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Analysis of the TRIGA Reactor Pool Water

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AFRRI Technical Report 93-5

ANALYSIS OF THE TRIGA REACTOR POOL WATER

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The authors wish to thank the reactor staff for its assistance in reducing contamination in the reactor pool and for its efforts in sampling and testing the pool water. The algae in the reactor pool have been eradicated, and with the continued vigilance of the staff the pool should remain clean and free of algae.

Contents

Introduction

The reactor at AFRRI is a Mark F, 1 megawatt TRIGA (training, research, isotope, General Atomic) reactor. The reactor hangs in a cloverleaf-shaped tank that contains 15,000 gallons of demineralized water. The aluminum tank varies in thickness from 1/4 inch for the exposure room projections to 1/2 inch for the tank bottom. Eighty percent of the reactor building and all of the reactor tank are below ground level.

Algae growth in the reactor tank stimulated efforts to remove the algae from the pool. The source of nutrients for the algae had not been explored until recently. Reports that aluminum reactor tanks develop leaks prompted the reactor staff to begin a reactor pool water quality monitoring program to establish a baseline of measurable contaminants. Baseline data would be used to provide early detection of leaks because a change in baseline contaminants could indicate the start of a leak.

In this program, the staff collected data on environmental conditions in the reactor room and began chemical testing of the reactor pool water. When high levels of ammonia, nitrate, and nitrite were found, AFRRI contracted with the Calvert Marine Museum, Solomons, Maryland, to assist in determining the source of the contaminants and the best way to eliminate them (1).

This report summarizes the data collected, the steps taken to reduce the impurities, and the efforts to kill the algae and bacteria in the pool.

History and Program Initialization

In May 1991, a cloudy bloom was observed in the reactor pool water. This bloom was suspected to be algae or bacterial growth. Two similar incidents occurred in 1980 and 1986 when groundwater leaked into the reactor room and entered the reactor pool. No groundwater leakage has contaminated the pool water since 1986; therefore, the observed growth may have entered the pool from different sources. Similar biological growths have been observed in various pool systems of other reactor facilities. At AFRRI, each bloom first appeared in the water column and later attached or plated out on the surface of the pool. The bloom was assumed to be caused by freshwater algae, but this assumption was never substantiated. Most of this biological growth was removed from the surface of the pool by use of a special pool vacuum; however, this method could not remove all the organisms growing in crevices or small corners of the pool. The organisms would continue to grow for at least 6 months before the pool needed to be cleaned again.

Understanding the Nitrogen Cycle

Biological organisms of any type require basic nutrients to sustain life. The observed bloom indicated that some quantity of nutrients had contaminated the pool, which is filled with deionized, demineralized water (resistance of approximately 2 megohms/cm). Ammonia is produced by microbiological decay of plant or animal protein. Ammonia is a basic nutrient for algae as well as bacteria. Bacteria are able to oxidize (convert) ammonia to nitrite and then convert nitrite to nitrate. Algae use the ammonia, nitrites, or nitrates to grow. When the algae die, they undergo microbiological decay in which ammonia is released; this however, does not add to the cycle because the dead algae actually release the same amount of algae that was assimilated from the cycle in the first place. To maintain the cycle, there must be an input of nitrogenous compounds from outside sources (see figure 1). This natural process is known as the nitrogen cycle. The compounds produced by the bacteria are actually produced as nitrous acid and nitric acid. Concerns arose among the staff that if nutrients are present and are stimulating bacterial growth, acids may be produced that will eventually cause corrosion of the reactor components in the pool and even the tank itself.

