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August 26, 1946

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RLO-CG-3 Rev. 1

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FINAL REPORT ON PRODUCTION TEST 105-2-P

ACTIVITY OF PILE DISCHARGE WATER

Prepared By:

J. H. Yost

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FINAL REPORT ON PRODUCTION TEST 105-2-P

ACTIVITY OF PILE DISCHARGE WATER

Introduction

The radiation characteristics of the pile discharge water, and the factors which cause these characteristics to vary, have been studied under this Production Test. Detailed discussions of various phases of this problem have been reported in interim reports. The present report summarizes and correlates significant facts from previous reports, and includes an extensive bibliography.

Summary

By means of activity decay curves and chemical tests, the identities of all important water activity components have been established. The activities of these components have been measured from time to time under a variety of conditions. The following conclusions can be drawn from these measurements:

1. The radioactive isotopes in the order of decreasing strength in the water as it leaves the pile are: N^{16}(8 sec.), O^{19}(31 sec.), Al^{28}(2.4 min.), Mg^{27}(10.2 min.), Cl^{38}(37 min.), Ca^{49}(30 min.), Mn^{56},(2.6 hrs.) and Na^{24} (14.8 hrs.). The relative activities of these components and their variability under certain conditions are discussed in this report.

2. For water whose composition does not change, the intensity of each component is directly proportional to the power level of the pile. ?

3. Except for the Al^{28} component, which arises principally from corrosion of aluminum tube and slug surfaces, the amount of each activity component varies in direct proportion to changes in the concentration of its respective parent element in the process water.

4. Some elements, particularly manganese, and probably magnesium, stick temporarily in the water tubes of the pile. The intensity of the Mn^{56} component is increased by a factor of 25-30 due to sticking of about 2 per cent of the manganese in the water for an average irradiation time of 45 minutes.

5. The intensities of water activity components are largely independent of the amount of film in the water tubes of the pile. However, a temporary decrease in the strength of the Mn^{56} component results from removal of the film by purging. Only two or three days are required after a purge for this component to build up to its former value.

6. The radiation dosage rates at the outlets of the Retention Basins average about 2.5 mrep./hr. for piles operating at rated capacity. During surges of the Mn^{56} component, which has been known to vary by as much as a factor of five, the intensity has approximated 4.17 mrep./hr. for short periods of time. The dilution by other plant waste water has always been sufficient to reduce the intensity below the tolerance limit before the water reached the river.

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7. The water activity at the outlets of the Retention Basins during purges with 100 p.p.m. of diatomaceous earth, beginning 1-2 hours after shutdown from 250 M.W., is normally 2-3 mrep./hr. It is estimated that the intensity would be considerably above tolerance if a purge of an entire pile were to be carried out while operating at 250 M.W.

8. The elements manganese, copper, sodium, chromium, phosphorus, and iron have been identified in samples of film from the water tubes. Other elements may also be present since a large part of the film activity remains unidentified.

9. Any corrective action aimed at reducing or eliminating the variable Mn^{56} water activity component is expected to involve (a) the use of coagulants which are free of manganese impurity, or (b) changes in water treatment facilities and procedures to insure more effective removal of manganese from the water by filtration.

Details

I. Calculated Values For Water Activity

Various spectroscopic and chemical analyses of samples of 100 Area process water have been made to determine the elements present and the amounts of each. Some of these analyses were made routinely in connection with water control work and numerous results are available from which the average concentrations of the more abundant constituents were obtained. In other cases the tests have been few and the results are only rough approximations.

By taking into account the concentration of each element in the water and making use of available information on neutron induced reactions, (Project Handbook, C1-697) estimates of the contributions of all constituents to the effluent water activity have been made. The disintegration rates shown in Table I represent the average amounts from an entire pile operated at 250 M.W., at the instant the water reaches the discharge header (hereinafter called zero time).

The contributions of corrosion products to the water activity have also been calculated. The calculations have been based on spectrochemical analyses of the slug and tube surfaces together with the assumption of average corrosion rates of 0.0001 and 0.00006 cm. per month for slug and tube surfaces respectively. Results are shown in Table II.

It will be observed (Table I) that the strong activity components in the order of descending strength are: N^{16}(8 sec.), O^{19}(31 sec.), Al^{28}(2.4 min.), Cl^{38}(37 min.), Mg^{27}(10.2 min.), Na^{24}(14.8 hrs.) A^{41}(110 min), Ca^{49}(30 min.), Cu^{66}(5 min.), and Mn^{56}(2.6 hrs.). The only strong component of the corrosion product group (Table II) is Al^{28}(2.4 min.), the contribution from corrosion being greater than that from irradiation of the small amount of aluminum in the process water as it traverses the unit.

