions of these activities removed by the wipe technique and descaling procedure as well as the fraction of activity remaining are presented in Table XII. From an examination of the data in these two tables, the following observations can be made:

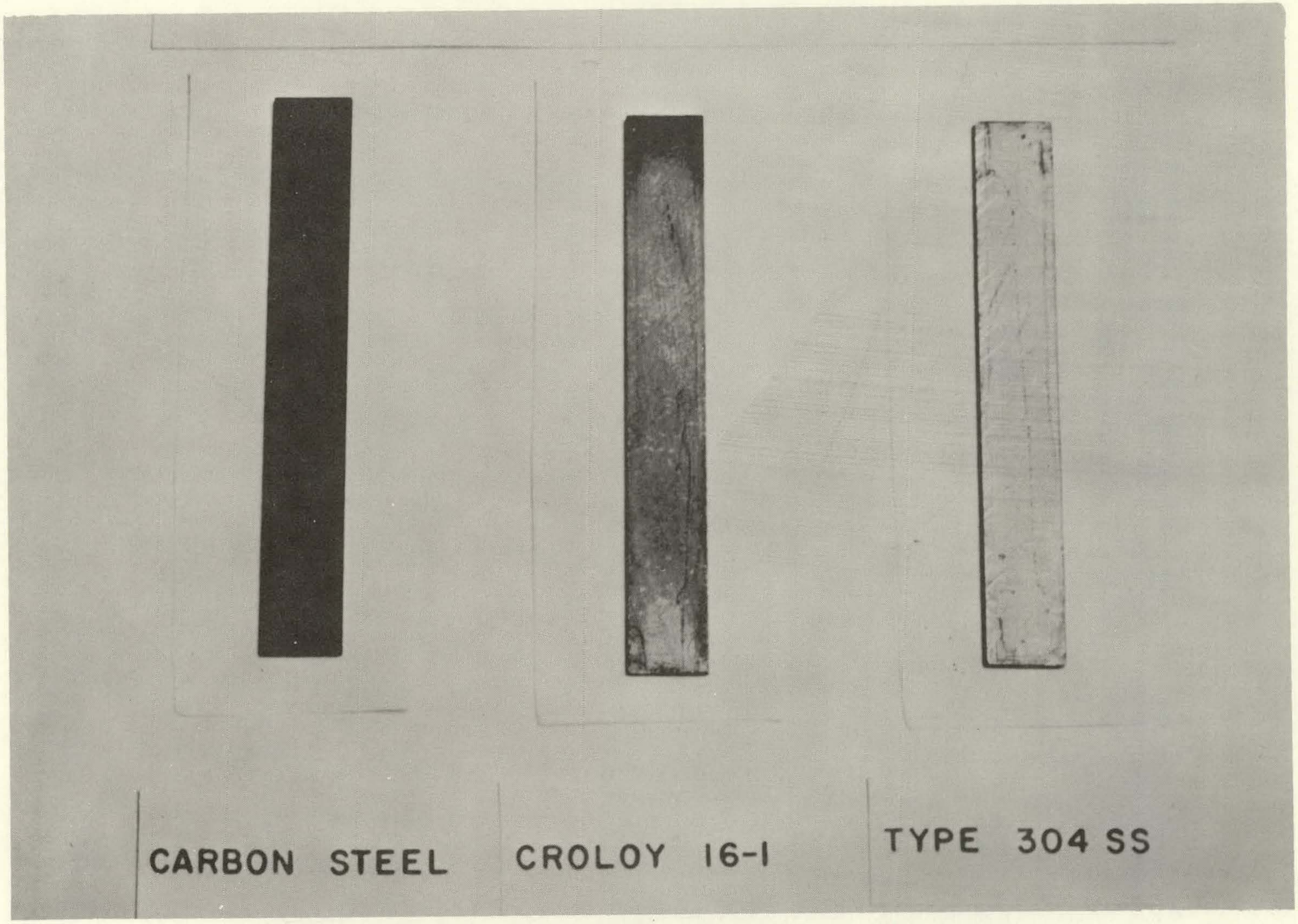

FIG. 4 SPECIMENS EXPOSED TO 432 F PRIMARY COOLANT FOR 1200 HOURS

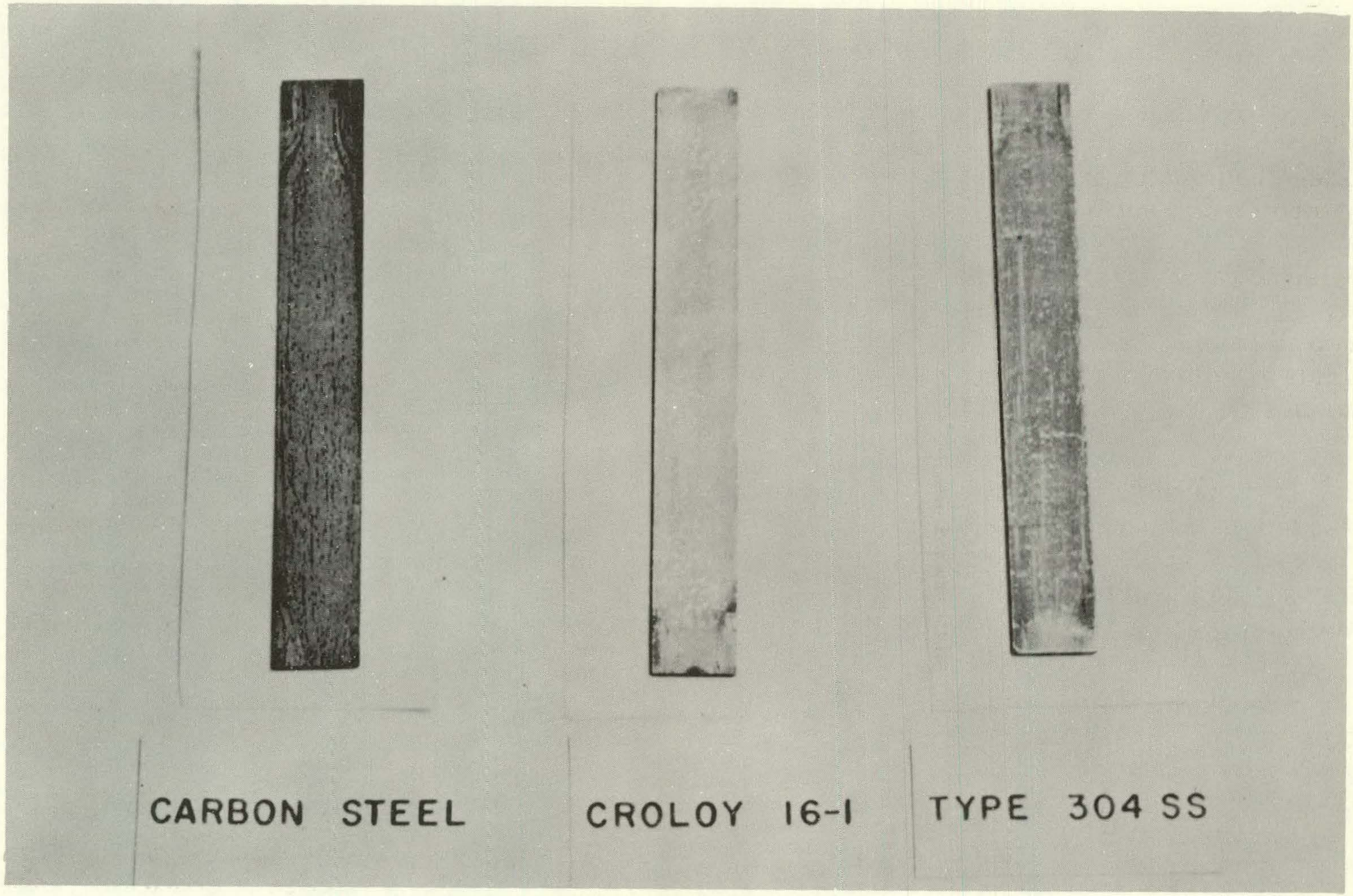

FIG. 5 SPECIMENS EXPOSED TO 120 F PRIMARY COOLENT FOR 1200 HOURS

Table X Weight Changes of Test Samples Compared with Original Weight

Total Exposure Time Hours	Sample	Location from Blowdown Cooler	Weight Change as rec'd, mg.	Net Weight Change after Wipe, mg.	Net Weight Change after Descaling, mg.	Visual Appearance as Received and Other Remarks
970	304 SS	Up	------	+ 0.5	+ 0.3	Slight dull appearance. Very thin corrosion film.
	Croloy 16-1	Up	------	- 8.7	-17.4	Very black, lustrous adherent corrosion film.
	Carbon Steel	Up	------	-40.4	-47.3	Uniform black, dull oxide coating -- loosely adherent.
970	304 SS	Down	------	+ 2.1	+ 2.0	Straw-colored temper film.
	Croloy 16-1	Down	------	+ 0.8	- 0.3	Uneven temper film. Some spots that appear to be red rust.
	Carbon Steel	Down	------	- 5.1	-10.6	Uneven rust colored deposits with black oxide specks.
1198	304 SS	Up	+ 0.8	------	+ 0.6	Dull gray color. No temper or general oxide film. Faint oxide flow patterns at ends of coupon.
	Croloy 16-1	Up	- 0.2	- 0.7	- 5.4	Lustrous black deposit. Deposit appears thicker at downstream end of coupon.
	Carbon Steel	Up	-49.9	-51.3	-58.0	Uniform thick black deposit. Identification number nearly obliterated by oxide deposits.