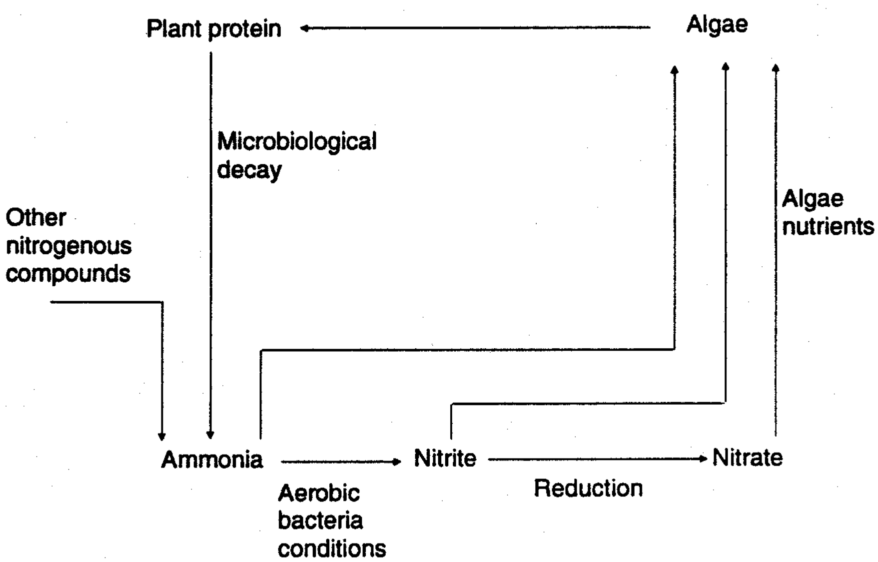

Figure 1. Nitrogen Cycle

Coolant and Purification Systems

The pool water enters a recirculating coolant and purification system through piping suspended in the pool water column and from a skimmer at the surface of the tank. Water is pumped through the coils of a 1.5-megawatt heat exchanger at a rate of 350 gallons per minute (gpm). Of the 350 gpm of primary water returning to the pool from the heat exchanger, 12 gpm are directed through a purification system consisting of a 5-

micron filter and mixed-bed anion- and cation-demineralizing resins. A makeup water still compensates for any primary water loss from evaporation or during maintenance procedures. Water is manually added to the pool from the makeup water still (2). The heat exchanger maintains a pool water temperature between 17°C and 25°C by means of a secondary automated water system. The secondary water is directly cooled by air contact and evaporative cooling in a cooling tower and is replaced automatically by a float valve in the cooling tower. The water added to the secondary system is tap water.

Reactor Pool Water Quality Study

Baseline Data Collection

In-house testing of the water began in the summer of 1991. Testing equipment used were the LaMotte Model STC and the LaMotte Model TRL colorimeters (LaMotte Company, Chestertown, Md.) (3). Baseline data was collected over a 6-week period. Water chemistry tests were performed for the ions in table 1. In preparation for taking samples, the reactor pool filtration system was shut down for 2-4 days to allow any accumulation of contaminants to increase to detectable levels. Measurable concentrations of ammonia, nitrite, and nitrate and negligible concentrations of aluminum, iron, copper, silicon, calcium, and chloride were found in the pool water samples. Baseline measurements of carbon dioxide and oxygen were obtained only for informational purposes. See table 1 for baseline data.

Table 1. Baseline data (mg/l), 5 July to 5 August, 1991.

Ion	Sampling date						Water	
	7/5	7/9	7/15	7/22	7/29	8/5	Tap	Stream
Aluminum	0.04	0.01	0.02	0.02	0.04	0.04	0.04	0.02
Ammonia	0.27	0.33	0.14	0.07	0.07	0.30	0.34	0.46
Calcium	0.00	2.00	2.00	3.00	0.00	0.00	148.00	182.00
Carbon dioxide	2.00	2.50	3.00	2.50	2.20	1.10	3.00	4.50
Chloride	10.00	12.00	14.00	11.00	10.00	6.50	30.00	58.00
Copper	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00
Iron	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.19
Nitrate	0.04	0.20	0.04	0.04	0.07	0.36	1.27	0.82
Nitrite	0.06	0.06	0.07	0.10	0.08	0.08	0.09	0.10
Oxygen	1.50	2.80	3.70	1.20	1.80	2.30	2.80	2.10
Silicon	0.03	0.70	0.00	0.30	0.03	0.00	3.00	3.00

Average ammonia was 0.196; average nitrate was 0.125; and average nitrite was 0.075.

Part 1. In-Depth Study of Nitrogen Contaminants

Water chemistry tests were performed to determine the possible sources of contamination of the reactor pool water. Since ammonia, nitrite, and nitrate had the only significant concentrations in the pool water in the previous study (3), and because these compounds can stimulate the growth of algae as well as bacteria, the pool water was only analyzed for the presence of ammonia, nitrite, and nitrate in part 1 of this study. Part 1 consisted of a 3-week chemical analysis of the reactor pool water system and adjacent areas to determine the possible sources of contamination of the reactor pool water. Nitrogenous wastes that might have contaminated the pool water were also noted. Following part 1 of this study, action was taken to eliminate sources of contamination. Part 2 of this study consisted of monitoring water quality over a 5-month period to determine the effectiveness of the action taken (see part 2, Follow-up Testing).

Water Chemistry Tests

All measurements in part 2 of the study were performed using Hach test kits (Hach Company, Loveland, Colo.). These test kits contain premeasured, prepackaged reagents that can easily be added to a water test sample. Ammonia was measured using the Hach ammonia-nitrogen salicylate test kit, and distilled water was used as the blank sample; nitrite was measured using the Hach nitrite-nitrogen diazotization method test kit for low-range detection; and nitrate was measured using the Hach nitrate-nitrogen cadmium reduction method test kit for low-range detection; for nitrite and nitrate, pool water was used as the blank sample. Ammonia, nitrite, and nitrate levels were measured with the Hach DR/2000 spectrophotometer (4), and all measurements were recorded in milligrams of nitrogen per liter of pool water (mg/l).