II. Measurement of Water Activity

Two types of instruments were frequently used for running activity decay curves on water samples. One assembly consisted of a G. M. Tube mounted

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vertically in a cylindrical water container. The thickness of water filling the annular space around the G. M. Tube was approximately 1½ inches. The other instrument was a vertically mounted thin mica window tube for counting residues of evaporated samples. Absolute disintegration rates were determined with the mica window tube by evaporating small known volumes of water and comparing the counting rates with that obtained from a uranium oxide source with identical geometry. The annular type of counter was used for measuring the activity of the water in liquid form and possessed the advantage that counting could begin very soon after a sample was taken, thereby permitting measurement of the components having short half lives.

Decay curves on water samples were graphically analyzed in the usual manner to determine the half lives and intensities of individual components. The results were then compared with expectations based on concentrations and cross sections of elements known to be present in the water. It should be emphasized that a graphical analysis of a decay curve in which several components having similar half lives are represented is subject to considerable uncertainty unless supported by chemical data. It was first thought that the decay curves could be resolved best into components having half lives of 2.4 min., 16-18 min., 2.6 hrs., and 14.8 hrs. (Reference 1) All half lives were attributable to elements known to be present in the water except the 16-18 minute fraction. More careful and detailed analyses showed that this portion of the decay curve could be resolved into a mixture of two parts having half lives of about 10 min. and 34 minutes. (Reference 2) This breakdown seemed particularly creditable since the concentration of magnesium in the water is sufficient to account for a strong Mg^{27} (10.2 min.) component. The 34 minute half life could easily be a mixture of Ca^{49}(30 min.) and Cl^{38}(37 min.) isotopes. The detailed analyses also showed the presence of a very small amount of activity having a half life of many days. The most likely contributors to each of these half lives have been taken from Tables I and II, and regrouped in Table III.

No measurements of the intensities of the N^{16}(8 sec.) and O^{19}(31 sec.) components have been made, because their short half lives make such measurements difficult. The theoretical estimates in Table I are probably fairly reliable, being subject only to errors associated with the cross sections and flux densities. No experimental intensity figures were obtained on the gaseous activity components, although decay curves run on samples of gas emitted from stacks at the junction boxes in the sewer from 105 Bldg. to the Retention Basin showed periods corresponding to A^{41}(110 min.) and Cl^{38}(37 min.) It it is assumed that 4000 cubic feet per minute of air enters the vents on the discharge riser and downcomer, the stack gases should have about 7 dis./cc/sec. from A^{41} and 2 dis/cc/sec. of Cl^{38} under standard conditions at 250 M.W. These active gases are swept from the cooling water by air entrained in the downcomer.

The measured intensities of all water components except the very short-lived ones and the gaseous products are listed in Table IV. The maximum and minimum values represent the extreme ranges of measured values. The average values are estimates of time averages based on past performance in all areas.

The component having a half life of 2.4 minutes is Al^{28}. The measured intensity (Table IV) is 3-4 times as high as expected from the amount of aluminum in the water and the rates of corrosion of tube and slug surfaces, however. The measured intensity of Mg^{27} (10.2 min.) is likewise higher by a factor of 7-10. Closer agreement between theoretical and experimental values for these components can

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be achieved by taking into account the following effects which were not considered in calculating the results shown in Tables I and II.

1. Recoil atoms of aluminum and magnesium are ejected into the water stream. The significance of this contribution is difficult to evaluate because of the presence of film on the surfaces, and the limited range of the recoil atoms. The range of the atom Mg^{27}, produced by the reaction $Al^{27}(n,p)$ is about 3×10^{-5} cm. in aluminum, while that of $Al^{27}(n,\gamma)$ is only 9×10^{-8} cm. (Reference 3)

2. Some elements in solution tend to stick temporarily on surfaces in the water tubes, thereby increasing the effective irradiation time and resultant activity many fold. This sticking effect has been demonstrated with manganese and copper solutions. (Reference 4) Similar effects probably occur with aluminum, silicon, and magnesium (particularly the latter) in the process water.

