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THE REDUCTION OF REACTOR EFFLUENT WATER RADIONUCLIDES
BY THE ADDITION OF SODIUM SILICATE
TO PROCESS WATER--105D HALF PLANT ADDITION

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D. E. Robertson

Radiological Sciences Section
Environmental and Radiological Sciences Department

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THE REDUCTION OF REACTOR EFFLUENT WATER RADIONUCLIDES BY THE ADDITION OF SODIUM SILICATE TO PROCESS WATER--105D HALF PLANT ADDITION--D. E. Robertson

INTRODUCTION

A continuous research and development effort is maintained at Hanford to devise and test methods of reducing the concentrations of radionuclides discharged to the Columbia River in reactor effluent water.⁽¹⁾

The radionuclide concentrations in the water and in environmental materials exposed to it are continually monitored to assure that permissible limits are not exceeded at communities downstream from Hanford.^(2,3)

The majority of the radionuclides present in reactor effluent water originate when their parent elements in process water are adsorbed on the aluminum surfaces in the reactors neutron flux region, become activated, and are subsequently released in the effluent.⁽⁴⁾ Minimizing the adsorption of these parent elements has reduced the release of the radioactive daughters. Laboratory and in-reactor studies have previously evaluated the effects of chemical additives and coating materials as adsorption inhibitors.^(5,6,7) Of the chemical additives for process water that were tested in the laboratory, sodium silicate was, by far, the most effective adsorption inhibitor. Because of favorable results from these tests a production scale experiment was initiated. Sodium silicate was added to the process water that supplied one-half of a reactor, while the other half, supplied by normal process water, served as a

control. This report summarizes the results during the period January 1964--January 1965.

SUMMARY AND CONCLUSIONS

The silicate addition to the process water supplying one-half of D Reactor commenced in January, 1965 and continued into 1966 at an average concentration of about 15 ppm as SiO_2 . The effluent water concentrations of many of the biologically important radionuclides decreased gradually over a several months period. After about the eighth month of the addition, an equilibrium condition was reached. At the time of maximum reductions, the radionuclides As^{76} , Cr^{51} , Np^{239} and P^{32} were lower by factors of about 9.0, 7.0, 6.0 and 3.0, respectively, in the effluent water from the test side of the reactor. The radionuclides Sb^{124} and Cu^{64} were reduced by factors of 3 to 5 and 1.5, respectively; the concentration of Zn^{65} remained essentially unchanged. The only significance increases were due to Na^{24} and the trace amounts of La^{140} (and presumable other rare earth radionuclides) that were increased 20 to 50% and a factor of 2 to 3, respectively. The radionuclides Sc^{46} and Co^{60} behaved in an erratic manner, perhaps because of their association with particulate matter in both the process and effluent waters.

Two mechanisms are apparently responsible for the sodium silicate re-

duction of the radionuclide concentrations in reactor effluent water. First, the silicate apparently reacts with the hydrous aluminum oxide surfaces to form a thin aluminosilicate protective film on the aluminum surfaces. Secondly, amorphous silica deposits over this protective film in a thin layer with a negative charge. This film inhibits the adsorption of anions and negatively charged colloids, which are present as trace impurities in process water, with no large corresponding increase in the effluent water concentrations of the cation radionuclides. It is possible that a significant fraction of the metal cations are trapped in the negatively charged colloids produced in the process water by the silicate treatment, and are, therefore, not available for adsorption onto the siliceous film on the process tube and fuel element surfaces.

Sodium silicate is an effective adsorption inhibitor for the parents of many, important, effluent water radionuclides. Good reductions for many of the important effluent water radionuclides were afforded. The radionuclides As^{76} , Np^{239} , and Cr^{51} , which were reduced by factors as great as 9, 6 and 7, respectively, are important because they contribute to over two-thirds of the gastrointestinal (GI) tract dose to the residents of Richland, Pasco, and Kennewick who use Columbia River water for drinking purposes. The radionuclide P^{32} , which was reduced by about a factor of 3 by the silicate treatment, is important because it is concentrated in whitefish and waterfowl (which inhabit the Columbia River) and are consumed by people. The ulti-

mate goal of these reactor studies is to reduce the radionuclide content entering the Columbia River in reactor effluent water. These studies suggest that if sodium silicate were used on a full scale (5 reactor basis), the river concentrations of the above radionuclides could then be expected to be proportionally reduced.