Table X (Cont.) Weight Changes of Test Samples Compared with Original Weight

Total Exposure Time Hours	Sample	Location from Blowdown Cooler	Weight Change as rec'd, mg.	Net Weight Change after Wipe, mg.	Net Weight Change after Descaling, mg.	Visual Appearance as Received and Other Remarks
	304 SS	Down	+ 3.7	+ 2.9	+ 1.3	Uniform straw-colored deposit over entire specimen. Black oxide flow pattern at ends of specimen.
1198	Croloy 16-1	Down	+ 1.7	+ 0.6	- 1.5	Speckled light straw color deposits. Occasional transverse streaks of black oxide.
	Carbon Steel	Down	- 5.4	- 6.9	- 11.7	Very evident flow pattern of black oxide deposits. Overall coating straw-colored, with black oxide along flow lines.
	304 SS	Up	+ 2.1	+ 0.7	+ 0.5	Thin black oxide film. Film evenly distributed with relatively large spots in some areas.
1565	Croloy 16-1	Up	- 10.3	- 12.3	- 14.9	Heavy lustrous black oxide film uniformly distributed. Some dull black oxide spotted on surface, with no apparent pattern.
	Carbon Steel	Up	-329.3*	-335.2	-341.5	Heavy dull black oxide film uniformly distributed.
	304 SS	Down	+ 3.4	+ 1.2	+ 0.7	Thin rust-colored film with some black oxide non-uniformly, thinly distributed over surface.
1565	Croloy 16-1	Down	+ 0.2	- 0.6	- 1.6	Light temper film with black oxide thinly distributed apparently along flow lines.
	Carbon Steel	Down	- 14.8	- 21.6	- 35.4	Black oxide film, with rust spots intermingled. Thickest of the films for the downstream samples.

* Appears to be in error. Initial sample weight may have been recorded in error.

1. The total activity associated with the specimens is increasing with exposure time for all materials both upstream and downstream of the blowdown cooler.

2. Temperature has a marked effect both upon the total activity accumulated by the samples, and upon the adherence of the activity (i.e., ease of removal of the activity). Thus, the specimens exposed to the high temperature water (430^o-450^o) upstream of the blowdown cooler are more radioactive than those of like material exposed downstream of the blowdown cooler (90-100^o F.). Similarly, the amount of activity remaining on the specimens exposed to high temperature water after descaling and wiping is greater than that remaining on the low temperature specimens of like material.

3. The accumulation of activity is dependent of the type of structural material of the specimens. For equal exposure times to reactor temperature water, Croloy 16-1 accumulates the greatest amount of activity, followed by carbon steel and Type 304 SS in that order. The activity of the Croloy 16-1 is approximately 3 to 6 times greater than that of Type 304 SS. At the lower water temperatures, carbon steel accumulates the greatest amount of activity.

4. The adherence of the activity (or the ease of removal of activity) is related to the structural material of the specimen. Croloy 16-1 exhibits the most adherent active film, in that better than 40 percent of its initial activity remains after descaling the specimen. Activity from the carbon steel specimens is the easiest and most completely removed.

It is not permissible to compare (from the data of Table XI) the gross activity of the pipe samples to that of the metal coupons. Counting geometry is vastly different, and the effects of a different flow pattern between the two type samples could effect total activity. However, since the activity of all pipe samples was counted in an identical manner, the data of Table XI does represent relative variations in the pipe sample activity as a function of exposure time and temperature.

In addition, because of the somewhat empirical nature of the wiping technique used and the fact that different personnel wiped the batch of coupons removed at different exposure times, one is not justified in inter-comparing the relative amounts of activity remaining after wiping as a function of exposure time. However, it probably is permissible to inter-compare the percent of total activity remaining after descaling, on the reasonable assumption that any activity not removed by a "light wiping technique" would be taken off by the descaling treatment.

The specific activity of the deposits is of interest to determine the mechanism of the activity buildup phenomena. However, the gross activity that accumulates with time on the reactor components is the point of major importance with regard to future reactor maintenance, accessibility, and ease of decontamination. The data of Tables XI and XII indicate therefore that of the three materials tested, the Croloy 16-1 is the least desirable from the activity buildup and ease of decontamination viewpoint.

Table XI Coupon Gross Activity, cpm

Total Exposure Time, Hours	Reactor efph	Sample	UPSTREAM B.D. COOLER			DOWNSTREAM B.D. COOLER		
			As rec'd	After Wipe	After Descal.	As rec'd	After Wipe	After Descal.
970	2796	304 SS	56,850	51,130	18,280	31,810	27,500	2,640
		Pipe	193,000	164,000	114,300	194,000	141,000	18,010
		Croloy 16-1	250,000	242,000	141,440	21,000	12,400	570
		Carbon Steel	77,400	63,240	1,700	40,700	27 900	860
1198	2971	304 SS	66,400	64,450	28,400	102,800	45,900	2,670
		Pipe	418,000	302,000	98,500	252,800	187,000	10,520
		Croloy16-1	440,000	314,000	194,000	139,000	49,000	8,300
		Carbon Steel	104,000	77,000	1,550	147,000	92,700	3,630
1565	3216	304 SS	242,500	75,300	30,800	55,300	20,600	4,160
		Pipe	1,014,000	471,000	224,400	188,300	110,400	54,320
		Croloy 16-1	615,000	377,000	226,000	26,300	8,470	860
		Carbon Steel	268,000	18,950	620	100,800	38,400	2,430

TABLE XII Relative Adherence of Activity to Test Specimens

Per cent Activity Removed by Wipe

Total Exposure Time, Hrs.	Reactor efph	304 SS		Pipe		Croloy 16-1		Carbon Steel	
		Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
970	2796	10.0	13.5	15.0	27.3	3.0	41.0	18.3	31.4
1198	2971	2.9	55.4	27.8	25.8	28.6	64.8	26.0	36.9
1565	3216	68.9	62.8	53.6	41.3	38.7	67.8	92.9	61.9

Per cent Activity Removed by Descaling

Total Exposure Time, Hrs.	Reactor efph	304 SS		Pipe		Croloy 16-1		Carbon Steel	
		Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
970	2796	58.	79.2	25.8	62.9	40.5	56.3	79.7	66.5
1198	2971	54.5	42.0	48.6	70.0	27.3	29.2	72.5	60.6
1565	3216	19.4	29.7	24.3	32.2	18.0	29.	6.9	35.7

Per cent Activity Remaining

Total Exposure Time, Hrs.	Reactor efph	304 SS		Pipe		Croloy 16-1		Carbon Steel	
		Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
970	2796	32.	8.3	59.2	9.8	56.5	2.7	2.	2.1
1198	2971	42.6	2.6	23.6	4.2	44.1	6.0	1.5	2.5
1565	3216	12.7	7.5	22.1	26.5	43.3	3.2	0.2	2.4

G. SPECIFIC ACTIVITY OF DEPOSITS ON METAL TEST SAMPLES

The specific activity of the material removed from the surface of the metal test samples was determined by radiochemical analysis. The measured values for the loosely bound material (material removed by wiping with filter paper) are given in Table XIII. Specific activities for the tightly bound material (that removed by electrolytic descaling) is presented in Table XIV. Ratios of the nuclide specific activities are also included in these two tables.

More data is required before it is possible to validly draw firm conclusions on the difference, if any, in isotopic distribution of tight and loosely bound deposits. However, some general trends may be noted from the limited data. It appears from the data in these tables that the specific activities of all nuclides for both loosely and tightly bound deposits increase with time. The rate of increase appears to be slightly greater for the specimens exposed to the high temperature water.

The specific activity for tightly bound deposits appear to be in the order: Type 304 stainless steel $>$ Croloy 16-1 $>$ carbon steel. For the loosely bound deposits, the specific activities appear nearly the same for all materials. The values do not appear to be temperature dependent for either loosely or tightly bound material. If a distinction were to be attempted on the basis of this data one would conclude that in general the specific activity in the loosely bound deposits is slightly greater than tightly bound deposits for all materials.

H. METALLOGRAPHIC EXAMINATION RESULTS

The test specimens were compared with sections of new (unexposed to reactor water) pipe and coupons to determine if the surfaces had been affected by either corrosion or erosion during the exposure time.