Sampling and Testing Locations

Reactor pool water system. Water sampling consisted of 40-ml water samples collected in sterile 50-ml polyethylene centrifuge tubes from six sites around the reactor pool system: reactor pool, makeup water still reservoir tank, heat exchanger, demineralizers, secondary water system from the cooling tower in the heat exchanger, and raw tap water. These sample sites were monitored to observe any variation in the nitrogen compound concentrations throughout the pool system and its water source. Before any sampling, the pool filtration system was shut down for 1 night (approximately 16 hours). Samples were frozen at -20°C until chemical analysis could be performed. Tests were performed within 12-40 hours after sampling. One set of samples was analyzed 60 hours after sampling. Each water sample was tested for the presence of ammonia, nitrite, and nitrate.

Surface smears of reactor room floor. Areas (100 sq. cm.) of floor space at the locations in table 2 were wiped with dry filter paper. Wipe samples were then placed in 40 ml of distilled water (resistance = 20 megohms/cm) and were frozen at -20°C. The samples were thawed immediately before testing. The water from each sample was tested for the presence of ammonia-nitrogen. The presence of high levels of ammonia-nitrogen in wipe samples taken from various areas in the reactor room would indicate the location of possible sources of nitrogen contamination that might enter the pool. While this type of measurement is not quantitative, it can be used to show the relative cleanliness of different locations within the reactor room and to locate specific sites of concern that might contaminate the pool.

Extraction of ammonia from air. We performed an experiment to see if ammonia gas could be extracted from room air into distilled water for measurement. Using an aquarium pump and an air stone, air was pumped or bubbled in a beaker of distilled water for 3 hours in a location isolated from the reactor ventilation system (an adjacent mechanical room) and in the reactor room itself; 40-ml samples of this water were tested for ammonia-nitrogen.

Table 2. Sampling locations of floor surface smears.

1. Trough at end of pool over exposure room 1
2. Edge of well at end of pool over exposure room 1
3. Trough at end of pool over exposure room 2
4. Edge of well at end of pool over exposure room 2
5. Above well at end of pool over exposure room 2
6. Reactor room floor over exposure room 2
7. Entrance into reactor room (2 feet from door)
8. Inside ventilation duct over reactor room deck
9. Reactor room deck

Results from Initial Testing Protocol

Reactor pool water samples. Water quality tests were performed on samples that were collected on different days (see tables 3-5). These tests showed that the pool water was free of nitrite and nitrate even after the filtration system had been shut down for 1 night. The secondary water system contained trace amounts of nitrite, but no nitrate was detected. Measurable amounts of ammonia were found in the secondary water system samples (>0.55 mg/l) and in the reactor pool water samples (0.04-0.09 mg/l), although on some sampling days, one or both of these sites contained virtually no ammonia.

Surface smears of reactor room floor. Smear samples initially showed some ammonia present in higher concentrations than those found in the pool water. Of the nine sampling sites, wipes taken from the trough over exposure room 2 and from the ventilation duct over the reactor deck showed significantly higher concentrations than wipes taken from the other sampling sites. After the floor and the trough area had been cleaned with distilled water by staff personnel (23 September 1991), the ammonia concentration in the

Table 3. Initial ammonia data (mg/l), 11-26 September 1991.

Sampling site	Sampling date				
	9/11/91	9/13/91	9/19/91	9/24/91	9/26/91
Reactor pool water	0.02	0.01	0.08	0.09	0.04
Heat exchanger	0.03	—	0.00	0.00	0.02
Secondary water system	0.03	>0.55	0.01	0.01	0.00
Demineralizer	0.02	0.00	0.00	0.01	0.03
Makeup water still	0.00	0.00	0.01	0.01	0.03
Raw water	0.03	0.00	0.01	0.01	0.03
Water samples bubbled with room air		0.05/0.04			
Background measurements		0.0-0.02			

Sample of reactor pool water at end of busy workday (9/13/91) was 0.06. Average ammonia in reactor pool water was 0.048.

Table 4. Initial nitrite data (mg/l), 13-26 September 1991.

Sampling site	Sampling date		
	9/13/91	9/19/91	9/26/91
Reactor pool water	0.000	0.003	0.000
Heat exchanger	—	0.004	0.003
Secondary water system	0.001	0.019	0.009
Demineralizer	—	0.004	0.000
Makeup water still	0.001	0.003	0.002
Raw water	—	0.005	0.003

Background measurements were 0.00-0.005. Average nitrite in reactor pool water was 0.001.

Table 5. Initial nitrate data (mg/l), 9-26 September 1991.