The portion of water activity having an apparent half life of about 34 minutes was expected to be a mixture of Ca^{49} (30 min.) and Cl^{38}(37 min.) isotopes. Confirmation was obtained by chemically separating these two elements from the water and measuring their half lives. (Reference 5) The strengths of the two components were shown to be approximately equal. The isotope Ca^{49} decays by beta emission to Sc^{49}, which in turn decays by beta emission, with a half life of 57 minutes. The 57 minute daughter isotope was not detected in composite decay curves, because its effect was masked by other stronger components.

At first glance (Figures III and IV) the 2.6 hr. activity might be a mixture of the isotopes Mn^{56} (2.6 hrs.), Si^{31}(2.8 hrs.) and Ca^{49}(2.5 hrs.) in unknown proportions. The experimental value for the strength of this activity was much higher than expected from simple cross section and flux density considerations. Chemical separation tests have shown this activity to be almost entirely due to Mn^{56} (2.6 hrs.). (Reference 6) The low concentration of manganese in the process water, together with the experimentally verified presence of Mn^{56} activity in effluent water after scrams of the units, led to the belief that some of the manganese in the process water sticks temporarily on surfaces in the tubes. Strong Mn^{56} activity was found in samples of film from discharged slugs and in samples of effluent water during purging operations. (Reference 7) In a special test in which manganous sulphate solution was added to the cooling water of a single tube, it was demonstrated that the Mn^{56} activity in effluent water is increased by a factor of 25-30 due to sticking. (Reference 4) It was estimated that approximately 2 per cent of the manganese in the water stuck on the tube and slug surfaces for an average sticking time of about 45 minutes. By similarly adding ferric nitrate solution to a single tube, it was also shown that no significant amount of Mn^{56} activity results from the $Fe^{56}(n,p)$ reaction on iron in the water or film.

The presence and strength of the 14.8 hr. component were in agreement with expectations. This activity is due to Na^{24} resulting from the reaction $Na^{23}(n,\gamma)$ on sodium in the water. Approximately 2 p.p.m. of sodium occur normally in Columbia River water. (Reference 8) An equal or slightly greater amount is added in the form of sodium silicate and sodium dichromate for film and corrosion control. The amount of Na^{24}(14.8 hr.) activity is believed to be directly

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proportional to the sodium content of the water and is not affected by sticking in the tubes or other abnormal factors. A component of activity of 12-16 hrs. half life in film samples was first thought to be Na^{24} (Reference 7), but was later shown to be largely Cu^{64}(12.8 hrs.) (Reference 11).

The long lived activity (Table IV) is believed to be a mixture of several isotopes. The contribution of Fe^{59}(47 days) is probably much greater than indicated in Table III. The presence of iron in the film (References 7 and 9) would increase its irradiation time a great deal. If subsequent partial washing away occurred, the strength of the Fe^{59} component could conceivably be great enough to account for all of the observed long lived activity. The weakness of the long lived activity prevented measurement of its half life.

III. Variations In Water Activity

It has been shown that, for outlet tube temperatures below 53° C., all water activity components increase linearly with power level. (Reference 10) Activity components such as Al^{28} which are functions of the corrosion rate of the aluminum surfaces may be expected to increase faster than the established linear rate if the operating power level is raised high enough to produce an accelerated rate of corrosion.

Water activity was once thought to be a function of the amount of film in the water tubes. More extensive data showed that the previous indication of positive correlation between the intensity of water activity and the amount of film in the unit was merely a coincidence. All components except Mn^{56}(2.6 hrs.) are unaffected by purges. (Reference 10) Since the amount of Mn^{56} activity depends upon temporary holdup of manganese in the film, a sharp decrease in this component can be expected immediately after a purge. The average holdup time of manganese is only about 45 minutes, (Reference 4) however, and the saturated concentration of manganese is reached again within a few days after the purge. After an extended shutdown, several hours are also required for the Mn^{56} in the film to build up to its saturation valve. There are no indications that the amount of Mn^{56} is dependent upon the thickness of the film. The Mg^{27} component would also be expected to decrease temporarily if a unit were purged quickly while operating, since magnesium is believed to stick on surfaces in the water tubes. The half life of this component is so short (10.2 min.), that the saturation valve would be reached again very quickly. In normal operation, in which purging is done only when the unit is in a shutdown condition, no changes in the Mg^{27} component as a result of purging are likely to be observed.

The intensities of all water activity components are believed to be directly proportional to the concentrations of their respective parent isotopes in the water. Rapid random fluctuations of about 20 per cent in the strength of the Na^{24} component have been observed. This slight instability may be an indication of non-uniformity of sodium concentration in the water.