Table XIII Specific Activities of Loosely Bound Deposits (Wipe Samples) Samples Upstream of Blowdown Cooler

Specific Activity 10^6 cpm/mg Fe		304 Coupons efph 2796	2971	3216	Pipe efph 2796	2971	3216	Croloy 16-1 Coupons efph 2796	2971	3216	Carbon Steel Coupons efph 2796	2971	3216
Co^{60}	1.33 Mev	*.26	1.4	3.1	.75	2.9	3.9	.51	1.7	4.3	-	22.	1.8
	1.17 Mev	*.26	1.5	2.9	.75	3.0	3.3	.53	2.0	3.5	-	22.	1.5
Co^{58}		.88	5.6	11.	2.8	10.	12.	1.5	7.6	14.	-	80.	5.6
Fe^{59}		.27	1.9	4.5	.39	3.3	3.7	*.35	3.1	3.3	.48	16.	2.2
Cr^{51}		-	*4.1	28.	1.8	10.	6.6	1.9	*1.8	30.	-	24.	*4.6
Mn^{54}		.22	.60	2.3	.24	1.6	1.4	.16	.88	2.6	.18	6.8	0.97
Nuclide Ratios													
Co^{58}/Co^{60}		*3.4	3.9	3.5	3.7	3.5	3.3	2.9	4.2	3.6	-	3.6	3.4
Fe^{59}/Co^{60}		*1.0	1.3	1.5	.52	1.1	1.0	*.68	*1.7	.84	-	*.70	1.4
Cr^{51}/Co^{60}		-	*2.8	9.3	2.4	3.6	1.8	3.6	*.98	7.6	-	1.1	*2.8
Mn^{54}/Co^{60}		*.85	.41	.77	.32	.53	.40	.31	.49	.66	-	.31	.59

* Value doubtful due to very low counting rates

Table XIII (Cont.) Specific Acitivities of Loosely Bound Deposits (Wipe Samples)
Samples Downstream of Blowdown Cooler

Specific Activity		304 Coupons			Pipe			Croloy 16-1 Coupons			Carbon Steel Coupons		
			efph			efph			efph			efph	
10^6 dpm/mg Fe		2796	2971	3216	2796	2971	3216	2796	2971	3216	2796	2971	3216
Co^{60}	1.33 Mev	.34	28.	*1.1	.99	14.	1.1	.21	6.3	* .46	-	2.1	.55
	1.17 Mev	.40	29.	*1.2	.96	12.	.90	.21	6.8	* .36	-	2.2	.51
Co^{58}		1.3	98.0	*3.8	2.82	49.	2.8	.60	22.	*1.4	-	7.0	1.8
Fe^{59}		.42	22.	3.1	.60	19.	.82	* .11	9.3	* .23	.10	1.7	.84
Cr^{51}		*.25	*15.	-	* .48	47.	* .81	* .33	*2.4	*1.2	* .12	* .55	*.22
Mn^{54}		.18	7.2	1.1	.39	6.8	.53	.08	2.4	1.1	.03	1.1	.62
Nuclide Ratios													
Co^{58}/Co^{60}		3.5	3.5	*3.2	2.9	3.7	2.7	2.9	3.4	*3.4	-	3.3	3.5
Fe^{59}/Co^{60}		1.1	.78	2.6	.62	1.5	*.80	.52	1.4	.56	-	.78	1.6
Cr^{51}/Co^{60}		*.68	.54	-	*.49	3.6	*.79	*1.6	*.37	*3.1	-	* .26	*.42
Mn^{54}/Co^{60}		*.49	.26	*.92	.40	.52	.52	.38	.37	*2.8	-	.54	1.2

* Value doubtful due to very low counting rates

Table XIV Specific Activities of Tightly Bound Deposits (Descaled Samples)

Samples Upstream of Blowdown Cooler

Specific Activity		304 Coupons			Pipe			Croloy 16-1 Coupons			Carbon Steel Coupons		
		efph			efph			efph			efph		
10^6 dpm/mg Fe		2796	2971	3216	2796	2971	3216	2796	2971	3216	2796	2971	3216
Co^{60}	1.33 Mev	.97	3.3	16.	.62	1.3	1.7	1.4	1.2	2.3	.42	.75	.77
	1.17 Mev	.82	4.4	13.	.47	1.0	1.4	1.4	0.93	1.8	.42	.79	.63
Co^{58}		3.9	15.	55.	2.0	4.1	4.7	1.6	3.6	6.0	1.5	2.2	2.1
Fe^{59}		*1.4	2.4	*2.5	*.38	*.67	1.2	.66	.79	.92	.33	.44	*.57
Cr^{51}		*15.	13.	35.	*.13	1.5	-	*3.7	2.4	1.6	.91	.98	.63
Mn^{54}		.46	1.2	1.9	.12	0.44	.66	.15	*.18	.42	.12	.21	.15
Nuclide Ratios													
Co^{58}/Co^{60}		4.3	4.4	3.8	3.6	3.5	3.0	1.1	3.4	2.9	3.5	2.9	3.0
Fe^{59}/Co^{60}		*1.5	.72	.17	.69	.58	.78	.47	.75	.44	.79	.57	*.82
Cr^{51}/Co^{60}		*17.	.35	2.4	.24	1.3	-	*2.6	2.2	.77	2.2	1.3	.90
Mn^{54}/Co^{60}		.51	.35	.13	.22	.38	.42	.11	*1.7	.20	.29	.27	.22

* Value doubtful due to very low counting rates

Table XIV (Cont.) Specific Activities of Tightly Bound Deposits (Descaled Samples)

Samples Downstream of Blowdown Cooler

Specific Activity		304 Coupons			Pipe			Croloy 16-1 Coupons			Carbon Steel Coupons		
		efph			efph			efph			efph		
10^6 dpm/mg Fe		2796	2971	3216	2796	2971	3216	2796	2971	3216	2796	2971	3216
Co^{60}	1.33 Mev	1.1	2.1	1.8	.87	1.2	-	.17	1.7	*1.1	.36	.98	* .51
	1.17 Mev	0.95	2.1	1.4	.69	1.0	-	.21	1.7	* .37	.31	.99	* .40
Co^{58}		3.6	7.7	4.5	2.5	3.1	-	.85	4.7	1.5	1.1	2.7	*1.2
Fe^{59}		1.7	3.1	*3.0	.65	* .51	*1.4	* .33	.71	*1.1	.61	.41	* .55
Cr^{51}		11.	5.8	-	* .49	1.4	9.9	4.4	.26	*2.8	.29	* .13	* .81
Mn^{54}		.35	1.3	1.2	.44	.26	.52	.08	.46	.65	.46	.45	.87
Nuclide Ratios													
Co^{58}/Co^{60}		3.6	3.5	3.0	3.2	2.8	-	4.5	2.8	*	3.3	2.8	*2.6
Fe^{59}/Co^{60}		1.7	1.5	*2.0	.83	* .46	-	*1.7	.43	*-	1.8	.42	*1.21
Cr^{51}/Co^{60}		11.	2.8	-	*.63	1.3	-	23.	.16	*-	.87	* .13	*1.8
Mn^{54}/Co^{60}		.34	.6	.81	.56	.24	-	.42	.28	*-	1.4	.46	*1.9

* Value doubtful due to very low counting rates

The results of the examination revealed that portions of both the outside and inside surfaces of the original pipe were coated with small amounts of oxide scale, and that shallow surface seams, about 0.002 inch deep, were present at the inside surface. These seams were filled with a tightly adhering oxide scale. This oxide and seams probably originated during manufacture of the pipe. A photomicrograph of a section of the original pipe is shown in Figure 6. The original coupon showed a slight amount of grain boundry oxidation at the surface, probably resulting from the heat treatment applied during fabrication. This surface grain boundary oxidation is shown in Figure 7.

There was no evidence of intergranular corrosion or erosion on any of the specimens examined. A slight material buildup was observed on the inside surfaces of the pipe samples and the surfaces of the coupons. The buildup thickness varied from 0.001 - 0.002 inch on the pipe samples. The buildup on the test coupons could not be accurately determined, but appeared to have a maximum thickness of about 0.0005 inch. Typical photomicrographs of the pipe and Type 304 stainless steel coupon specimens after exposure are shown in Figures 8 and 9. The buildup thickness could be clearly seen through the microscope with the eye. However, in the photograph, this buildup cannot be distinguished from the plastic mount.

The thickness of the material buildup on the samples should not be considered accurate due to the difficulty in preserving the original thickness of this relatively soft-material during metallographic polishing. It appeared, however, that the thickness of this deposited material increased with exposure time.