Sampling site	Sampling date				
	9/9/91	9/12/91	9/13/91	9/19/91	9/26/91
Reactor pool water	0.01	0.02	0.05	0.06	0.05
Heat exchanger	0.00	—	—	0.06	0.05
Secondary water system	0.02	0.01	0.04	0.02	0.03
Demineralizer	0.01	—	0.06	0.06	0.06
Makeup water still	0.01	0.02	0.06	0.06	0.06
Raw water	0.01	—	0.04	0.04	0.03

Background measurements were 0.00-0.06. Average nitrate in reactor pool water was 0.038.

smear samples taken around the pool (sampling sites 1-6 in table 6) were reduced to almost background levels when compared to levels measured before this cleaning.

Extraction of ammonia from air. The water samples that were aerated with room air contained low but measurable amounts of ammonia (0.05 mg/l) (table 3). This test shows that measurable amounts of ammonia can enter into a water system over a relatively short period of time.

Table 6. Initial ammonia data (mg/l) from floor surface smears, 13-26 September 1991.

Sampling site[a]	Sampling date			
	9/13/91	9/19/91	9/24/91	9/26/91
1[b]	0.42	—	0.02	0.05
2	0.31	—	0.02	0.02
3	26.0	>0.55	0.00	0.01
4	—	—	0.03	0.05
5	—	—	0.05	0.01
6	0.24	—	0.07	—
7[c]	0.13	0.02	0.04	0.26
8[d]	—	>0.55	0.27	0.53
9	—	0.20	0.20	0.20

[a]Description of sampling sites:
1. Trough at end of pool over exposure room 1.
2. Edge of well at end of pool over exposure room 1.
3. Trough at end of pool over exposure room 2.
4. Edge of well at end of pool over exposure room 2.
5. Above well at end of pool over exposure room 2.
6. Reactor room floor over exposure room 2.
7. Entrance into reactor room (2 feet from door).
8. Inside ventilation duct over reactor room deck.
9. Reactor room deck.

[b]Average at trough over exposure room 1: 0.163
[c]Average at reactor room entrance: 0.113
[d]Average inside ventilation duct: 0.450

Possible Sources of Contamination

During part 1 of the study, possible sources of contamination in and around the reactor pool were observed. These observations included nitrogen sources as well as mineral sources that might supply nutrients to algae and bacteria.

- The air handling system for AFRRI is located on the top floor of the building. Large intake vents located along the top front wall of the building feed the system that directly services the reactor work area. As many as 14 pigeons were observed roosting in areas near the intake of the ventilation system. The area around the intake vent, as well as the sidewalk and ground below, was covered with bird excrement. This excrement may be a source of ammonia contamination if pigeon excrement is tracked inside the reactor room, or may be a source of ammonia gas (produced as the excrement decomposes) that can enter the ventilation system servicing the reactor pool area. Droppings from birds perched very close to the intake duct have been aspirated into the ventilation system. This observation was verified by finding bird excrement on the intake filters just inside the air intake vent. As demonstrated by bubbling air through water, ammonia gas can easily enter a water system from ambient air, and action was taken to minimize ammonia gas in the ventilated air.

- One of the components of the wax/wax stripper combination used on the floors of the AFRRI facility by the custodial staff is ammonium hydroxide. Areas of the trough were covered with dried wax that had been sprayed over the edge and into the trough and the pool when the wax was applied to the floor. This observation may explain the high ammonia values in the smear samples taken of the reactor room floor.

- Material contributing to pool water contamination may be brought in on shoes and may enter the pool water. On 13 September 1991, reactor pool samples were taken at the beginning of the day and also later in the day after the staff had been working over the pool. The earlier samples contained 0.01 mg/l ammonia, while the samples taken later in the day contained 0.06 mg/l ammonia (table 3).

- There are many areas in AFRRI where conduits of one type or another pass through holes in the walls and floor into the reactor room. Some of these areas (prep areas) temporarily house animals whose urine may also be a source of ammonia gas that may enter the reactor room through the holes in the walls and floor.

- Ammonium hydroxide is regularly added to the cobalt pool (2-4 liters, three times per week) and may be a source of ammonia gas. The cobalt irradiation facility is on the same ventilation system as the reactor, but normally the same air does not go to both the reactor and the cobalt areas. However, any sort of reverse flow of the ventilation system may spill ammonia gas into the reactor room. This, however, is highly unlikely since no power shutdowns were observed during this study period.

- Oil was observed on the surface of the water in the pool. It is believed to have originated from the reactor carriage drive gears. What effect this oil may have had on the ammonia level and bacterial growth in the pool is unknown at this time.

- Groundwater leakage into the basement of the AFRRI facility was observed in areas adjacent to the reactor pool. Eighty percent of the reactor building as well as the entire reactor pool tank is below ground level. At this time, the effect of this groundwater on the water quality of the pool is unknown and is not suspected of having any effect. The tank itself, however, does not leak.

- An additional source of contamination was dust originating from materials used in the construction of the reactor room. In one area in the room, the wallboard was disintegrating, and wallboard dust and sand was falling into the reactor room. Concrete dust from soft concrete used to construct the offices and the control room was also a source of dust that could contaminate the pool water.