EXPERIMENTAL

The half-plant silicate addition was conducted at 105D Reactor. The "N" grade sodium silicate (Philadelphia Quartz Company) was selected because of its higher purity and higher silica content (SiO_2 to Na_2O ratio of 3.2:1) relative to most other available sodium silicates. The sodium silicate was added (as a 1:5 dilution of the "N" silicate) to the process water supplying the test side of the reactor, at a point following the water treatment process. Final pH adjustment was made in large storage tanks prior to pumping the silicate treated water to the reactor. The other water treatment variables, i.e., alum feed of 18 ppm, sodium dichromate feed of 1 ppm and a pH of 6.6 remained constant for both sides of the reactor. The addition was started on January 17, 1965 at a concentration of 5 ppm SiO_2 . The concentration was gradually increased to 10 to 20 ppm SiO_2 over a period of 9 days. The concentration of added silicate throughout the remainder of the test averaged about 12 to 15 ppm SiO_2 . Normal process water usually contains about 4 to 5 ppm of naturally dissolved SiO_2 . During reactor shutdowns, the silicate addition was continued, but at a reduced concentration of 5 to 10 ppm SiO_2 . Daily samples of

500 ml of effluent water from the test side and control side of the reactor were collected for radiochemical analyses from continuously flowing sampling lines. The radionuclides Na^{24} , P^{32} , Cr^{51} , Mn^{56} , Cu^{64} , Zn^{65} , As^{76} , and Np^{239} were measured in the effluent water from both sides of the reactor by standard radiochemical and instrumental analysis.⁽⁸⁾ The radionuclides Sc^{46} , Co^{60} , Sb^{124} , and La^{140} , present in much lower concentrations, were periodically measured by direct counting of the residue from evaporated effluent water samples on a multidimensional gamma-ray spectrometer.⁽⁹⁾ The silicate was measured in the effluent water from both sides of the reactor by a standard colorimetric method.

DISCUSSION

Background radionuclide measurements on effluent water from both sides of the reactor were made for several weeks prior to starting the addition. These measurements showed that the concentrations were essentially the same for the radionuclides being studied. The silicate addition began in January, 1965 and continued into 1966. Thus, any seasonal trends due to water temperature, trace element variations in the river water, etc., could be observed. During the first several weeks of the addition (at 5 to 10 ppm SiO_2) the sodium silicate caused a slight increase in most effluent water radionuclides and a large increase in the P^{32} concentration (see Appendix A). This increase may be the result of a gradual sloughing-off of a portion of the old corrosion film which contained large amounts of the effluent water

radionuclides incorporated into its structure. This sloughing effect has been observed by other investigators in their use of sodium silicate as a water treatment chemical.⁽¹⁰⁾ After the sloughing-off period, which lasted several weeks, a reduction in most radionuclides in the effluent water from the test side was observed, which gradually improved over a period of several months (see Appendix A). In mid-May the silicate addition was discontinued for about a week. Laboratory tests have shown that the efficiency of silicate treatment is dependent upon a continual supply of sodium silicate, and this period did cause slight increases in most radionuclides in the test side effluent. After about 8 months, the reduction appeared to have reached an equilibrium condition for most radionuclides. This condition lasted until the reactor was shut down in early November for several weeks of maintenance work. After startup, the reductions in most radionuclides in the test side effluent improved further and resulted in maximum reductions in this test for As^{76} , Cr^{51} , Np^{239} , and P^{32} of 9.0, 7.0, 6.0 and 3.0, respectively. The Na^{24} and Mn^{56} concentrations were increased 20 to 50% throughout most of the test and reached an equilibrium condition very rapidly. The increase in the concentration of Na^{24} in the test side effluent was due to the addition of sodium ion as sodium silicate. The concentration of Cu^{64} in the test side effluent was slightly reduced, while the concentration of Zn^{65} remained essentially unchanged, except for a period in December, 1965 to January, 1966, where it was about a 1 year.