FIG. 6 PHOTOMICROGRAPH OF ORIGINAL TYPE 304 SS PIPE SAMPLE. X100 OXALIC ACID ETCH

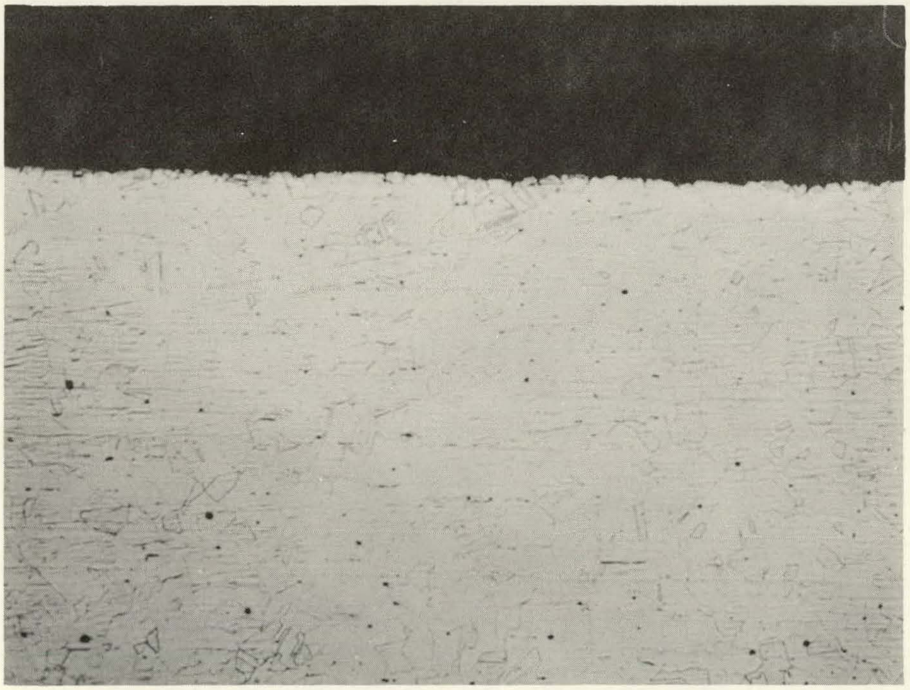

FIG. 7 PHOTOMICROGRAPH OF ORIGINAL TYPE 304 SS METAL COUPON X100 OXALIC ACID ETCH

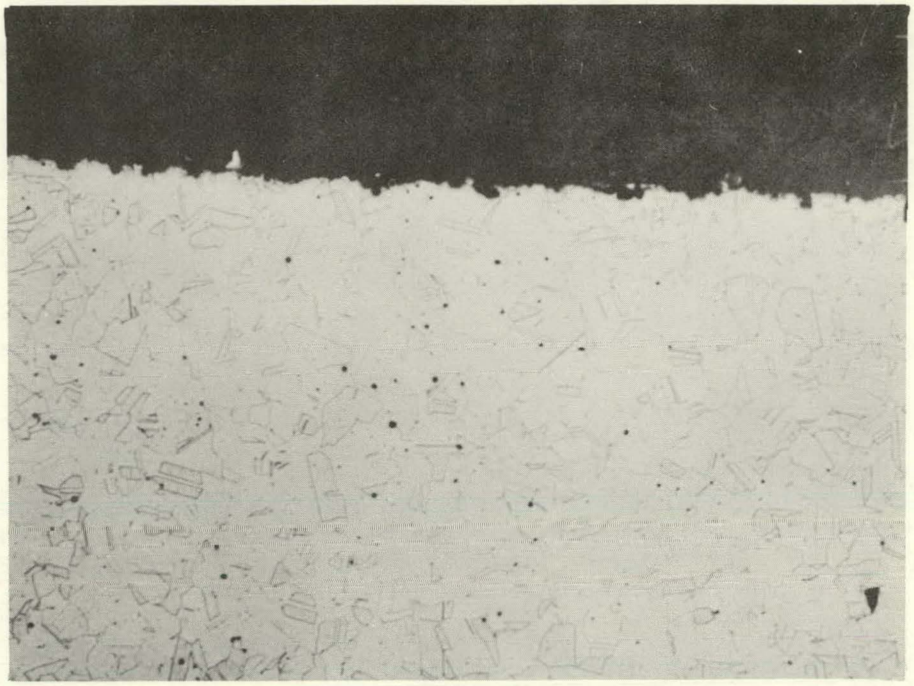

FIG. 8 PHOTOMICROGRAPH OF TYPE 304 SS PIPE SAMPLE AFTER 1200 HOURS EXPOSURE X100 OXALIC ACID ETCH

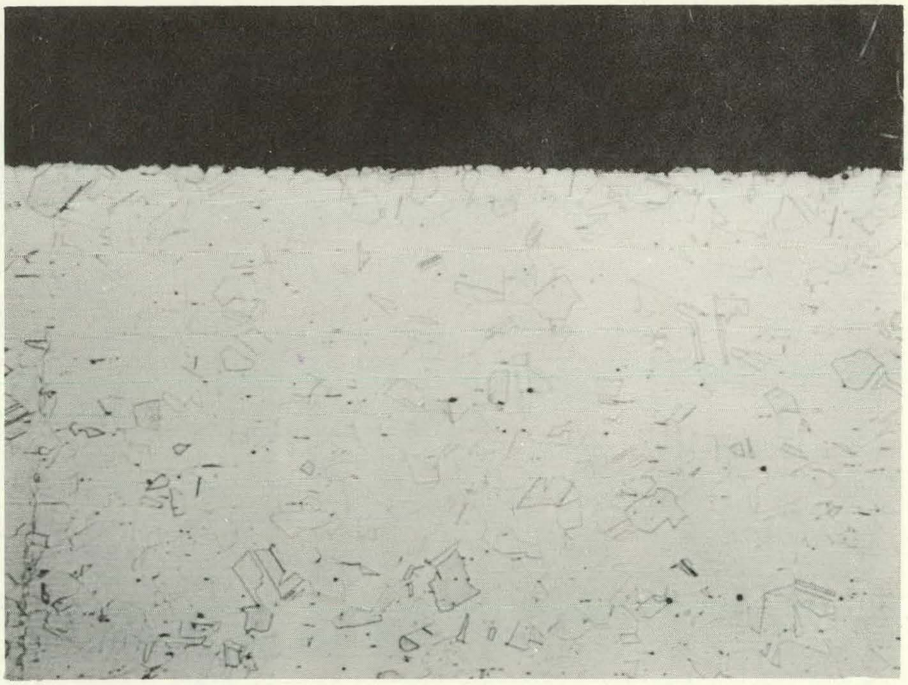

FIG. 9 PHOTOMICROGRAPH OF TYPE 304 SS METAL COUPON AFTER 1200 HOURS EXPOSURE

I. RELATIONSHIP OF DEPOSITED ACTIVITY TO CRUD SPECIFIC ACTIVITY

The uncertainty regarding the mechanism for accumulation of radioactivity on the surface of primary system components has led to the search for relationships between circulating and deposited activity. If a relationship is found to exist, predictions of activity levels for maintenance and other purposes can be made with more confidence. As pointed out when data were presented in Section V F, it is the total activity which is of major concern but the specific activity (dpm/mg) yields the most information on the mechanisms and phenomena which occur.

Only three samples of each material have been analyzed in the period covered by this report. On the basis of this number of samples, only a limited analysis can be made.

The relationship between the specific activity of the deposited material and that of the circulating crud can best be shown by comparing the ratios of their nuclide specific activities. The ratios of deposited activity to crud activity for each nuclide are presented in Table XV, XVI, XVII, and XVIII.

From the data in these tables, it appears that the specific activity of the deposited material is generally less than that of the circulating crud. The pipe samples show a significantly lower ratio than those of the 304 SS coupons. This could possibly be due to a flow effect. The ratio of the activity of the deposits on the carbon steel samples to that of the crud is markedly lower than that of the other type coupons. This would be expected because of the greater amount of oxide corrosion film present on these specimens, which in effect "dilutes" the specific activity.

The isotopic distribution of the nuclides in the material deposited on the

Table XV

SPECIFIC ACTIVITY RATIO OF DEPOSITS TO CRUD FOR Co^{60} AND Co^{58}

		Tightly Bound Deposits			Loosely Bound Deposits		
		2796 efph	2971 efph	3216 efph	2796 efph	2971 efph	3216 efph
				UPSTREAM			
$\frac{\text{304 Coupon}}{\text{Crud}}$	Co^{10}	*.16	.44	1.5	.15	.11	*.30
	Co^{58}	.18	.46	1.6	.13	.17	.30
$\frac{\text{Pipe}}{\text{Crud}}$	Co^{60}	.10	.13	.16	.14	.34	.36
	Co^{58}	.10	.13	.14	.13	.33	.34
$\frac{\text{Croloy 16-1}}{\text{Crud}}$	Co^{60}	.26	.12	.21	.10	.21	.39
	Co^{58}	0.75	.12	.17	.07	.32	.40
$\frac{\text{Carbon Stl.}}{\text{Crud}}$	Co^{60}	.08	.09	.07	----	2.6	.17
	Co^{58}	.07	.071	.06	----	2.5	.16
				DOWNSTREAM			
$\frac{\text{304 Coupon}}{\text{Crud}}$	Co^{60}	.16	.30	.24	.03	4.1	.18
	Co^{58}	.19	.32	.22	.02	4.3	*.18
$\frac{\text{Pipe}}{\text{Crud}}$	Co^{60}	.12	.16	----	.20	1.9	.16
	Co^{58}	.13	.13	----	.15	2.2	.14
$\frac{\text{Croloy 16-1}}{\text{Crud}}$	Co^{60}	.03	.24	*.11	.04	.95	*.06
	Co^{58}	.04	.20	.07	.03	.97	*.07
$\frac{\text{Carbon Stl.}}{\text{Crud}}$	Co^{60}	.05	.14	.07	----	.31	.08
	Co^{58}	.06	.12	*.06	----	.31	.09

* Value doubtful due to low counting rates

Table XVI

SPECIFIC ACTIVITY RATIO OF DEPOSITS TO CRUD FOR Fe^{59}

Ratio	Tightly Bound Deposits			Loosely Bound Deposits		
	2796 efph	2971 efph	3216 efph	2796 efph	2791 efph	3216 efph
			UPSTREAM			
$\frac{\text{304 Coupon}}{\text{Crud}}$	*.22	.34	*.30	.14	.28	.54
$\frac{\text{Pipe}}{\text{Crud}}$	*.05	*.09	.15	.07	.47	.45
$\frac{\text{Croloy 16-1}}{\text{Crud}}$	.12	.10	.11	*.06	.45	.39
$\frac{\text{Carbon Stl.}}{\text{Crud}}$	.05	.06	*.07	.08	*2.2	.27
			DOWNSTREAM			
$\frac{\text{304 Coupon}}{\text{Crud}}$	.25	.55	*.60	.06	3.9	.61
$\frac{\text{Pipe}}{\text{Crud}}$	.08	.08	*.29	.09	3.3	*.16
$\frac{\text{Croloy 16-1}}{\text{Crud}}$	*.05	.10	*.23	*.02	1.6	*.05
$\frac{\text{Carbon Stl.}}{\text{Crud}}$	.09	*.07	*.11	.02	.29	.17