Action Taken to Eliminate Nutrient Buildup in the Reactor Pool Water

On completion of part 1 of this nitrogen study, action was taken to reduce contamination in the pool from outside sources. The action taken is detailed below.

- The troughs and floor of the reactor room were cleaned with distilled water to remove any ammonia residue left from floor wax/wax stripper and contamination tracked in on shoes.

- Surfaces around the edge of pool were painted to seal in any absorbed contaminants and to create a new clean surface.

- The pool was thoroughly vacuumed to remove any debris (including any biological growth). The pool had previously been vacuumed the month before.

- The core drive rack and pinion and the lead shield door gear housings were cleaned to eliminate any dirt and oil dripping into the pool.

- An ultraviolet sterilizer was installed in the purification system to deactivate bacteria or algae that might grow in the water column of the pool.

- After thoroughly vacuuming the surface of the pool, the pool water was heated up to 50°C (122°F) to destroy any remaining organisms in the pool. The vacuuming before the heat treatment minimized the amount of dead organic matter in the pool. Ammonia produced by decomposition of any remaining organisms and occurring in the ionized form should have been removed by the demineralizers.

- A carpet was placed outside the entrance of the reactor room to catch large debris, and a sticky mat was placed inside the reactor room door to remove the maximum amount of debris from the shoes of staff and visitors.

- All holes and conduits where air can enter the reactor room from other areas or rooms, especially from those rooms that house animals, were sealed to prevent airflow into the reactor room.

- Areas in the reactor room where the wallboard was breaking down were repaired.

- The storage area above the control room was cleaned, and the concrete was painted to seal it.

Part 2. Follow-up Testing

After taking action to eliminate nutrient buildup in the reactor pool water, part 2 of the study began and continued for 5 months. The following tests were conducted to determine the effectiveness of the changes made.

Ammonia in reactor pool water, tests performed in triplicate.
Nitrite in reactor pool water, tests performed in triplicate.
Nitrate in reactor pool water, tests performed in triplicate.
Smears (100 sq. cm.) of the trough over exposure room 1.
Smears (100 sq. cm.) of the floor inside the reactor room door.
Smears inside the air duct over the reactor room deck.

Since the nitrogen levels in the pool water were the only contaminants of concern, no other water samples from the reactor pool system were tested. Pool water samples were tested for ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen. The results of each of the three water samples are reported in table 7 as the averaged measured value of the

Table 7. Nitrogen levels measured (mg/l) from reactor pool samples.

Sampling date	Ammonia	Nitrite	Nitrate
5 Nov 1991	0.01	0.002	0.04
12 Nov 1991	0.04	0.002	0.06
19 Nov 1991	0.01	0.002	0.05
26 Nov 1991	0.01	0.003	0.05
3 Dec 1991	0.01	0.003	0.05
10 Dec 1991	0.00	0.002	0.05
17 Dec 1991	0.00	0.002	0.05
31 Dec 1991	0.02	0.002	—
7 Jan 1992	0.00	0.002	—
14 Jan 1992	0.02	0.002	—
28 Jan 1992	0.00	0.002	—
6 Feb 1992	0.02	0.002	0.04
11 Feb 1992	0.00	—	—
19 Feb 1992	0.00	0.002	0.05
25 Feb 1992	0.03	0.002	—
3 Mar 1992	0.00	0.002	0.05
10 Mar 1992	0.03	0.002	0.05
17 Mar 1992	0.00	0.002	0.05
Average levels	0.01	0.002	0.05
Background levels	0.01	0.002	0.05

triplicate samples. Wipe samples were tested for ammonia-nitrogen only; data are provided in table 8.

Table 8. Ammonia-nitrogen levels measured (mg/l) from surface smears.

Sampling date	Trough[a]	Floor[b]	Ventilation duct[c]
5 Nov 1991	0.03	—	0.28
12 Nov 1991	0.05	—	0.33
19 Nov 1991	0.05	—	0.24
26 Nov 1991	0.03	—	0.15
3 Dec 1991	0.02	—	0.02
10 Dec 1991	0.16	—	—
17 Dec 1991	0.55	0.06	0.21
31 Dec 1991	0.07	—	0.04
7 Jan 1992	—	0.12	0.19
14 Jan 1992	—	0.07	0.04
28 Jan 1992	0.23	0.12	0.11
6 Feb 1992	0.12	0.11	0.21
11 Feb 1992	0.55	0.09	0.55
19 Feb 1992	0.15	0.10	0.07
25 Feb 1992	0.11	0.11	0.02
3 Mar 1992	0.19	0.07	0.02
10 Mar 1992	0.19	—	0.05
17 Mar 1992	0.11	0.10	0.03
Average levels	0.163	0.095	0.151

[a]Trough at end of pool over exposure room 1.
[b]Entrance into reactor room (2 feet from door).
[c]Inside ventilation duct over reactor room deck.