TABLE I. Maximum Reductions Obtained for Reactor Effluent Water Radionuclides by Treatment of Process Water with Sodium Silicate

<u>Radionuclide</u>	<u>Reduction Factor:</u>	<u>Ratio of Control Side Activity</u> <u>Addition Side Activity</u>
As ⁷⁶	9.0	
Cr ⁵¹	7.0	
Np ²³⁹	6.0	
P ³²	3.0	
Cu ⁶⁴	1.5	
Zn ⁶⁵	1.0	
Mn ⁵⁶	0.50 - 0.75	
Na ²⁴	0.50 - 0.75	
<u>Trace Radionuclides</u>		
Sb ¹²⁴	3-5	
Co ⁶⁰	0.75	
La ¹⁴⁰	0.33 - 0.50	
Sc ⁴⁶	?	
Cs ¹³⁴	6.0	
Fe ⁵⁹	6.0	

factor of 1.7 lower in the test side effluent water. The behavior of the trace radionuclides Sc⁴⁶, Co⁶⁰, Sb¹²⁴, and La¹⁴⁰ was more difficult to interpret. The radionuclides Sc⁴⁶, Co⁶⁰ and La¹⁴⁰ are associated with particulate matter in the effluent water, and their apparent extreme variations may be associated with sampling problems. The La¹⁴⁰ (and presumably the other less abundant rare earths) and Co⁶⁰ were increased by about a factor of 2 to 3 and 25%, respectively. The variation in the Sc⁴⁶ concentrations was so great that the effect of the silicate addition on its effluent concentration is still uncertain. The

Sb¹²⁴ was consistently reduced by about a factor of 3 to 5 by the silicate treatment. Several samples showed measurable amounts of Fe⁵⁹ and Cs¹³⁴, and their concentrations in the silicate treated effluent water was a factor of six lower than in the normal effluent water.

The only seasonal trends observed were for Zn⁶⁵ and possibly Cr⁵¹. The Zn⁶⁵ concentration in the effluent from both sides of the reactor reached a minimum during the summer months, which was about four times lower than its concentration in January. It appeared that after adding silicate for 1 yr, the silicate treatment prevented

(to an extent) a seasonal increase in January, 1966 in the concentration of Zn^{65} in the effluent from the test side of the reactor. The seasonal trend for Zn^{65} was unusual since the minimum zinc concentration in the Columbia River occurs during the winter months when the Zn^{65} concentrations in effluent water is at a maximum. The seasonal trend for Cr^{51} showed a minimum concentration from both sides of the reactor from about March to June, with the highest concentrations occurring during the winter months. The concentration of chromium in the process water supplying both sides of the reactor remained essentially constant throughout the year (by adding 1 ppm sodium dichromate), yet there is a minimum in the Cr^{51} concentration in the effluent water during the summer months. It appears that these seasonal trends may be caused by variations in the water temperature, with the period of lowest Zn^{65} and Cr^{51} concentrations in effluent water corresponding to the period of highest inlet water temperature.

ADSORPTION INHIBITION MECHANISM

Corrosion Film Studies

The mechanism by which sodium silicate reduces the concentrations of reactor effluent water radionuclides is not fully understood. However, its role as an adsorption inhibitor is clearly part of the mechanism. Silicates at concentration of a few ppm in water are known to act as corrosion inhibitors by depositing on metal surfaces to form protective films.⁽¹¹⁻¹⁶⁾ It has been suggested by previous investigators that these silicate films are formed in

either of two ways: 1) by a chemical reaction between the metal and/or its corrosion products with sodium silicate and/or silica micelles to form metal silicate compounds; 2) by the neutralization of negatively charged silicate ions or silica micelles by positively charged metal ions or corrosion products resulting in coagulation and adsorption on metal surfaces. Lehrman and Shuldener⁽¹²⁾, in studying the mechanism of adsorption, concluded that silicate ions or silica micelles deposit on metal surfaces by an adsorption process which results in the formation of an adsorption compound. In our experiments, the mechanism of silicate film formation on aluminum surfaces appears to be a two-fold process similar to those mentioned above. To study this process, the films deposited on perforated aluminum cylinders (rear nozzle Van Stone flange inserts) that had been exposed to normal effluent water and silicate treated effluent water were analyzed to determine the film composition, structure, and other properties which might explain their formation on metal surfaces. There existed a gross difference between films from the silicate treated side and the control side of the reactor. The film from the silicate treated side consisted of an outer, loosely held, light brown film. Beneath this outer film, there appeared to be an extremely thin, translucent, inert film, which was perhaps an aluminosilicate compound (Figure 1). The film from the control side of the reactor consisted of an outer layer, relatively darker and more firmly bound. Beneath this layer was a light brown film tightly bound to the