* Value doubtful due to low counting rates

Table XVII

SPECIFIC ACTIVITY RATIO OF DEPOSITS TO CRUD FOR Cr^{51}

Ratio	Tightly Bound Deposits			Loosely Bound Deposits		
	2796 efph	2971 efph	3216 efph	2796 efph	2971 efph	3216 efph
			UPSTREAM			
304 Coupon / Crud	*2.1	.62	1.1	----	.19	.87
Pipe / Crid	* .02	.07	----	.24	.47	.21
Croloy 16-1 / Crud	* .50	.11	.05	.25	*.08	.93
Carbon Stl. / Crud	.12	.05	.02	----	1.1	*.15
			DOWNSTREAM			
304 Coupon / Crud	2.4	.91	----	*.06	*2.4	----
Pipe / Crud	* .11	.22	1.3	*.11	7.4	*.10
Croloy 16-1 / Crud	.97	.05	*.36	*.07	*.38	*.16
Carbon Stl. / Crud	.07	*.02	*.10	*.03	*.09	*.03

* Value doubtful due to low counting rates

Table XVIII

SPECIFIC ACTIVITY RATIO OF DEPOSITS TO CRUD FOR Mn^{54}

Ratio	Tightly Bound Deposits			Loosely Bound Deposits		
	2796 efph	2971 efph	3210 efph	2796 efph	2791 efph	3216 efph
			UPSTREAM			
$\frac{\text{304 Coupon}}{\text{Crud}}$	.21	.41	.64	.17	.21	.78
$\frac{\text{Pipe}}{\text{Crud}}$	.06	.16	.25	.11	.56	.49
$\frac{\text{Croloy 16-1}}{\text{Crud}}$	.07	*.06	.14	.07	.31	.88
$\frac{\text{Carbon Stl.}}{\text{Crud}}$	.06	.08	.06	.08	2.4	.33
			DOWNSTREAM			
$\frac{\text{304 Coupon}}{\text{Crud}}$	.17	.57	.41	.05	3.3	.35
$\frac{\text{Pipe}}{\text{Crud}}$	.21	.12	.17	.19	3.1	.18
$\frac{\text{Croloy 16-1}}{\text{Crud}}$	.04	.21	.22	.04	1.1	.38
$\frac{\text{Carbon Stl.}}{\text{Crud}}$	.22	.21	.29	.02	.52	.21

* Value doubtful due to low counting rates

coupons is essentially the same as that in the crud. This appears true from the data in Tables VII, XIII, and XIV which indicate the nuclide ratios (Co^{58}/Co^{60}, etc.) are about the same for the deposits and the circulating crud. These ratios show about the same rate of change with time.

J. RADIATION SURVEY DATA

Measurements of the dose rate emanating from various components of equipment within the vapor container were measured from the period of August 24, 1957 to January 12, 1958. Spots were painted at different locations on the primary system components and piping to insure reproducible measurements. The locations surveyed are listed in Table XIX. The dose rate measurements were made external to all components. As a consequence, only gamma radiation was measured. For operation within the vapor container, but external to the primary system components, the gamma radiation is of major concern. However, during a maintenance operation wherein it would be necessary to repair a pump or, for example, plug a steam generator tube, both beta and gamma radiation would be of importance.

A typical example that illustrates this point is as follows: Following the conclusion of the 700-hour continuous test, a dose rate measurement was made at position 15 (bottom of the steam generator). The measured value was approximately 2 mr/hr. Following this measurement, extensive flushing of the steam generator was performed with pure water. The 7 inch steel steam generator head was then dropped for a demonstration tube plugging test. Emanating from the inside of the steam generator was a radiation level of approximately 280 mr/hr.

Survey data is an extremely useful means to measure, and possibly predict,

Table XIX

SURVEY DATA POSITION

Position	Location
1	Hand Rail in Front of Door
2	Top of Primary Pump #2
3	Side of Steam Generator
4	Bottom of Lower Ladder
5	Pressurizer Elbow
6	Reactor Outlet
7	Shield Tank (Panel A)
8	Shield Tank (By Chute)
9	Reactor Inlet
10	Flow Tubes
11	Rod Drive Pit Ladder
12	Rod Drive Pit, Around Corner
13	Steam Generator on Upper Ladder
14	Seal Leakage Tank (Nameplate)
15	Bottom of Steam Generator
16	3 Feet From Bottom of Steam Generator on Inlet
17	3 Feet From Bottom of Steam Generator on Outlet
18	8 Feet, 5 Inches From Bottom of Steam Generator on Inlet
19	8 Feet, 5 Inches From Bottom of Steam Generator on Outlet
20	Primary Inlet to Steam Generator
21	Primary Outlet From Steam Generator
22	Reactor Inlet on Horizontal
23	Drain on Bottom of Steam Generator

the buildup of radioactivity on primary system components. Unfortunately, to obtain good survey data, reactor operations and testing must cease while measurements are being performed. Due to the nature of operations required at the APPR, this was seldom possible. For example, during portions of the survey data measurements rod drop tests were being performed. This testing, in all probability, somewhat stirred up loose deposits on some of the primary system components resulting in confused survey data.

Survey measurements were made during scheduled shut-down periods. Unfortunately, the shut-down periods were seldom sufficiently long to permit measurement of the intermediate half-life activity. In several cases surveys were made when the shut-down time was less than 24 hours. In addition the magnitude of any errors introduced in the instrument readings due to scattering or radiation emitted from adjacent components has not been taken into account. These limitations preclude the prediction of the exact activities contributing to the build-up. Since there was delay in time of approximately two hours from the time of reactor shut-down until the first measurements were made, extremely short half-life material was not detected. All survey data, however, has been corrected to the time of reactor shut-down by neglecting any undetected activity that might be present prior to the first measurement. Thus, activity contributions from such nuclides as Nitrogen 17 are not included in this data.

There are wide variations in the dose rate values measured during the different shutdowns. To allow comparison of the data taken at different times, certain assumptions have been made. By assuming the ratio of short to long half-life activity remains the same when each survey is made, the data was corrected to the time of shut-down. This assumption implies that the short half-life activity is building up at the same time rate as the long-lived activity. This assumption may be open to question, but a mechanism can be visualized by which this is possible. The survey data indicates that the activity due to short-lived nuclides is increasing. In several cases with the more recent survey measurements, the short-lived activity is greater than the combined short and long-lived activity measured during earlier shut-downs.

The ratio of short-lived to long-lived activity for each survey point was based on measurements made during a ten day shut-down period starting January 12, 1958. The survey data collected during this period allowed an opportunity to measure the dose rates over a sufficient length of time so that a reliable picture of the rate of decay of short-lived activity (less than 20 hours half-life) and the true value of long-lived activity could be obtained. Decay curves were then plotted for each survey point and the curves analyzed for short and long-lived components. Typical decay curves for this January 12 shut-down are shown in Figures 10, 11-A and 12-A. Figure 10, the decay curve for Survey Point 5, shows a typical one component, (long-lived) system. Figures 11-A and 11-B, the decay curve for Survey Point 3, is a typical two component system and a short lived component having a half life of 3.8 hours. Figures 12-A and 12-B the decay curve for Survey Point 19, has three half life components: two short lived components of 2 hours and 14 hours plus the long lived component. A summary of the analysis of the decay curves for all survey points showing the proportion of short lived and long lived activity at the time of reactor shutdown is given in Table XX.

TABLE XX
Analysis of Decay Curves from 12 January Shutdown

Point Number	Location	Analysis of Decay	(% of Total)	Decay Pattern 2 hrs.	(Fraction of Total Remaining) 4 hrs.	6 hrs.	8 hrs.	10 hrs.	12 hrs.
3	Side of S. G.	3.8 hrs long	50 50	.85	.74	.66	.62	.58	.56
5	Pressurizer Elbow	long	100	1.0	1.0	1.0	1.0	1.0	1.0
6	Reactor Outlet	3.3 hrs long	52	.82	.70	.63	.58	.55	.52
9	Reactor Inlet	3.4 hrs long	50	.83	.72	.68	.59	.57	.54
10	Flow Tube Taps	9.4 hrs long	39 61	.94	.90	.86	.82	.79	-
15	Bottom of S. G.	long	100	1.0	1.0	1.0	1.0	1.0	1.0
16	3' from bottom of S. G. on Inlet Side	2.5 hrs long	51 49	.78	.65	.58	.54	.52	.51
17	3' from bottom of S. G. on Outlet Side	6.5 hrs long	15 85	.97	.97	.96	.95	.94	.93
18	8' 5" from bottom of S. G. on Inlet Side	2.8 hrs long	66 34	.74	.57	.49	.43	.39	-
19	8' 5" from bottom of S. G. on Outlet Side	2 hrs 14 hrs long	46 16 38	.76	.63	.56	.52	.49	-
20	Primary Inlet to S. G.	3.3 hrs long	45 55	.85	.74	.68	.63	.62	-
21	Primary Outlet from S. G.	4 hrs long	52 48	.85	.74	.66	.61	.57	-
22	Reactor Inlet on Horizontal	3.6 hrs long	34 66	.89	.82	.77	.73	.71	-

A summary of the dose rates measured at the various points during the period August 24, 1957 to January 12, 1958 is presented in Table XXI. The data has been corrected to time of reactor shutdown and the contribution of short lived and long lived activity was assumed to be in the same proportion as that measured for the January 12 shutdown. The sum of the two activities is considered to be due to the total activity of these nuclides present during the first measurement of each survey.