Summary of Testing Results

For ease of comparison the average values of each of the testing protocols are provided in tables 9 and 10. Ammonia in the reactor pool water showed a steady decline over the testing period for a total drop of 100% to background levels; nitrite declined 100% to background levels; nitrate, however, decreased below background and then increased to background levels for a total drop of 100% (table 9). Surface smears showed some decline in nitrogen levels, although not as significantly as was desired (table 10); trough samples maintained the same average from initial to follow-up testing; surface smears inside the reactor room declined in ammonia content only 16%; surface smears inside the air duct decreased by 66% (table 10). The significant decrease in nitrogen levels inside the ventilation duct may have been caused by repeated wiping with swipes, which cleaned an area inside the duct.

Background levels are those levels measured in distilled water open to the atmosphere after several hours of sitting on a table. These measured background levels demonstrate that the reactor water had reached background levels by the end of the testing period.

Table 9. Results of nitrogen testing in reactor pool water.

Testing protocol	Ammonia	Nitrite	Nitrate
Baseline	.196	.075	.125
Initial	.048	.001	.038
Follow-up	.010	.002	.050
Background levels	.010	.002	.050
Percent change	-100%	-100%	-100%

Table 10. Results of ammonia surface smears.

Testing protocol	Trough	Reactor room floor	Inside ventilator duct
Initial	.163	.113	.450
Follow-up	.163	.095	.151
Percent Change	0%	-16%	-66%

Additional Action Implemented Since Testing

Wire screens were installed below the fresh air intake vent to permanently eliminate the pigeons' roosting site. This action may eliminate a major source of nitrogen contamination in the reactor area; however, this has not been tested.

Foam Fractionation Device to Be Tested

The reactor staff may install and test a foam fractionation device to remove proteins and other organic compounds from the pool system before they decompose and produce ammonia. The staff is unsure that a foam fractionation device will be effective with the reactor pool water because of the very low concentration of organic compounds; however, the staff is planning to test a foam fractionation device when time allows.

Conclusions

This study was initiated because biological growth was observed in the reactor pool. During initial data collection nutrient contamination in the pool was discovered to be the primary problem. The biological growth was an indicator of the contamination, and the contamination was occurring faster than the ion exchange resins could remove it. Of greatest concern, however, was the possibility that the nutrients could stimulate the growth of acid-producing bacteria that could weaken or damage the aluminum tank. Tests were performed to determine concentration levels of nitrogenous compounds at sites in and around the pool. Possible sources of contamination were identified, and action was taken to prevent or limit any additional contamination. Concurrent pool maintenance (cleaning in and around the pool and heating the pool) removed the organisms and organic debris from the pool and the surrounding area. The results of follow-up water quality monitoring over the 5-month testing period showed that the reactor pool water contained no significant accumulation of nitrogen nutrients. The pool has remained free of biological growth since its last thorough cleaning over 24 months ago. The action taken to eliminate excessive nutrient contamination from the reactor pool was successful. If biological growth is observed again, the pool water will be immediately tested for contaminants. The procedures in this report, if followed carefully, may prove to be successful in other similar facilities.

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4. Hach Company. DR/2000 Spectrophotometer Procedures Manual. pp. 218-221, 230-233, 242-245. 1988.