Silicated
Film

Normal
Film

Loose, Outer Films Before
Removal by Ultrasound
Treatment in $1N$ HNO_3

Silicated
Film

Normal
Film

Tightly Bound Inner Films After
Removal of Loose Outer Film by
Ultrasound Treatment in $1N$ HNO_3

FIGURE 1. Typical Appearance of Silicated and Unsilicated Inner and Outer Corrosion Films on Downstream Aluminum Inserts

aluminum base metal. The outer films were readily removed by immersing the aluminum cylinders in cold $1N$ HNO_3 and applying ultrasonic sound treatment. The inner film on aluminum cylinders from the control side was easily removed by immersion in $90^\circ C$ $1N$ HNO_3 , while the inner film on the silicated aluminum cylinder was apparently unaffected by this treatment. Outer film samples of both the silicated and un-

silicated films were analyzed by emission spectroscopy (Table II). These measurements, although only semiquantitative, showed a high silicon concentration in the film from the silicate addition side. The outer films from the test and control sides had relatively large amounts of iron, chromium, and zinc incorporated into their structure. Trace amounts of copper, magnesium, manganese, nickel, and titanium

TABLE II. Emission Spectrographic Determination of the Composition of Silicated and Unsilicated Corrosion Film on Downstream Aluminum Surfaces

Element	Composition - Percent	
	Silicated Film	Unsilicated Film
Aluminum	20	50
Silicon	10	2
Chromium	10	10
Iron	10	10
Zinc	5	5
Titanium	5	0.5
Magnesium	1	1
Copper	0.2	0.5
Nickel	0.05	0.02
Manganese	0.2	0.1

were also present. The corrosion films on the aluminum cylinders from the addition side and the control side of the reactor were analyzed by X-ray diffraction techniques in an attempt to elucidate their crystalline structures and, perhaps, show the existence of an aluminosilicate adsorption compound. The silicate film showed very little crystalline patterns and indicated the majority of the material was amorphous in composition. Thus, the film appeared to be amorphous silica, which had deposited from solution, plus the hydrous oxides of aluminum and iron. No crystalline pattern of any of the common aluminosilicate compounds was observed, but it is believed that a compound of this type is formed as a very thin, tightly bound layer at the surface of the aluminum metal. The aluminosilicates, sillimonite (Al_2SiO_5) and montmorillonite ($\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$) have been shown by other investigators (13,15) to exist under conditions sim-

iliar to this present test. The control side film showed several crystalline patterns, none of which could be identified.

Since these films had also incorporated reactor effluent water radionuclides into their structure, a radiochemical analyses of the outer and inner films was conducted (see Table III). Table III indicates the outer silicate film tends to concentrate the radionuclides Zn^{65} and La^{140} (and presumably other rare earth radionuclides) relative to the control side film. The other radionuclides measured were present in both the silicate and control side outer films in about equal abundance. The inner films showed a marked difference in concentrations. The test side inner film, which was leached in 90°C 1N HNO_3 , had relatively little radioactivity associated with it. The control side inner film, which was bulky and darker colored, contained several orders of magnitude higher con-

TABLE III. Radiochemical Analyses of Inner and Outer Silicated and Unsilicated Corrosion Films on the Surfaces of Downstream Aluminum Inserts

Silicated Outer Film Total D/M/Insert		Unsilicated Outer Film Total D/M/Insert	Ratio of Silicated Outer Film to Unsilicated Outer Film
Sc ⁴⁶	6.60×10^6	1.38×10^7	0.48
Cr ⁵¹	9.08×10^7	1.45×10^8	0.63
Fe ⁵⁹	6.00×10^6	4.72×10^6	1.3
Co ⁶⁰	1.33×10^6	1.29×10^6	1.03
Zn ⁶⁵	3.12×10^8	5.48×10^7	5.7
La ¹⁴⁰	6.04×10^7	2.23×10^7	2.7

