United States
Environmental Protection
Agency

Risk Reduction
Engineering Laboratory
Cincinnati, OH, 45268

Research and Development

EPA/600/SR-92/117 Sept. 1992

EPA

Project Summary

Inorganic Chemical Characterization of Water Treatment Plant Residuals

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To achieve drinking water maximum contaminant levels (MCLs) promulgated by the United States Environmental Protection Agency (U.S. EPA), municipal water treatment plants are using efficient water treatment systems. The contaminants removed by water treatment technologies become concentrated in residuals such as chemical sludges, brines, and wastewaters. In order to determine the safest and most economical way to dispose of water treatment plant (WTP) wastes, the chemical content of the residuals must be characterized.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Existing Regulations

Currently, wastewaters (containing nonradioactive inorganic contaminants) discharged to surface waters and storm sewers are regulated under the Clean Water Act (CWA). Sections 301 and 307 of the CWA establish the minimum treatment technologies required for industries that want to discharge their wastewater into surface waters. A permit to discharge pollutants into surface waters must be obtained under the National Pollutant Discharge Elimination System (NPDES). Although the U.S. EPA drafted a document establishing compliance guidelines for drinking water facilities discharging wastewater into surface waters and storm sewers, EPA has not revised the document nor established formal guidelines. Until the U.S. EPA provides guidance to the water treatment industry, the nonradioactive inorganic effluent quality of wastewater discharged from WTPs into surface waters will continue to be regulated on a state-by-state basis.

The disposal and recycling of WTP solid wastes are regulated under the 1976 Resource Conservation and Recovery Act (RCRA). Under RCRA, solid wastes are defined as hazardous or non-hazardous based on their chemical and physical properties. Consequently, if sludges and other solid wastes produced by water treatment facilities have certain chemical and physical properties, they can be defined as hazardous. Because WTP wastes are not specifically listed as hazardous RCRA wastes, they must be tested to determine if they possess at least one of the following characteristics: ignitability, corrosivity, reactivity, or toxicity of leachate. The characteristic of main concern for WTP solids is the toxicity of leachate. Extracts from solid wastes exceeding the concentrations listed in Table 1 exhibit the toxicity characteristic.

In addition to nonradioactive inorganics, there is also concern about the radium concentrations of WTP wastes. The health effects of radium are well documented; the radionuclide poses the greatest health concern when exposure occurs by ingestion because it replaces calcium in bones. Once in place, radium can emit alpha (Ra^{226}) or beta (Ra^{228}) particles which may

Table 1. The Maximum Concentration of Contaminants for Toxicity Characteristics[1]

Contaminant	Concentration (mg/L)
Arsenic (As)	5.0
Barium (Ba)	100.0
Cadmium (Cd)	1.0
Chromium (Cr)	5.0
Lead (Pb)	5.0
Mercury (Hg)	0.2
Selenium (Se)	1.0
Silver (Ag)	5.0

[1]*June 29, 1990* Federal Register.

increase the risk of cancer. Improper disposal of radium containing wastes, augmented by the long half-life of the radionuclide (1,670/yr for Ra^{226} and 6.7/yr for Ra^{228}), could result in a long-term contamination threat to the environment and the accumulation of radium in the food chain.

In 1990, the U.S. EPA published a document "Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides." The document reviews the relevant federal regulations and the corresponding EPA guidelines for the disposal of radium (and uranium) containing liquid and solid wastes.

Previous Studies

Previous investigators of water treatment technologies have expressed concern about the residuals produced and their disposal. In 1985, Snoeyink et al. characterized the sludge, brine, and backwash water from 10 water treatment plants. The treatment processes included in the study were 1) iron (Fe) and manganese (Mn) removal, 2) lime softening, and 3) ion exchange (IX). The data showed that backwash water from Fe and Mn removal plants had Ra^{226} and Ra^{228} concentrations ranging from 21.2 to 106 pCi/L and 5.7 to 20 pCi/L, respectively. Ra^{226} and Ra^{228} in lime softening sludges ranged (on a dry weight basis) from <1.2 to 21.6 pCi/g and <2.4 to 11.7 pCi/g, respectively. In ion exchange brines, Ra^{226} concentrations were as high as 217 pCi/L and 1,144 pCi/L.