Purging with diatomaceous earth for film removal introduces active film particles into the process water. The amount of this activity depends upon the composition of the film and the length of time after shutdown of

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the unit that the purge occurs. Beta and gamma decay curves on typical film samples have been measured and reported. (Reference 7) Radiochemical tests have also been performed to determine the identities and concentrations of the constituents. (Reference 9) The results of graphical analyses of decay curves indicated the presence of components having half lives which were tentatively assigned as follows: Mn^{56}(2.6 hrs.), Na^{24}(14.8 hrs.), Ca^{41}(8.5 days), and Fe^{59}(47 days). A fraction of activity having a half life of 50 hours was not identified. Subsequent radiochemical assay results indicated that the portion of activity previously attributed to Na^{24}(14.8 hrs.) was actually largely Cu^{64}(12.8 hrs.). The presence of Mn^{56}(2.6 hr.) and Fe^{59} (47 day) components in the film was verified. Other components identified were Cr^{51}(26.5 days), P^{32}(14.3 days), and a small amount of Na^{24}(14.8 hrs.) A very small amount of alpha activity was found, but its source could not be determined. No fission product or calcium activities were detected in the film emulsions. Eighty per cent of the gross activity remained unidentified.

During periods when the Mn^{56} component is abnormally high in effluent water, the film also contains relatively more of this component. Higher Fe^{59}(47 day) activity relative to other components in the film has also been observed during these periods. These observations are consistent with the conclusion that high Mn^{56} activity in exit water occurs simultaneously with higher iron concentrations in the process water.

IV. Activity During Purges

During purges with diatomaceous earth for removal of accumulated film from the tubes, active film particles are carried away in the wash water. The amount of this activity is variable, depending upon the following factors:

1. Operating power level of the unit prior to the purge.
2. Elapsed time after shut down until the purge occurs.
3. Composition of the film.
4. Concentration of solids in the wash water.
5. Flow rate of the wash water.

The major part of film activity, during the first few hours after shutdown is due to Mn^{56}(2.6 hrs.). Since the concentration of manganese in the film is extremely variable, corresponding variations in the activity of purge water can be expected under otherwise identical purge conditions. For film of identical composition, the activity per unit weight is proportional to the previous operating power level, and decreases with time after shutdown. The rate of film removal, and hence the water activity, is believed to be proportional to the concentration of solids in the wash water. By making simultaneous activity and pressure drop measurements on individual tubes during purges, it has been demonstrated that the activity of discharge water can be used as a reliable indicator of the rate of film removal. (References 11 and 12) In this manner it was shown that the rate of removal is greatest in the tubes having highest flow rates.

During purges in which the solids concentration is held constant, the peak activity occurs immediately after the addition of solids begins, decreasing rapidly in approximately exponential fashion thereafter. This peak

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activity varies widely in strength. A value of 20 mrep/hr. at the inlet of the Retention Basin is typical of a purge with 100 p.p.m. diatomaceous earth beginning 1-2 hours after shutdown from 250 M.W. Three factors which operate to reduce this peak activity below the tolerance level before the water is discharged into the river are:

1. Radioactive decay of activity while the wash water is held in the Retention Basin. At a flow rate of 31000 g.p.m., the holdup time of the basin is 5 3/4 hrs. The flow rate is normally reduced for metal discharging operations immediately after a purge. The holdup time will thus become considerably greater than 5 3/4 hours.

2. Adherence of active film particles to the diatomaceous earth particles. As much as 80 per cent of the activity can be removed by 100 p.p.m. of diatomaceous earth which is allowed to settle for several days. A reduction by about 50 per cent due to settling, is typical of the Retention Basins.

3. Mixing of water in the Retention Basin. A sharp decrease in activity ordinarily follows the initial peak. Due to slight mixing (both by turbulence and by settling of solids) with surrounding water, the peak activity is substantially reduced.

Due to this combination of factors, the activity of purge water is reduced to a level below tolerance (4.17 mrep./hr.) before the water is discharged into the river. Values of 2-3 mrep./hr. at the outlets of the Retention Basins are typical of purges with 100 p.p.m. diatomaceous earth, of one hour duration beginning 1-2 hours after shutdown from 250 M.W.