Silicated Inner Film Total D/M/Insert		Unsilicated Inner Film Total D/M/Insert	Ratio of Silicated Inner Film to Unsilicated Inner Film
Sc ⁴⁶	2.25×10^3	8.58×10^5	0.0029
Cr ⁵¹	2.18×10^6	3.16×10^7	0.069
Fe ⁵⁹	8.12×10^3	3.22×10^5	0.025
Co ⁶⁰	4.50×10^3	7.93×10^5	0.0057
Zn ⁶⁵	2.39×10^5	1.94×10^7	0.012
La ¹⁴⁰	2.90×10^5	5.28×10^5	0.55

centrations of most effluent water radionuclides than the test side inner film. The sodium silicate treatment appeared to completely inhibit the formation of this inner film. The absence of this bulky inner film on the silicate treated aluminum surfaces undoubtedly accounted for part of the reductions in concentrations obtained by the silicate treatment for many of the radionuclides present in effluent water.

Zeta-Potential Measurements

Since the sodium silicate treatment is more effective in reducing the concentrations of anion (rather than cation) radionuclides in the effluent water, it was postulated that the deposited silicate film on the alumin-

um reactor components was electro-negatively charged and thereby repelled the adsorption of anions and negative colloids in the process water. This was confirmed by determining the zeta-potential of particles and colloids in fresh slurries of test side and control side film by measuring their electrophoretic mobility. The silicate film from the test side had a zeta-potential of -17 to -21 m.v., while the film from the control side was + 0 m.v., or very nearly neutral. It therefore appeared that part of the adsorption inhibiting mechanism was electrical in nature. The negatively charged silicate film repelled anions and negatively charged colloids in the process water. The fact that no large corresponding

increase in the cation radionuclide concentrations in the silicate treated effluent water occurred may be due to their association with particulate matter in process water. The colloids in normal process water are usually negatively charged, but the addition of sodium silicate to process water further increases the electronegative zeta-potential of colloids in the water. Thus, a fraction of the cations and any positively charged colloids apparently became associated with the negatively charged colloids and were not free to deposit on the silicate film. This effect, of reversing the charge on positive colloids by negatively charged silica micelles has been observed by other investigators.⁽¹⁷⁾

Abnormal Filming and Rear Face Dose Rates

One of the problems encountered during this test was an abnormally high filming rate in the fringe process tubes which caused hydraulic pressure increases to occur in several tubes supplied by the silicate treated process water. This only occurred when the inlet water temperature was below 10 °C, and only in those fringe tubes where the water temperature was not significantly increased during passage through the reactor.⁽¹⁸⁾ The reason for this high filming is not clear; however, when the water temperature increased during the summer months, the abnormal filming ceased.

Another problem occurring during the test was an increase in the radiation levels on the rear face of the addition side of the reactor, which averaged 2 to 4 times higher than on the control

side. This resulted in increased exposure to personnel working on the rear face.⁽¹⁸⁾ This radiation decayed with approximately a 12 to 15 hr half-life, and both sides appeared to decay at nearly the same rate. Corrosion film, deposited on the rear nozzle Van Stone flange inserts from both sides of the reactor, was radiochemically analyzed to determine the cause of the higher radiation readings on the test side. It was observed that the rare earth radionuclides, notably La¹⁴⁰ and Sm¹⁵³ and possibly Zn⁶⁵, concentrate on the downstream surfaces of the reactor piping. The rare earth radionuclides were in greater abundance in the corrosion film from the addition side by a factor of 2 to 3, while the Zn⁶⁵ varied from essentially the same to a factor of 5 higher concentration on the addition side inserts. Why the downstream silicated film preferentially absorbs these radionuclides cannot be explained at present.

In the original pilot plant work for the Hanford reactors by Kidder⁽¹⁹⁾, sodium silicate did appreciably reduce film formation, and its use in the reactors at 10 to 30 ppm as SiO₂ was recommended. It was actually used in the reactors at a concentration of 5 ppm until 1949;⁽²⁰⁾ however, its discontinuance, at that time was reported to have reduced the rate of film formation and also the effluent radioactivity at the retention basin.⁽²¹⁾ The decrease in total radioactivity was probably caused by the decreased Na²⁴ produced when the sodium silicate was discontinued. However, no detailed radiochemical analyses were made at that time to

show the effect of the silicate on individual radionuclides in effluent water.