In 1990, a study funded by the American Water Works Association Research Foundation (AWWARF) examined the issue of land application of water treatment sludges. In the study, Elliot and his staff chemically characterized water treatment sludges. They found that the sludges contained, by weight, 3% organic carbon and 6% organic nitrogen. Trace metals were found in concentrations less than those found in sewage sludges. Based on results obtained from the EPA's extraction procedure toxicity test, the trace metals that were present in the sludge were not readily extractable.

The disposal cost of water treatment residuals depends significantly upon their toxicity, reactivity, corrosivity, or radioactivity. The more hazardous the waste, the greater the cost of disposal. Disposal costs for various water treatment technologies have been estimated based on theoretical removal efficiencies and calculated levels of residual contamination (Malcolm Pirnie Inc.,1986). Laboratory bench-scale studies of water treatment technologies have also been used to predict levels of contaminants in sludge and to estimate disposal costs.

There is no typical treatment plant and, therefore, no typical treatment residual produced. All plants adjust their operations according to raw water quality, finished water quality, and unforeseen conditions. All of these variables can affect the quantity of residual produced and the concentration of contaminants in the residual. Because of these operational and environmental variables, lab-bench scale estimates and theoretical mass balance computations are limited by their assumptions of uniform raw water qualities and consistent treatment removal efficiencies. Waste management procedures and policies should not be made solely on these theoretical estimates.

Field verification is required to characterize residuals produced at actual water treatment plants. As evidence, barium and radium in residuals collected from water treatment plants in Illinois were found to vary ten-fold from plant to plant (Snoeyink, et al., 1985).

Study Objective

The purpose of this study was to characterize the inorganic composition of water treatment plant residuals and to define the corresponding disposal practices. A secondary objective was to view, where possible, the residual characterizations in light of current waste disposal regulations and guidelines.

Procedures

Site Visits and Plant Selection

Visiting the WTPs was a critical step in selecting plants suitable for the study. During the visits, National Sanitation Foundation (NSF) investigators toured the facilities, reviewed plant schematics, identified all waste handling operations and waste disposal facilities, and reviewed records of plant removal rates and other relevant data. Sampling locations were identified and, when possible, NSF collected the first samples and trained WTP personnel in proper sample collection techniques. (Subsequent samples were collected by WTP personnel.) The information collected during the visits was used to develop and write sampling and analytical plans.

The WTPs selected to participate in the study had to meet several criteria. The first criterion was that the plant's raw water had to contain inorganic contaminants. Whenever possible, plants with inorganic concentrations exceeding the MCLs defined in the National Primary Drinking Water Regulation (NPDWR) were selected and included in the study. The plant also had to be a well operated facility that achieved efficient contaminant removal rates. This particular criterion guaranteed the concentration of contaminants in the plant residuals. Finally, the treatment process had to be of a technology commonly accepted by the water treatment industry to remove a specific contaminant. (For example, lime/soda softening is a common treatment method used to remove heavy metals from raw water.) Table 2 lists and describes the WTPs that participated in the study.

Sampling and Analytical Plans

A sampling and analytical plan was developed for each WTP in the study. Each plan was designed to assure the proper collection, handling, and analysis of representative samples.

Sampling Procedures

Sampling followed the EPA procedures and methods set forth in "Test Methods for Evaluating Solid Waste, Volume II: Field Manual Physical/Chemical Methods." This field manual was also used for guidance in sample handling and preservation. All sample containers and equipment were polyethylene to assure compatibility with inorganic analytes.

Sample Handling and Sample Preservation

Sample handling and sample preservation followed U.S. EPA guidelines as set forth in "Methods for Chemical Analysis of Water and Wastes." Samples were shipped by overnight delivery service to assure that sample holding times were not exceeded.