From data obtained by irradiating a sample of diatomaceous earth in the 305 Bldg. test unit, (Reference 8) it is estimated that if a unit were purged with 100 p.p.m. while operating at 250 M.W., the activity of the solid particles themselves would amount to at least 1.1 mrep./hr. at the outlet of the Retention Basin. In making this estimate no allowance was made for increased effective irradiation time due to temporary sticking of diatomaceous earth particles in the water tubes. It is probable that the activity would be increased many fold due to sticking. The activity of the film particles would probably contribute an additional 3-5 mrep./hr. at the outlet of the basin. These increases would be in addition to the normal water activity of 2-3 mrep./hr. It is very unlikely that a purge with 100 p.p.m. could be carried out in a pile operating at 250 M.W. without exceeding the upper limit of 4.17 mrep./hr. for water discharged into the river. A procedure might be worked out whereby only a part of the pile is purged at one time or reductions in solids concentration or power level are made to permit purging while operating.

V. Radiation Hazard In Process Water

The contribution of each activity component to the radiation hazard in average effluent water has been estimated. Detailed and fairly reliable data were available on disintegration schemes for Mn^{56} and Na^{24} isotopes. (References 13, 14) The energies used for other isotopes are rough approximations based on data from the Project Handbook. The total radiation dosages are calculated at points corresponding to zero decay time (discharge face of pile), 3 minutes decay (sample rooms), 5½ minutes decay (inlet to

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100-F Retention Basin), and 5 3/4 hours decay (outlet of Retention Basin). Average initial disintegration rates of the individual components were used. Results are shown in Table V. The dosage rates apply to fishes, or other animals totally immersed in the water.

It will be observed that the N^{16} component accounts for more than 99 per cent of the radiation hazard at the discharge face. After 3 minutes decay the N^{16} has disappeared and Al^{28} is the strongest component in the water as it reaches the sample rooms, with strong contributions by O^{19} and Mg^{27} also. At the inlet to the Retention Basin the Al^{28} continues to dominate, while O^{19} has almost disappeared. At the outlet of the Retention Basin, Na^{24} normally represents 75-80 per cent of the radiation dosage rate. This percentage varies widely, depending upon the concentration of sodium in the water, as well as the strength of the Mn^{56} component.

Samples of Columbia River water have been taken at various locations relative to the discharge point of water from the Retention Basins. (Reference 15) Activity measurements on these samples showed that dilution of the active water occurs rapidly as it flows from the discharge point. At a time when the radiation intensity of water leaving a Retention Basin was 2.2 mrep./hr., the rate was only half as great twenty-five feet from the discharge point. Further downstream, the maximum intensities found at distances of 1000 feet and [illegible] miles were 0.1 and 0.002 mrep./hr., respectively.

Characteristics of Retention Basin performance, as it pertains to reduction of water activity to a tolerable level prior to discharge into the river, have been investigated. (Reference 16) It was found that the effective holdup time of an entire basin, at a flow rate of 31,000 g.p.m. is about 5 3/4 hours. The theoretical maximum, based on actual basin dimensions, and no mixing is 6½ hours. Some channeling occurs, but the amount is small, as shown by direct water activity measurements at various points in the basin as well as the overall efficiency of about 88 per cent in the effective holdup time. A statistical analysis of Retention Basin outlet water activity data, and wind velocity records, showed no correlation between the outlet water activity and the direction or velocity of the wind. (Reference 16)

Water from the Retention Basins is mixed with other inactive water wastes before being discharged into the Columbia River. The amount of dilution varies but on the average the activity after dilution is about 70 per cent of the exit basin activity. (Reference 17) This dilution is particularly advantageous during surges when the activity has sometimes exceeded 4.17 mrep./hr. at the outlet of the basin.

According to recent literature (Reference 13) Mn^{56} decays by emitting a beta and a gamma ray. Three different combinations of beta and gamma energies are believed to exist. Beta rays of maximum energies 2.88, 1.07, and 0.75 mev. are accompanied by gamma rays of 0.845, 2.66, and 2.98 mev., respectively. The percentages of disintegrations occurring by these processes are 50, 25, and 25 per cent respectively. The disintegration of Na^{24} is believed to occur

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by emission of a beta particle of maximum energy 1.4 mev. followed by two gamma rays in cascade, of 1.35 and 0.36 mev. (Reference 14) By assuming the average beta energy to be equal to 40 per cent of the maximum and weighting each mode of disintegration in proportion to the probability of its occurrence, the average beta and gamma energies per disintegration of Mn^{56} are 0.76 and 1.82 mev. respectively. Corresponding values per disintegration of Na^{24} are 0.56 and 4.20 mev. for beta and gamma rays, respectively. By using these average energy values, together with the assumption that the absorption of one roentgen is equivalent to the absorption of 83 ergs of energy per c.c. of tissue, (Reference 18) radiation dosage rates due to beta and gamma radiation separately have been calculated for the Mn^{56} and Na^{24} components. Results are shown in Table VI. The disintegration rates are the same as those shown in Table IV.