To determine the increase in dose rates with reactor operating time, the dose rates for the long lived component at each survey point were plotted as a function of equivalent full power hours. Typical plots for two of the survey points are shown in Figure 13. To assist in an evaluation of the plotted data, it was assumed that the buildup followed a straight line relation, expressed by the equation:

$$\log D = mT + c$$

where D = dose rate, in mr/hr

T = time, in equivalent full power hours

m = slope of the straight line

c = constant (the intercept with the axis)

The straight line relationship for each survey point was obtained by the method of least squares using an IBM 650 computer from the experimental data of Table XXI. The straight lines shown on Figure 13, are the least mean square curves for Survey Points 10 and 15. The slope and intercepts of the straight line curves for the other survey points are given in Table XXII.

Only additional experimental data can verify whether the dose rate buildup will follow the assumed straight line relation. Should this analysis prove

TABLE XXI

APPR-1 Dose Rate Measurements (mr/hr)

Date	efph	Pt. 3 Side of SG Short Lived	Pt. 3 Side of SG Long Lived	Pt. 5 Press. Elbow Short Lived	Pt. 5 Press. Elbow Long Lived	Pt. 6 Reactor Outlet Short Lived	Pt. 6 Reactor Outlet Long Lived	Pt. 9 Reactor Inlet Short Lived	Pt. 9 Reactor Inlet Long Lived	Pt. 10 Flow Tubes Short Lived	Pt. 10 Flow Tubes Long Lived	Pt. 15 Bottom of SG Short Lived	Pt. 15 Bottom of SG Long Lived
24 Aug.		8.5	8.5	-	120	69	64	34	34	109	170		
8 Oct.	1655	42	42	-	120	65	60	52	52	45	71		
17 Oct.	1705	26	26	-	100	36	34	30	30	60	94		
7 Nov.	2060	61	61	-	120	123	113	89	89	85	133	-	42
15 Nov.	2100	30	30	-	120	43	40	32	32	71	110	-	24
7 Dec.	2400	62	62	-	160	95	88	90	90	66	104	-	34
13 Dec.	2530	38	38	-	150	58	54	47	47	80	125	-	29
*2 Jan.	2780	100	100	-	300	152	140	120	120	100	156	-	50
12 Jan.	2960	51	50	-	100	72	67	54	53	79	125	-	36

* These values appear to be unrealistically high, possibly due to instrument malfunction.

TABLE XXI (Cont.)

APPR-1 Dose Rate Measurements (mr/hr)

Date	efph	Pt. 16 3' from Bottom on Inlet		Pt. 17 3'from Sg Bottom on Outlet		Pt. 18 8'5" from SG Bottom on Inlet		Pt. 19 8'5" from SG Bottom on Outlet		Pt. 20 Primary Inlet to SG		Pt. 21 Primary Outlet from SG		Pt. 22 Reactor Inlet on Horizontal	
		Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long
7 Nov.	2060	141	136	21	120	46	24	44	27	102	125	39	36		
15 Nov.	2100	45	42	7	40	11	5	25	15	39	48	20	18		
7 Dec.	2400	111	107	22	123	60	30	62	38	94	114	45	42	77	148
13 Dec.	2530	59	57	9	51	34	18	33	20	53	65	-	-	67	133
*2 Jan.	2780	144	138	37	210	70	36	76	40	170	208	-	-	122	237
12 Jan.	2960	75	71	9	50	39	20	35	22	57	70	24	22	82	158

* These values appear to be unrealistically high, possibly due to instrument malfunction.

Table XXII

LEAST MEAN SQUARE CURVES FOR LONG LIVED DEPOSITS

$$\log D = mT + c$$

Survey Point	Slope m	Intercept (c)
3	2.43×10^{-4}	1.14
5	1.90	1.72
6	1.94	1.42
9	2.07	1.32
10	1.62	1.69
15	1.20	1.25
16	0	1.96
17	.77	1.80
18	3.74	0.381
19	1.25	1.12
20	2.67	1.24
21	-0.74	1.05
22	2.22	1.65

correct, the buildup of activity could be extremely high. For example, if the least mean square curve for Survey Point 15 could be considered valid, the dose rate reading below the steam generator head at the end of core life (ca. 11,000 efph) would be 370 mr/hr. With an attenuation factor of approximately 125 across the steam generator head, the internal dose rate reading would then be approximately 46 R/hr. Actually, predictions of dose rates thus far in the future are not justified from the present data, and must await additional measurements.

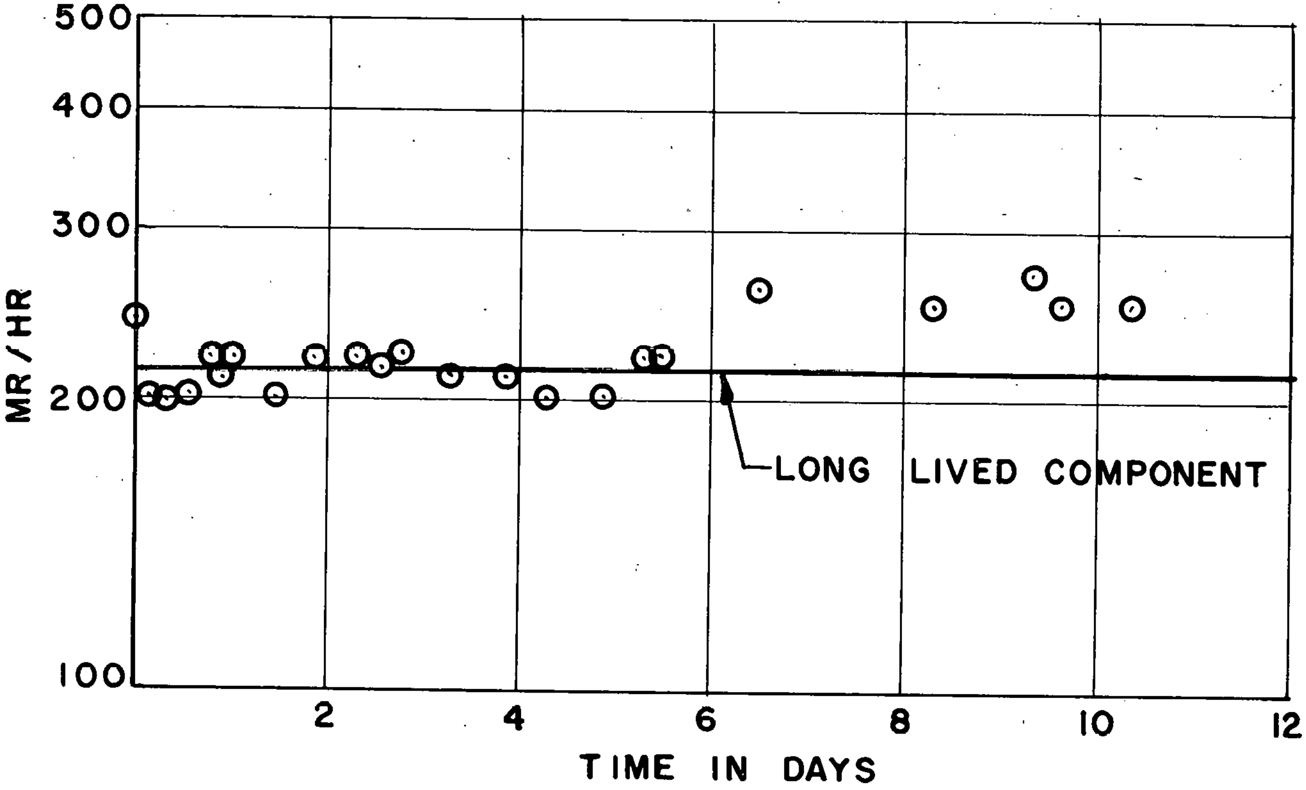

FIG. 10 DOSE RATES AT SURVEY POINT 5

(JAN. 12, 1958 SHUTDOWN)