Appendix: Data Charts

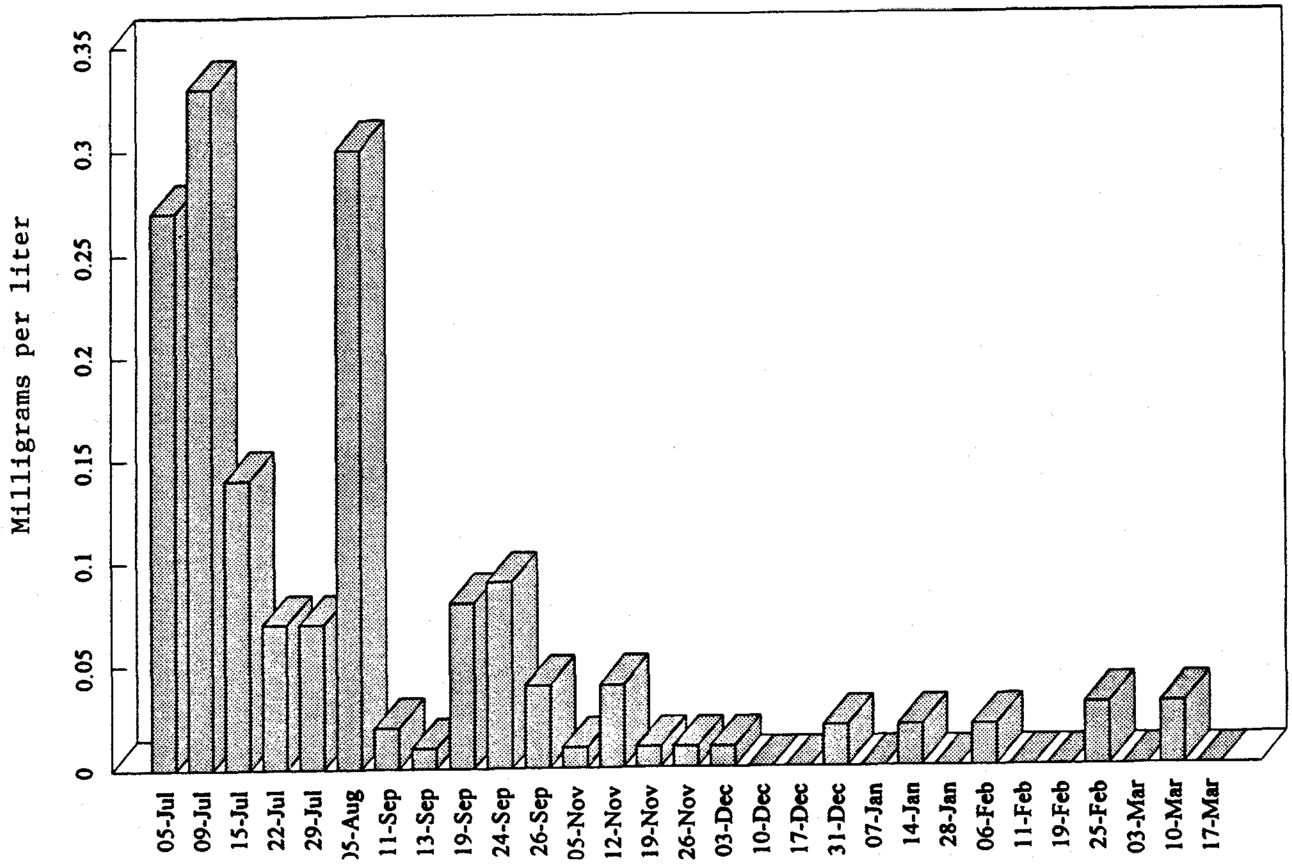

Figure A-1. Ammonia in reactor pool water, July 1991 through March 1992.