Sample Preparation and Sample Analysis

Sludge samples were separated into two aliquots. One aliquot was filtered with a 0.6-0.8 μm glass filter. The filtrate portion

Table 2. Plants Selected to Participate in the Study

Plant Name	Water Processed Day	Raw Water Source	Contaminants	Process
Cincinnati-California	235 MGD	Surface water	Inorganics from urban run-off	Alum coagulation/ filtration
Cincinnati-Bolton	15 MGD	Groundwater	Hardness	Lime softening
Elgin-Riverside	16 MGD	Surface water Groundwater	Inorganics from urban run-off	Coagulation/ filtration lime treatment
Elgin-Airlite	7 MGD	Groundwater	Hardness, radium	Lime softening
Confidential	18 MGD	Surface water Groundwater	Arsenic, hardness	Ferric sulfate precipitation
Kaukauna	2 MGD	Groundwater	Iron, radium	Synthetic greensand with $KMnO_4$
Charlotte Harbor	.5 MGD	Groundwater	Total dissolved solids, radium	Reverse Osmosis
Arrowbear[1]	.285 MGD	Groundwater	Uranium	Anion exchange

[1]*Data from this plant will be compiled and published in a separate report by the U.S. EPA's Drinking Water Division located in Cincinnati, OH.*

(liquid) was preserved with HNO_2 to pH<2; the solid portion was kept unpreserved. The second sludge aliquot was analyzed by the TCLP procedure. To obtain the TCLP extract that was analyzed for the TCLP metals (As, Ba, Cd, Cr, Pb, Hg, Se, and Ag), Method 1311 was followed as written in the June 13, 1986, *Federal Register* (Volume 51, No. 114). Depending on the analytical procedure, water samples, filtrates, solids, TCLP extracts, brines, and treatment chemicals were digested with the appropriate acids. To determine levels of total recoverable metals, inorganic anions, and total suspended solids, NSF laboratories followed EPA standard procedures. In addition, NSF laboratories and data control monitored the accuracy of the data with QC check samples and matrix spikes.

Results

Tables 3 through 9 list the inorganic concentrations that were found at detectable levels in samples of raw water, finished water, wastes, and TCLP extracts collected from each of the plants. (Analyses may have been conducted that are not summarized in the tables.)

Discussion and Conclusions

The California Water Treatment Plant in Cincinnati, OH, uses alum coagulation/ filtration to treat raw water obtained from a surface water. Results from this study (Table 3), indicated that finished water As, Ba, Cd, Cr, Pb, Hg, Se, Cu, Fe, and Mn concentrations were below their current U.S. EPA National Primary and Secondary Drinking Water Regulation (NPDWR and NSDWR) MCLs. Of the metals tested for in the sludge filtrate (liquid portion of the sludge), Mn was the only element that exceeded its drinking water MCL. The sludge solid, on the other hand, contained detectable levels of all of the elements except for Se. Of the metals analyzed for in the sludge solids, the highest mean concentrations were Al (30,000 mg/Kg), Ca (17,400 mg/Kg), Fe (6,200 mg/Kg), Mg (3,900 mg/Kg) and Mn (1,760 mg/Kg). The sludge produced during the treatment of water is currently being discharged into a surface water under a National Pollutant Discharge Elimination System (NPDES) permit.

The Bolton Water Treatment Plant, also located in Cincinnati, OH, uses lime softening technology to treat raw water obtained from wells. As indicated by data in Table 4, the plant's finished water As, Ba, Cd, Cr, Pb, Hg, Se, Cu, Fe, and Mn mean concentrations were below their respective primary and secondary MCLs. The sludge filtrate concentrations of the same metals were also below the primary and secondary drinking water MCLs. The solid portion of the sludge had mean total suspended solids (TSS) of 22,700 mg/L. Cd, Cr, Hg, Ni, and Se were found at non-detectable levels in the sludge solids. Of the elements tested for in the sludge solids, Ca (316,000 mg/Kg), Mg (11,400 mg/Kg), Al (910 mg/Kg), Fe (544 mg/Kg), and Ba (224 mg/Kg) had the highest mean concentrations. Ba was the only metal found at detectable levels in the toxicity characteristic leachate procedure (TCLP) extract. The Ba concentration was not high enough to qualify the waste as hazardous under the Resource Conservation Recovery Act (RCRA). Sludge produced by the Bolton plant is discharged to one of two onsite lagoons.