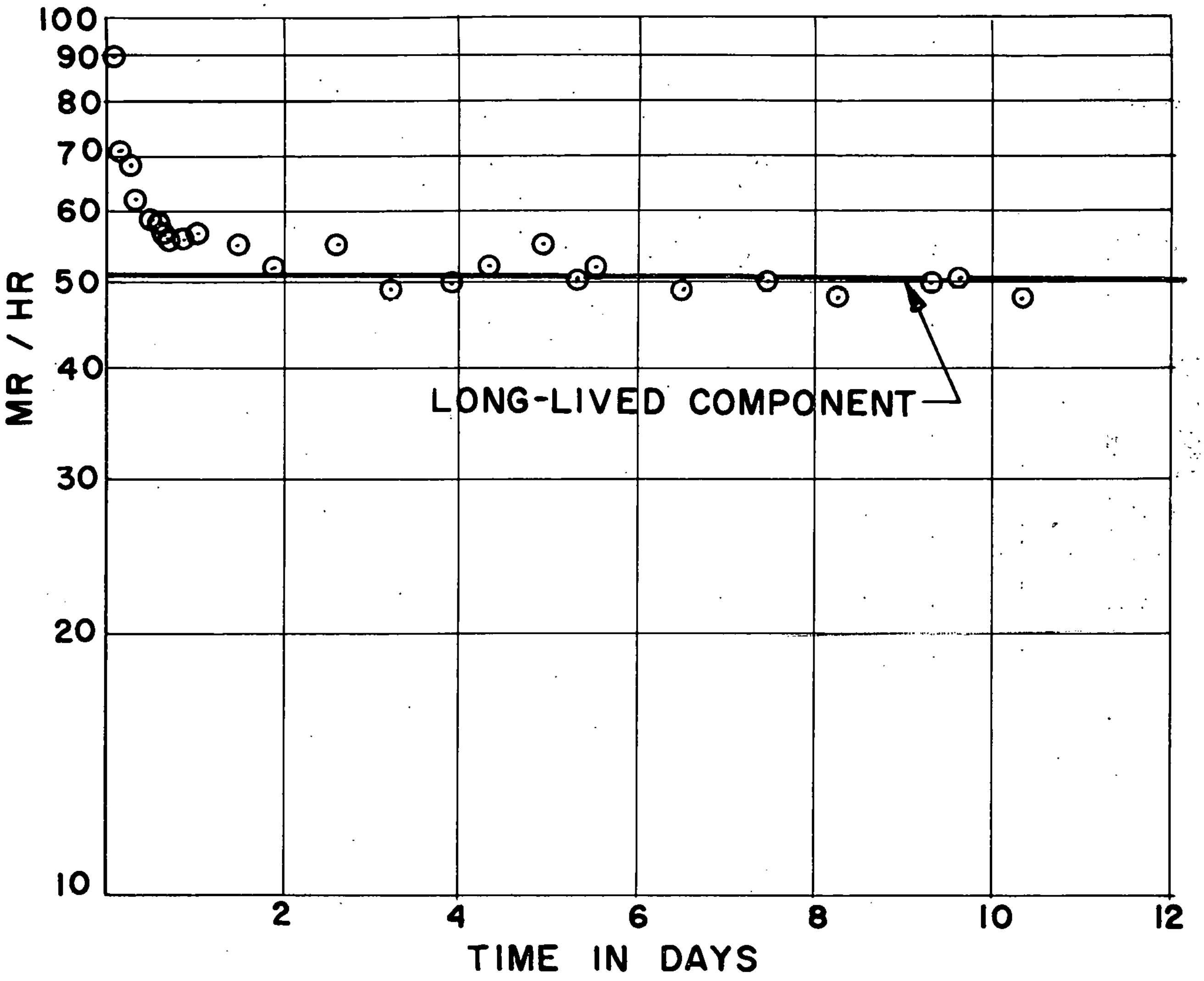

FIG. 11-A DOSE RATES AT SURVEY POINT 3

(JAN. 12, 1958 SHUTDOWN)

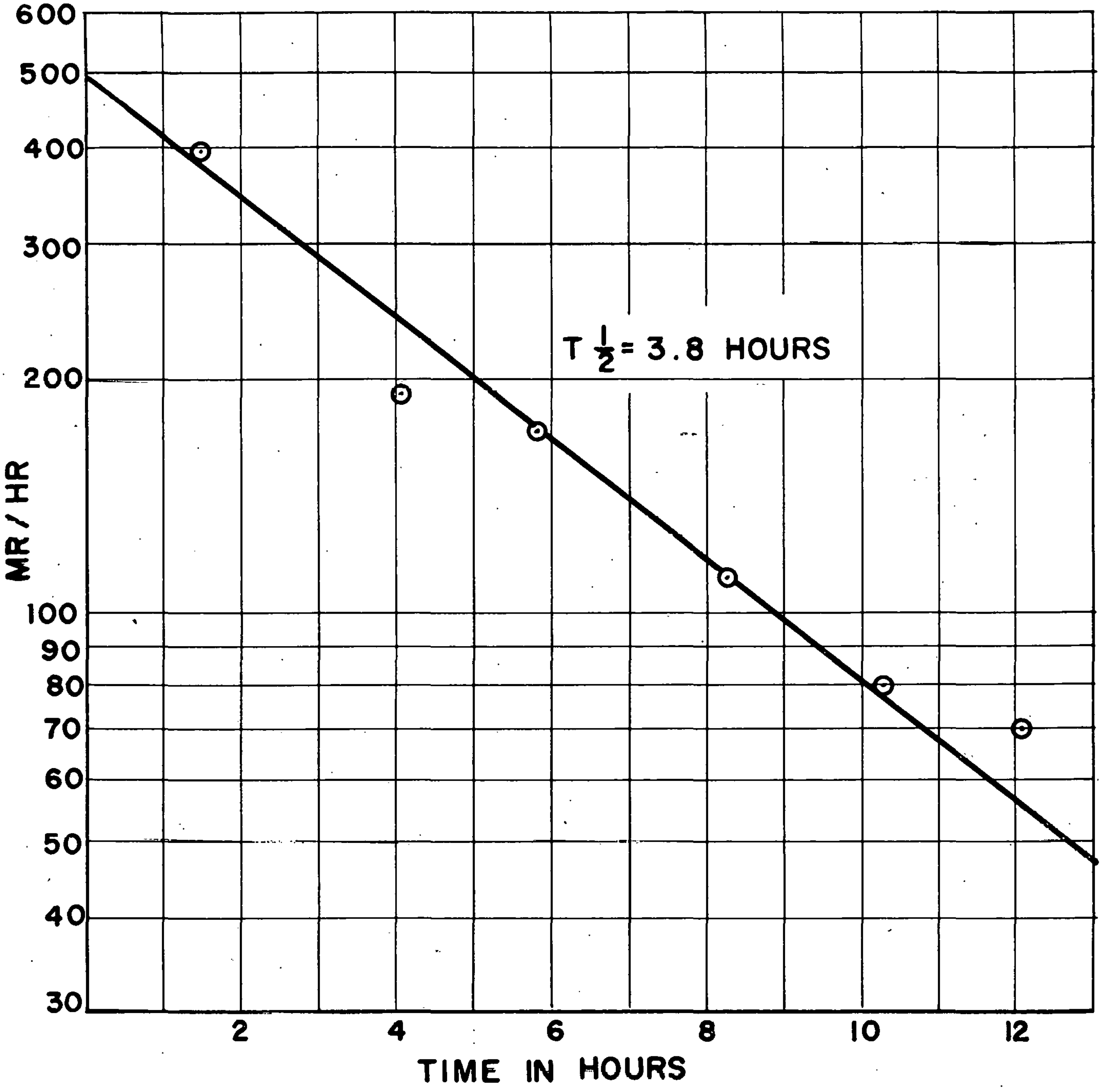

FIG. 11-B DOSE RATES AT SURVEY POINT 3

(JAN. 12, 1958 SHUTDOWN)

ANALYSIS OF COMPOSITE DECAY CURVE (FIG. 11-A)