It will be observed (Table VI) that the percentage of the total dosage rate at the outlet of the basin due to the Mn^{56} component varies from about 12 to 35 per cent. Due to the lower relative gamma energy from the Mn^{56} component the ratio of gamma to beta dosage decreases as the Mn^{56} component increases.

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TABLE I

CALCULATED ACTIVITY OF
EFFLUENT WATER (EXCLUDING CORROSION PRODUCTS)

Element	Concentration in P.P.M.	Isotopic Cross Section x 10^{24}	Reaction	Half Life	Disintegrations Per C.C. per Sec.
N	0.011	0.01	$N^{15}(n,g)N^{16}$	8s	0.02
O	8.88×10^5	0.00022	$O^{18}(n,g)O^{19}$	31s	2000
--	8.88×10^5	0.000012	$O^{16}(n,p)N^{16}$	8s	400000
Na	4-5	0.69	$Na^{23}(n,g)Na^{24}$	14.8 h	9
Mg	5.	0.05	$Mg^{26}(n,g)Mg^{27}$	10.2 m	10
--	5.	0.0014	$Mg^{24}(n,p)Na^{24}$	14.8 h	0.004
Al	0.01	0.23	$Al^{27}(n,g)Al^{28}$	2.4 m	3
--	0.01	0.0009	$Al^{27}(n,a)Na^{24}$	14.8 h	0.000007
--	0.01	0.006	$Al^{27}(n,p)Mg^{27}$	10.2 m	0.005
Si	7.5	0.012	$Si^{28}(n,p)Al^{28}$	2.4 m	20
--	7.5	0.0003	$Si^{29}(n,p)Al^{29}$	6.7 m	0.01
--	7.5	0.11	$Si^{30}(n,g)Si^{31}$	2.8 h	0.6
P	0.015	0.23	$P^{31}(n,g)P^{32}$	14.3 d	0.0005
--	0.015	0.05	$P^{31}(n,p)Si^{31}$	2.8 h	0.0001
--	0.015	0.006	$P^{31}(n,a)Al^{28}$	2.4 m	0.02
S	9.0	0.08	$S^{32}(n,p)P^{32}$	14.3 d	0.02
--	9.0	0.26	$S^{34}(n,g)S^{35}$	88 d	0.002
Cl	0.8	0.01	$Cl^{35}(n,a)P^{32}$	14.3 d	0.002
--	0.8	0.61	$Cl^{37}(n,g)Cl^{38}$	37 m	9
Cl (gas)	0.2	0.01	$Cl^{35}(n,a)P^{32}$	14.3 d	0.00005
--	0.2	0.61	$Cl^{37}(n,g)Cl^{38}$	37 m	2

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TABLE I (Cont'd.)

CALCULATED ACTIVITY OF
EFFLUENT WATER (EXCLUDING CORROSION PRODUCTS)

Element	Concentration in P.P.M.	Isotopic Cross Section X 10^{24}	Reaction	Half Life	Disintegrations Per C.C. per Sec.
A (gas)	0.4	0.62	$A^{40}(n,\gamma)A^{41}$	110 m	7
K	0.1	1.0	$K^{41}(n,\gamma)K^{42}$	12.4 h	0.02
Ca	25.	0.55	$Ca^{48}(n,\gamma)Ca^{49}$	30 m	2.
--	25.	0.21	$Ca^{48}(n,\gamma)Ca^{49}$	2.5 h	0.1
--	25.	0.6	$Ca^{44}(n,\gamma)Ca^{45}$	180 d	0.002
--	25.	0.00013	$Ca^{40}(n,\gamma)Ca^{41}$	8.5 d	0.0005
Ti	0.1	0.04	$Ti^{50}(n,\gamma)Ti^{51}$	72 d	0.000005
--	0.1	0.14	$Ti^{50}(n,\gamma)Ti^{51}$	6 m	0.2
Cr	0.8	10.0	$Cr^{50}(n,\gamma)Cr^{51}$	26.5 d	0.02
--	0.8	0.006	$Cr^{54}(n,\gamma)Cr^{55}$	1.3 h	0.002
Mn	0.005	11.2	$Mn^{55}(n,\gamma)Mn^{56}$	2.6 h	0.7
Fe	0.02	0.36	$Fe^{58}(n,\gamma)Fe^{59}$	47. d	0.00000005
Cu	0.01	3.2	$Cu^{63}(n,\gamma)Cu^{64}$	12.8 h	0.0004
--	0.01	1.9	$Cu^{65}(n,\gamma)Cu^{66}$	5 m	2
Mo	0.1	0.05	$Mo^{98}(n,\gamma)Mo^{99}$	2.8 d	0.0003
--	0.1	0.04	$Mo^{100}(n,\gamma)Mo^{101}$	14.6 m	0.02
Pt	0.01	4.3	$Pt^{196}(n,\gamma)Pt^{199}$	31 m	0.04
--	0.01	1.1	$Pt^{196}(n,\gamma)Pt^{197}$	18 h	0.001