The Riverside Water Treatment Plant in Elgin, IL, uses lime softening and coagulation/filtration to treat raw water obtained from a surface water source. Data in Table 5 indicates that the plant's finished water As, Ba, Cd, Cr, Pb, Hg, Se, Cu, Fe, and Mn mean concentrations were below their respective primary and secondary MCLs. The sludge filtrate concentrations of the same metals were also below the primary and secondary drinking water MCLs. Of the 16 inorganics analyzed for, 13 were found at detectable levels in the solid portion of the sludge. Of these 13 chemicals, Ca (250,000 mg/Kg), Mg (31,000 mg/Kg), Al (2,000 mg/Kg), and Fe (1,600 mg/Kg) were detected at the highest concentrations. The mean Ra^{226} concentration in the sludge solids was 4.6 pCi/L. Although Ba (0.423 mg/L) and As (0.004 mg/L) were found in the TCLP extracts, the waste would not qualify as hazardous under the RCRA. Sludge from the Riverside plant is currently directed to four excavated pits five miles away from the plant. One pit, the decant cell, receives supernatant from the other four pits. Supernatant from the decant cell is discharged to a surface water. When one of the four pits is filled, it is left to dry and then covered with two feet of soil to form a permanent landfill.

The Airlite Water Treatment Plant in Elgin, IL, uses lime softening technology to treat raw water obtained from deep wells. Data in Table 6 indicates that finished water and sludge filtrate As, Ba, Cd, Cr, Pb, Hg, Se, Cu, Fe, and Mn concen-

Table 3. *Mean Inorganic Concentrations in Samples from the California Water Treatment Plant[1] (Cincinnati, OH)*

	Raw Water (N=18) mg/L	Finished Water (N=18) mg/L	Sludge Filtrate (N=18) mg/L	Sludge Solid (N=18) mg/Kg
Al	1.46	ND	ND	30,000
As	ND	ND	ND	19
Ba	0.09	0.049	0.15	180
Cd	ND	ND	ND	0.84
Ca	34	40.0	38	17,400
Cr	ND	ND	0.003	28
Cu	0.019	0.005	0.004	38
Fe	2.47	0.052	0.050	6,200
Pb	0.002	ND	ND	36
Mg	9.8	9.7	10.2	3,900
Mn	0.54	ND	0.837	1,760
Hg	ND	ND	ND	0.23
Ni	0.089	0.100	0.004	54
Se	ND	ND	ND	ND
Ag	0.002	0.002	0.001	1.08
TSS	NA	NA	NA	6,200

[1]*Alum coagulation/filtration plant.*
ND-Mean not calculated because of frequent non-detectable results; NA-Not analyzed.

Table 4. *Mean Inorganic Concentrations Found in Samples from the Bolton Water Treatment Plant[1] (Cincinnati, OH)*

	Raw Water (N=18) mg/L	Finished Water (N=18) mg/L	Sludge Filtrate (N=18) mg/L	Sludge Solid (N=18) mg/Kg	TCLP Extract (N=18) mg/L
Al	0.11	0.11	ND	910	NA
As	ND	ND	ND	1.2	ND
Ba	0.12	0.048	0.11	224	0.50
Cd	ND	ND	ND	ND	0.001
Ca	92	32.0	22	316,000	NA
Cr	0.003	0.002	0.003	ND	0.005
Cu	0.012	0.006	0.002	1.8	NA
Fe	0.10	0.048	0.06	544	NA
Pb	ND	0.001	0.001	0.41	ND
Mg	28	25	16	11,400	NA
Mn	0.20	0.017	ND	740	NA
Hg	ND	ND	ND	ND	ND
Ni	0.038	0.065	0.011	ND	NA
Se	ND	ND	ND	ND	ND
Ag	0.002	0.003	0.001	0.282	ND
TSS	NA	NA	NA	22,700	NA

[1]*Lime softening plant.*
ND-Mean not calculated because of frequent non-detectable results; NA-Not analyzed.

trations were below their current EPA NPDWR and NSDWR MCLs. The solid portion of the sludge contained the following mean concentrations: Ca (310,000 mg/Kg), Ba (18,000 mg/Kg), Mg (11,200 mg/Kg), and Fe (4,300 mg/Kg). Ba (0.20 mg/L) and Cd (0.001 mg/L) were the only two metals detected in the TCLP extract. Neither of these concentrations qualify the waste as hazardous under the RCRA. The sludge produced by this plant is discharged to two onsite lagoons, partially dewatered, and then trucked to the same excavated pits used by the Riverside plant.