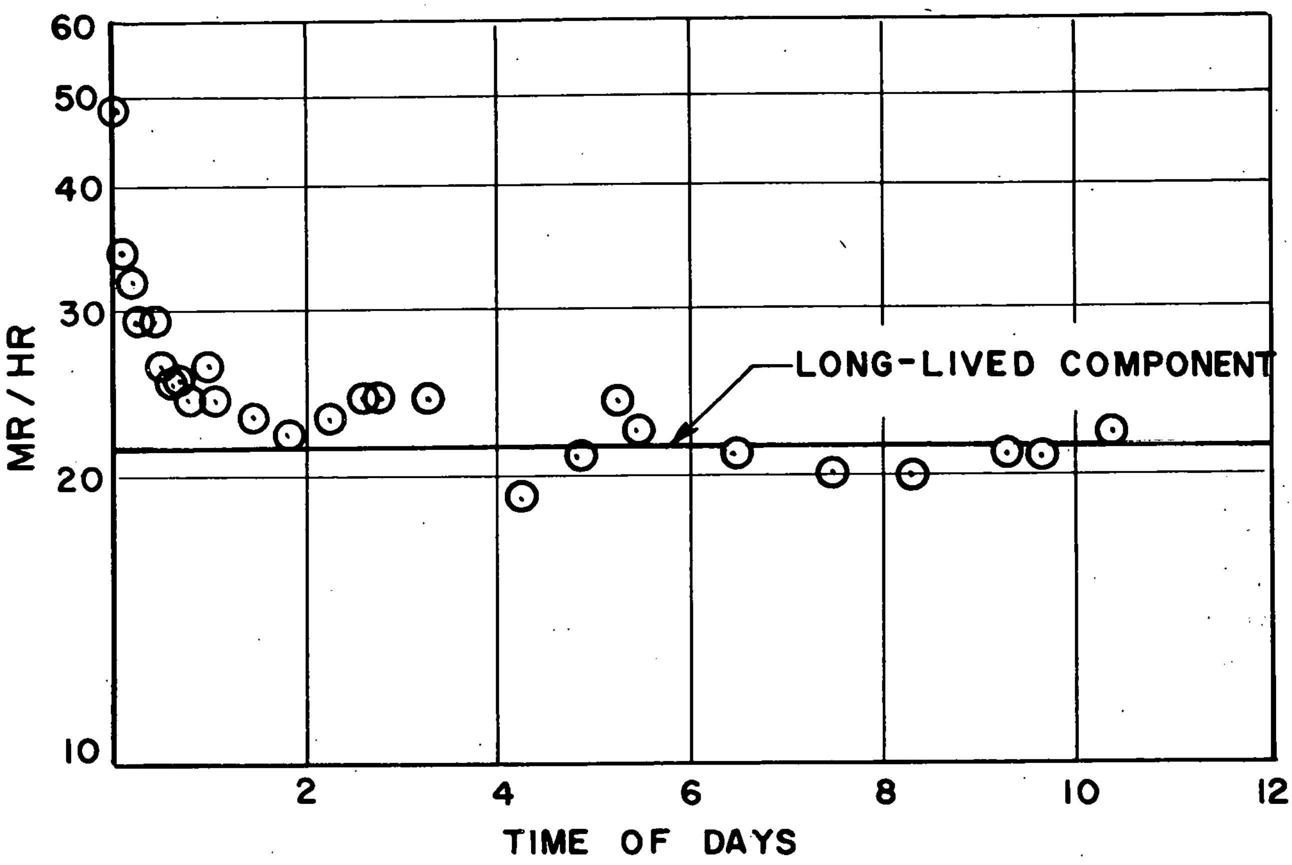

FIG. 12-A DOSE RATES AT SURVEY POINT 19

(JAN. 12, 1958 SHUTDOWN)

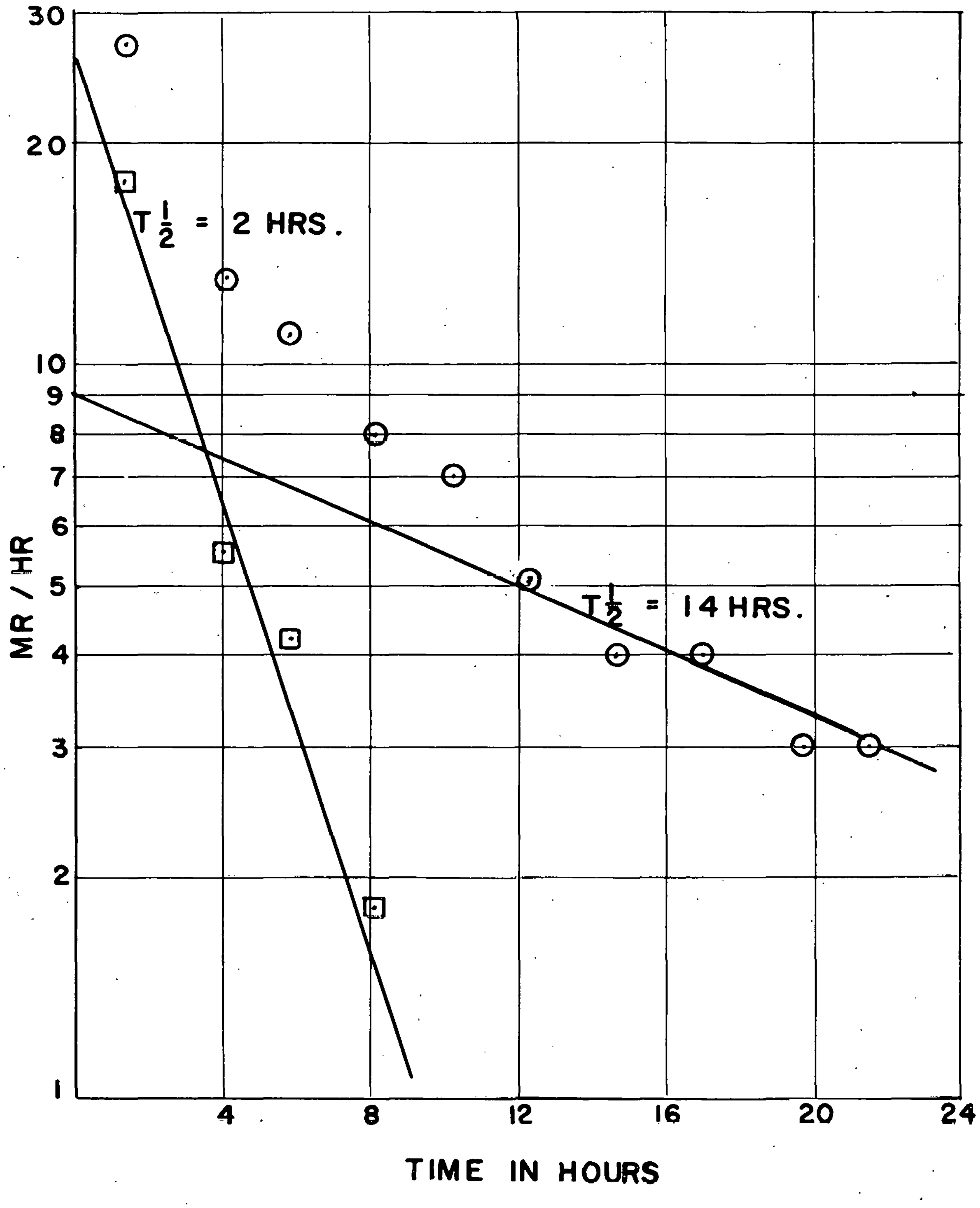

FIG. 12-B DOSE RATES AT SURVEY POINT 19

(JAN. 12, 1958 SHUTDOWN)

ANALYSIS OF COMPOSITE DECAY CURVE (FIG. 12-A)

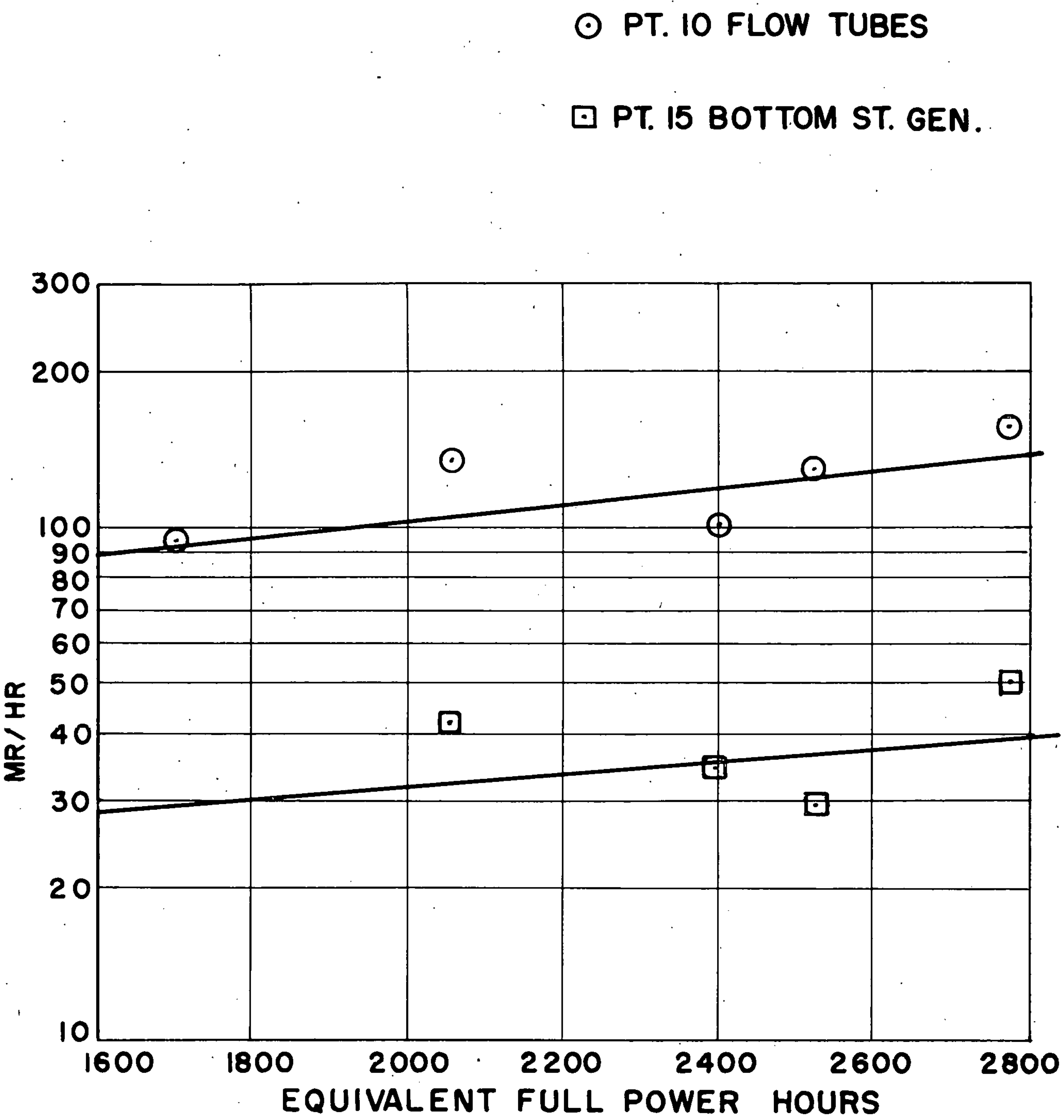

FIG. 13 DOSE RATES AT SURVEY POINTS 10 AND 15 AS A FUNCTION OF REACTOR OPERATING TIME

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