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TABLE II

CALCULATED CONTRIBUTIONS TO THE
EFFECTIVE WATER ACTIVITY FROM
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Element	Per Cent of Element in Slug Surface	Per Cent of Element in Tube Surface	Isotopic Cross Section X 10^{24}	Reaction	Half Life	Disintegrations Per CC. Per Sec.
Al	29.2	98.5	0.23	$Al^{27}(n,\gamma)Al^{28}$	2.4 m	50
--			0.0009	$Al^{27}(n,\alpha)Na^{24}$	14.8 h	0.03
--			0.006	$Al^{27}(n,p)Mg^{27}$	10.2 m	0.2
Na	0.01	0.01	0.09	$Na^{23}(n,\gamma)Na^{24}$	14.8 h	0.02
Mg	0.008	0.008	0.05	$Mg^{26}(n,\gamma)Mg^{27}$	10.2 m	0.0009
--			0.0014	$Mg^{24}(n,p)Na^{24}$	14.8 h	0.000002
Si	0.14	0.11	0.23	$Si^{30}(n,\gamma)Si^{31}$	2.8 h	0.001
--			0.0003	$Si^{29}(n,p)Al^{29}$	6.7 m	0.000005
--			0.012	$Si^{28}(n,p)Al^{28}$	2.4 m	0.0006
K	0.01	0.01	1.00	$K^{41}(n,\gamma)K^{42}$	12.4 h	0.0009
Cr	0.01	0.01	10.0	$Cr^{50}(n,\gamma)Cr^{51}$	26.5 d	0.005
Ti	0.01	0.01	0.04	$Ti^{50}(n,\gamma)Ti^{51}$	72 d	0.00002
V	0.01	0.01	6.2	$V^{51}(n,\gamma)V^{52}$	3.9 m	0.07
Mn	0.01	0.005	11.2	$Mn^{55}(n,\gamma)Mn^{56}$	2.6 h	0.09
Fe	0.46	0.20	0.36	$Fe^{58}(n,\gamma)Fe^{59}$	47 d	0.0003
Ni	0.01	0.01	0.019	$Ni^{58}(n,p)Co^{58}$	72 d	0.00002
--			0.50	$Ni^{62}(n,\gamma)Ni^{63}$	2.6 h	0.0002
Cu	0.13	0.01	3.2	$Cu^{63}(n,\gamma)Cu^{64}$	12.8 h	0.2
--			1.9	$Cu^{65}(n,\gamma)Cu^{66}$	5 m	0.04
Zn	0.01	1.0	0.51	$Zn^{64}(n,\gamma)Zn^{65}$	250 d	0.08
--		[redacted]	1.2	$Zn^{68}(n,\gamma)Zn^{69}$	57 m	0.06
[redacted]			0.31	$Zn^{68}(n,\gamma)Zn^{69}$	13.8 h	0.02