A water treatment plant located in the midwest uses ferric sulfate coagulation to treat a combination of surface and well water. One of the wells was contaminated with As by a local industry. The data for this plant is presented in Table 7. The mean As concentration of six finished water samples was 0.12 mg/L, which is below the current primary drinking water MCL. The mean As concentrations in the composite sludge filtrate was 0.017 mg/L. The mean As concentrations in the composite sludge solid was 5,880 mg/Kg. Although Ba and As were detected in the TCLP extracts, their concentrations were not sufficient to qualify the contact tank sludge as hazardous under the RCRA. The sludge that was analyzed is combined with sludge produced at other points of the treatment process. The combined sludge is disposed of in two onsite lagoons.

The Kaukauna Water Treatment Plant located in Kaukauna, WI, treats well water with a sand/anthracite filter and a sand/anthracite filter that has been coated with a synthetic greensand chemical. The coated filter and potassium permanganate pretreatment system were installed as a result of high radium levels in one of the wells. Based on data collected in this study (Table 8) and the volume of finished water processed by each filter, the mean total radium (Ra^{226} and Ra^{228}) concentration of the plant finished water was calculated to be 5.6 pCi/L, which exceeds the current MCL by 0.6 pCi/L. The Ra^{226} and Ra^{228} concentrations in the backwash samples were 52.5 pCi/L and 47.5 pCi/L, respectively. The backwash from both filters is discharged to a wastewater treatment plant. Consequently, the total radium content of the wastewater must comply with the State of Wisconsin's Radiation Protection Code. The total radium concentration in the wastewater from the plant did not exceed the state's radiation protection code. The synthetic greensand filter and the iron removal filter removed 27% and 25%, respectively, of the total radium in the raw water. Both of these percentages are considerably lower than radium removal efficiencies achieved by similar technologies. Higher radium removal efficiencies will result in backwash radium concentrations that are higher than what is reported in this study.

The Charlotte Harbor Water Association located in Harbor Heights, FL, uses reverse osmosis (RO) to treat well water. As indicated in Table 9, the mean concentration of Ra^{226} in the raw water was 14.3 pCi/L. The finished water produced by the plant had a mean Ra^{226} concentration of 1.2 pCi/L. The percent of Ra^{226} rejected by RO at the plant was calculated to be 91.6%, which indicates that the plant was efficiently removing Ra^{226} from the raw water. The reject water produced by the plant is discharged to an adjacent canal. Based on the data collected in this study, the Ra^{226} concentration (not including the corresponding Ra^{228} concentration) in the backwash water would exceed EPA (and NRC) suggested guidelines.

Recommendations

Additional WTPs need to be studied. Only eight WTPs were included in this study, and they are not necessarily representative of all WTPs. The selection criteria tended to include those WTPs that produced residuals with very concentrated

Table 5. *Mean Inorganic Concentrations Found in Samples from the Riverside Water Treatment Plant[1] (Elgin, IL)*

	Raw Water (N=19) mg/L	Finished Water (N=18) mg/L	Sludge Filtrate (N=18) mg/L	Sludge Solid (N=14) mg/Kg	TCLP Extract mg/L (N=19)
Al	0.27	ND	0.18	2,000	NA
As	ND	ND	ND	1.8	0.004
Ba	0.08	0.052	0.25	590	0.423
Cd	ND	ND	ND	ND	ND
Ca	81	35	27	250,200	NA
Cr	0.002	0.002	0.002	2.8	ND
Cu	0.006	0.003	0.004	5.3	NA
Fe	0.37	0.053	0.04	1,600	NA
Pb	0.001	ND	ND	1.5	ND
Mg	38	10.5	37	31,000	NA
Mn	0.05	ND	0.03	250	NA
Hg	ND	ND	ND	ND	ND
Ni	0.003	ND	0.002	4.5	NA
Se	ND	ND	ND	ND	ND
Ag	0.004	0.003	0.002	0.39	ND
TSS	NA	NA	NA	43,000	NA
Ra^{226} pCi/L	0.23	0.25	.69	4.6	NA

[1]*Lime softening and coagulation/filtration plant.*
ND-Mean not calculated because of frequent non-detectable results; NA-Not analyzed.