Current observations have shown that abnormal filming occurs in only fringe process tubes where the process water was not significantly heated in traversing the reactor, and only when the inlet water temperature was below 10 °C.

Throughout the test there existed some cross-mixing of water from both sides of the reactor. It has been estimated that this cross mixing amounts to about 15% of the total reactor coolant which was interchanged. (22) The efficiency of this test could then be expected to improve by this amount.

REFERENCES

1. R. G. Geier. Reactor Effluent Research and Development Program, HW-81063. February 28, 1964.
2. R. F. Foster and R. L. Junkins. Off-Project Exposure from Hanford Reactor Effluent, HW-63654 REV. February 1, 1960.
3. R. F. Foster. Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964, BNWL-90. July, 1965.
4. R. W. Perkins. Source of Reactor Effluent Water Radioisotopes, HW-69969. May, 1961.
5. R. W. Perkins and D. E. Robertson. The Effect of Chemical Additives and Coating Materials on the Adsorption of Radionuclide Parent Elements on Aluminum Surfaces, HW-75976. December 26, 1963.
6. D. E. Robertson and R. W. Perkins. Reduction of Radionuclides in Reactor Effluent Water: Final Report on the Effect of Chemical Additives and Coating Materials on the Adsorption of Radionuclide Parent Elements in Process Water on Aluminum Surfaces, HW-80557. December 23, 1963.
7. D. E. Robertson and R. W. Perkins. Reduction of Effluent Water Radionuclides by Addition of Sodium Silicate to Process Water, HW-75782. December 10, 1962.
8. R. W. Perkins. "Radiochemical Analysis of Reactor Effluent Waste Materials at Hanford," Talanta, vol. 6, pp. 117-132. 1960.
9. R. W. Perkins and D. E. Robertson. Selective and Sensitive Analysis of Activation Products by Multidimensional Gamma-Ray Spectrometry, 1965 International Conference, Modern Trends in Activation Analysis, College Station, Texas, April 19-22, 1965.
10. J. G. Vail. Soluble Silicates, vol. 2, p. 256, New York: Reinhold Publishing Corporation. 1952.
11. See Ref. 10, pp. 245-268.
12. L. Lehrman and H. L. Shuldener. "The Role of Sodium Silicate in Inhibiting Corrosion by Film Formation on Water Piping," J. Am. Water Works Assoc., vol. 43, pp. 175-188. March, 1951.
13. G. J. Bieffer and P. G. Anderson. Corrosion Behavior of Aluminum-Nickel-Iron Alloys in High-Temperature Water: Effect of Dissolved Silica as an Inhibitor, CRMet-859. 1959.
14. L. Lehrman and H. L. Shuldener. "Action of Sodium Silicate as a Corrosion Inhibitor in Water Piping," Ind. Eng. Chem., vol. 44, no. 8, pp. 1765-1769. August 1952.
15. H. W. McCune. "Corrosion Products and Inhibitor Films on Aluminum," Journal of the Electrochemical Society, vol. 106, no. 1, 1959.
16. W. Stericker. "Sodium Silicate in Water to Prevent Corrosion," Ind. Eng. Chem., vol. 30, no. 3, pp. 348-351. 1938.
17. R. K. Iler. "Adsorption of Colloidal Silica on Alumina and of Colloidal Alumina on Silica," Journal of the American Ceramic Society, vol. 47, no. 4, pp. 194-198, April, 1964.
18. R. G. Geier. Interim Report I, Production Test IP-728, Half-Plant Sodium Silicate Test, RL-REA-2546. September 16, 1965.
19. C. P. Kidder. CMX Final Report, HW-74444. July 31, 1946.
20. D. R. deHalas and R. B. Richman. Water Treatment History at Hanford, HW-39691. October 31, 1955.
21. W. R. Conley. Final Report, Production Test No. 105-214-P, Silicate Feed Elimination, HW-15943. February 1, 1950.
22. W. B. Silker. Cross Mixing of Reactor Cooling Water, BNWL-CC-275. September 30, 1965.

APPENDIX A. Relative Concentrations of Radionuclides in Reactor Effluent Water from the Control Side and Addition Side of "D" Reactor

APPENDIX A. Relative Concentrations of Radionuclides in Reactor Effluent Water from the Control Side and Addition Side of "D" Reactor

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