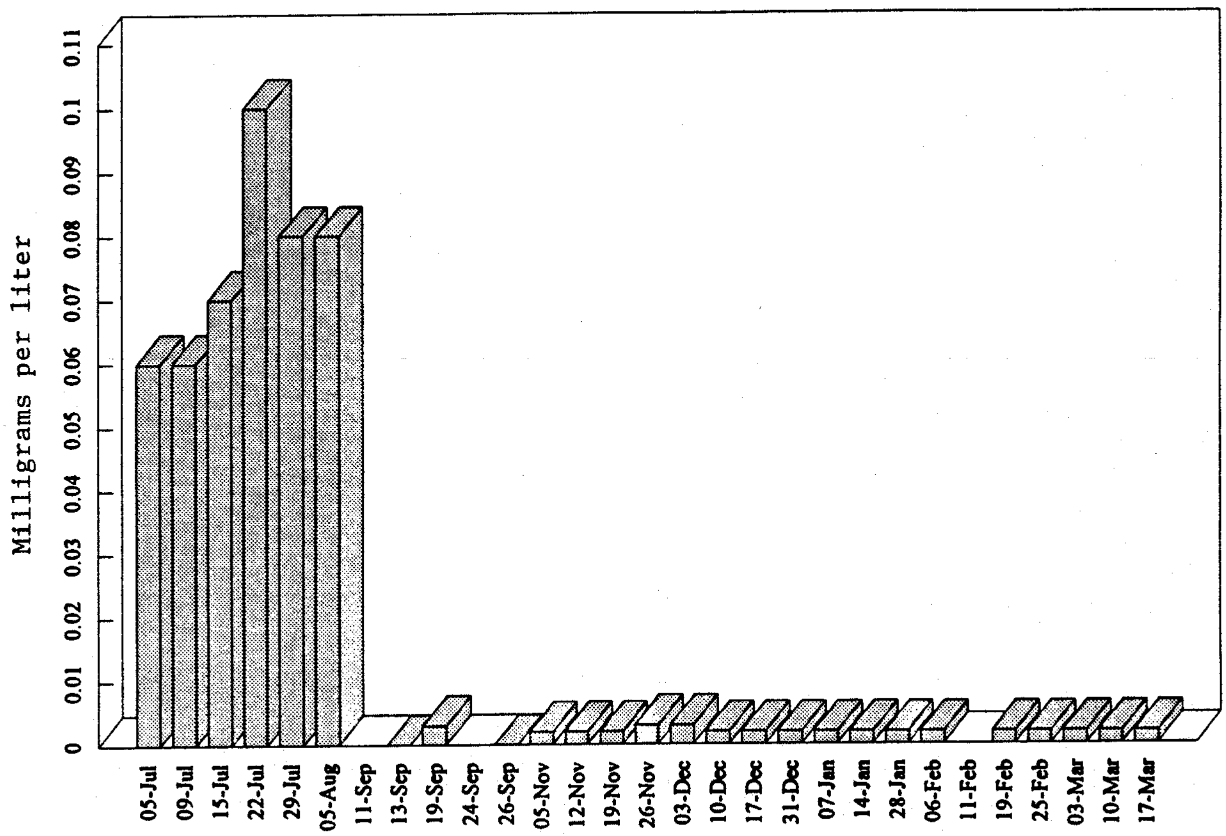

Figure A-2. Nitrite in reactor pool water, July 1991 through March 1992.

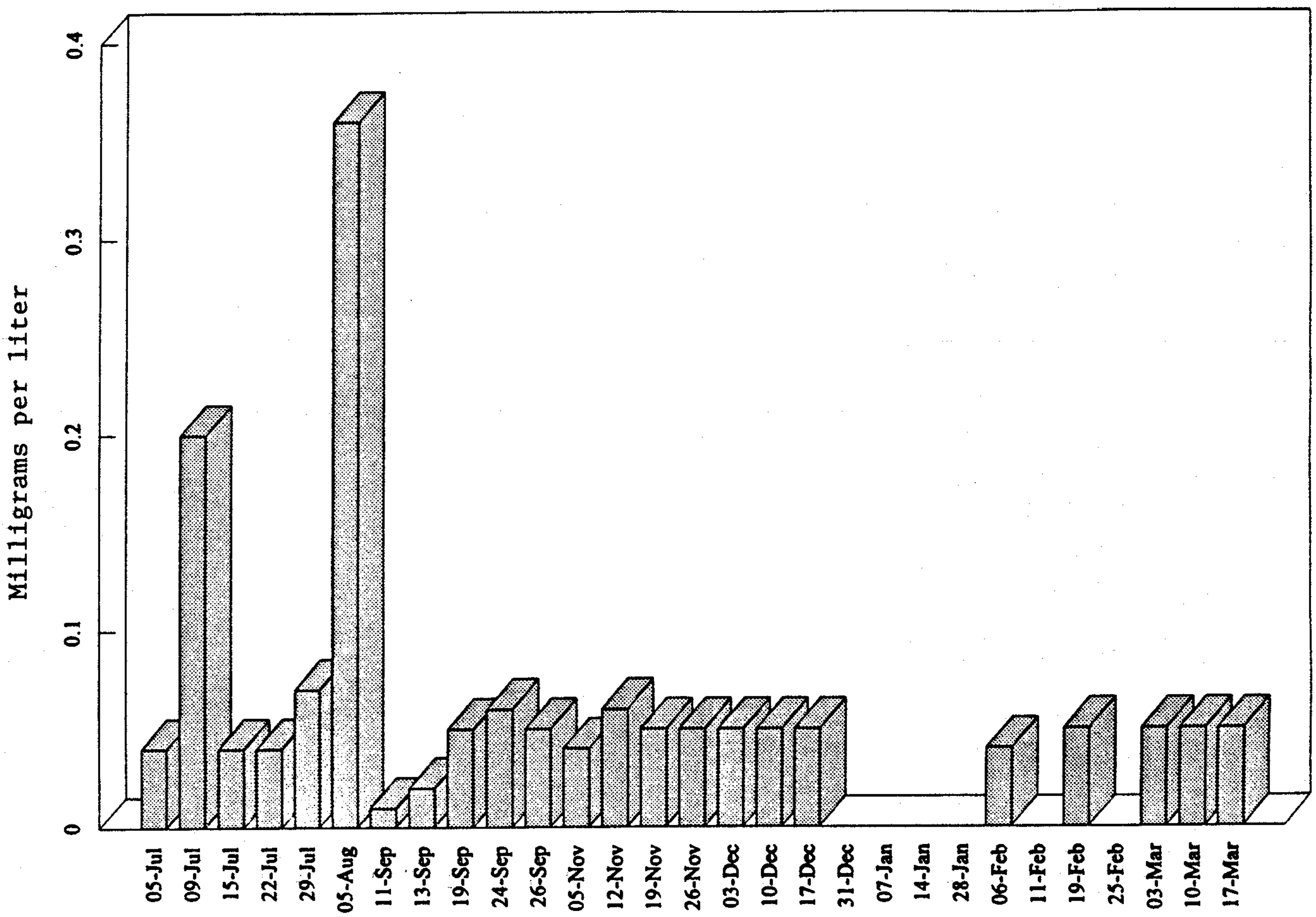

Figure A-3. Nitrate in reactor pool water, July 1991 through March 1992.

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