Table 6. *Mean Inorganic Concentrations Found in Samples from the Airlite Water Treatment Plant[1] (Elgin, IL)*

	Raw Water (N=19) mg/L	Finished Water (N=18) mg/L	Sludge Filtrate (N=18) mg/L	Sludge Solid (N=14) mg/Kg	TCLP Extract (N=18) mg/L
Al	0.12	ND	0.15	340	NA
As	ND	ND	0.003	ND	ND
Ba	10	0.74	0.43	18,000	0.2
Cd	ND	ND	ND	ND	0.001
Ca	60	14	24	310,000	NA
Cr	ND	0.003	0.004	3.1	ND
Cu	0.014	0.004	0.003	13.0	NA
Fe	0.20	0.08	0.06	4,300	NA
Pb	0.001	ND	ND	0.51	ND
Mg	25	20	54	11,200	NA
Mn	0.013	ND	0.05	52	NA
Hg	ND	ND	ND	0.07	ND
Ni	0.078	0.08	0.065	ND	NA
Se	ND	ND	ND	ND	ND
Ag	0.003	0.002	0.001	0.38	ND
TSS[2]	NA	NA	NA	27,000	NA
Ra^{226} pCi/L	3.2	0.57	0.23	7.1	NA

[1]*Lime softening plant.*
ND-Mean not calculated because of frequent non-detectable results; NA-Not analyzed.

contaminants. A study is recommended that is more representative of typical WTP operations.

Additional research should be conducted to further characterize the residuals produced from WTPs that use IX, greensand, and RO to treat raw waters containing radium.

A mass balance study of a water treatment plant using coagulation/flocculation should be conducted to assess (quantify) the role that treatment chemicals play in the inorganic contamination of WTP residuals.

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This report was submitted in fulfillment of Contract No. CR-814538-01-0 by NSF *International* under the sponsorship of the U.S. Environmental Protection Agency.

Table 7. *Mean Arsenic Concentrations Found in Samples from the Arsenic Removal Treatment Plant*[1]

	Arsenic	Units
Well 7[1] Raw Water	0.93 (N=6)	mg/L
Raw Water from other Wells	0.13 (N=1)	mg/L
Raw Water from Creek	0.004 (N=1)	mg/L
Finished Water	0.012 (N=6)	mg/L
Contact Tank[2] Effluent	0.42 (N=6)	mg/L
Contact Tank	0.017 (N=6)	mg/L
Sludge Filtrate		
Contact Tank	5,880 (N=6)	mg/Kg
Sludge Solid		
Ferric Sulfate	ND (N=3)	mg/Kg
(Treatment Chemical)		
TCLP Extracts	0.016 (N=6)	mg/L

[1]Ferric sulfate precipitation plant.
[2]Contact tank designed and built for the coagulation and settling of Well 7 raw water.
ND-Mean not calculated because of frequent non-detectable results.

Table 8. *Mean Radium Concentrations Found in Samples from the Kaukauna Water Treatment Plant*[1] *(Kaukauna, WI)*

	Ra^{226}	Ra^{228}	Units
Well 8 Raw Water	5.9 (N=6)	4.3 (N=2)	pCi/L
Wells 4/5 Raw Water	3.7 (N=6)	2.8 (N=3)	pCi/L
Finished Water from the			
Synthetic Greensand Coated Filter[2]	4.6 (N=6)	2.8 (N=1)	pCi/L
Finished Water from the Iron Removal Filter[3]	2.9 (N=6)	2.0 (N=3)	pCi/L
Synthetic Greensand Filter Backwash	52.5 (N=24)	47.5 (N=4)	pCi/L
Iron Removal Filter			
Backwash	33.5 (N=24)	17.8 (N=7)	pCi/L

[1]Synthetic greensand coated filter and iron removal filter plant.
[2]The synthetic greensand coated filter is used to treat water from Well 8.
[3]The iron removal filter is used to treat water from Wells 4/5.

Table 9. *Mean Radium Concentrations Found in Samples from the Charlotte Harbor Plant*[1] *(Harbor Heights, FL)*

	Ra^{226}	Units
Raw Water	14.3 (N=4)	pCi/L
Finished Water	1.2 (N=12)	pCi/L
Reject Water (Brine)[2]	46.1 (N=9)	pCi/L

[1]Reverse osmosis plant.
[2]Flow weighted average.

*U.S. Government Printing Office: 1992 — 648-080/60069

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The complete report, entitled "The Inorganic Chemical Characterization of Water Treatment Plant Residuals," (Order No. PB92-198 563/AS; Cost: $26.00, subject to change) will be available only from:
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