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TABLE III

THEORETICAL SOURCES OF MEASURED WATER COMPONENTS

Probable Sources	Concentration		Reaction*	Half Life	Disintegrations Per C.C. Per Sec.
(1) Aluminum in	Slug	99.2%			
Metal Surfaces	Tube	98.6%	$Al^{27}(n,g)Al^{28}$	2.4 m	50
Silicon in Water	7.5	P.P.M.	$Si^{28}(n,p)Al^{28}$	2.4 m	20
Aluminum in Water	.01	P.P.M.	$Al^{27}(n,g)Al^{28}$	2.4 m	3
(2) Aluminum in	Slug	99.2%			
Metal Surfaces	Tube	98.6%	$Al^{27}(n,p)Mg^{27}$	10.2 m	0.2
Magnesium in Water	5.0	P.P.M.	$Mg^{26}(n,g)Mg^{27}$	10.2 m	10
(3) Chloride in Water	.8	P.P.M.	$Cl^{37}(n,g)Cl^{38}$	37 m	9
Calcium in Water	25	P.P.M.	$Ca^{48}(n,g)Ca^{49}$	30 m	2
(4) Manganese in Water	0.005	P.P.M.	$Mn^{56}(n,g)Mn^{56}$	2.6 h	0.7
Silicon in Water	7.5	P.P.M.	$Si^{30}(n,g)Si^{31}$	2.8 h	0.6
Calcium in Water	25	P.P.M.	$Ca^{48}(n,g)Ca^{49}$	2.5 h	0.1
Manganese in	Slug	0.01%			
Metal Surfaces	Tube	0.005%	$Mn^{55}(n,g)Mn^{56}$	2.6 h	0.09
(5) Sodium in Water	4-5	P.P.M.	$Na^{23}(n,g)Na^{24}$	14.8 h	9
Copper in	Slug	0.13%			
Metal Surfaces	Tube	0.01%	$Cu^{63}(n,g)Cu^{64}$	12.8 h	0.2
Aluminum in	Slug	99.2%			
Metal Surfaces	Tube	98.6%	$Al^{27}(n,a)Na^{24}$	14.8 h	0.03
(6) Zinc in	Slug	0.01%			
Metal Surfaces	Tube	1.00%	$Zn^{64}(n,g)Zn^{65}$	250 d	0.08
Sulfur in Water	9.0	P.P.M.	$S^{32}(n,p)P^{32}$	14.3 d	0.02
Chromium in Water	0.8	P.P.M.	$Cr^{50}(n,g)Cr^{51}$	26.5 d	0.02
Chromium in	Slug	0.01%			
Metal Surfaces	Tube	0.01%	$Cr^{50}(n,g)Cr^{51}$	26.5 d	0.006
Calcium in Water	25	P.P.M.	$Ca^{44}(n,g)Ca^{45}$	180 d	0.002
Iron in Water	0.02	P.P.M.	$Fe^{58}(n,g)Fe^{59}$	47 d	0.00000006
Iron in	Slug	0.46%			
Metal Surfaces	Tube	0.20%	$Fe^{58}(n,g)Fe^{59}$	47 d	0.003

* n,g,a, represent neutron, gamma, and alpha respectively.

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TABLE IV

MEASURED STRENGTH OF INDIVIDUAL COMPONENTS OF WATER ACTIVITY
UNIT OPERATING AT 250 KW

Half Life	Disintegrations Per C.C. Per Sec. Minimum	Maximum	Average
2.4 min.	Probably Fairly Constant		250
10.2 min.	70	100	90
34 min.	6	9	7
2.6 hrs.	6	35	15
14.8 hrs.	7	10	8.5
many days	0.1	0.2	0.15

TABLE V

RADIATION DOSAGE RATES IN PILE DISCHARGE WATER

Component	Half Life	Approximate Effective Disintegration Energy (Mev.)	Mrep. Per Hour to Receptor Immersed in Water: Discharge Face	Sample Room	Retention Basin Inlet	Retention Basin Outlet
N^{16}	8 sec.	6.4	130,000	0	0	0
O^{19}	31 sec.	5	700	13	0.4	0
Al^{28}	2.4 min.	3.6	65	27	14	0
Mg^{27}	10.2 min.	1.6	9.9	8.0	6.7	0
Ca^{49} + Cl^{38}	34 min.	3	1.5	1.4	1.3	0
Mn^{56}	2.6 hrs.	2.6	2.7	2.7	2.6	0.59
Na^{24}	14.8 hrs.	4.8	2.9	2.9	2.9	2.20
Long	Many days	2	0.03	0.03	0.03	0.03
		Totals -	131,000	55.6	27.5	2.82

TABLE VI

RADIATION DOSAGE RATES AT OUTLET OF RETENTION BASINS

Component	Beta (mrep./hr.) Min.	Ave.	Max.	Gamma (mr./hr.) Min.	Ave.	Max.	Total (mrep./hr.) Min.	Ave.	Max.
Mn^{56}	0.071	0.18	0.42	0.17	0.43	1.00	0.24	0.61	1.42
Na^{24}	0.21	0.26	0.31	1.61	1.95	2.30	1.82	2.21	2.61
Totals	0.28	0.44	0.73	1.78	2.38	3.30	2.06	2.82	4.03

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