REMOVAL OF IODINE
FROM AQUEOUS SOLUTIONS BY SPARGING

by

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Typed by Edith Haught
PREFACE

This problem was completed as a research project while working for the General Electric Company at the Hanford Works in Richland, Washington. The writer wishes to express his sincere appreciation to Dr. Raymond E. Burns under whose guidance this research was performed.

Especial thanks are due to Mr. Philip B. Fisk, director of the counting room, for use of the Shonka Counter, without which this work would have been very tedious and time-consuming.

I also wish to thank my wife, Rosemary B. Holm, for invaluable assistance in the preparation of the various graphs and figures.

Date March, 1951 Charles Hawthorne Holm
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REMOVAL OF IODINE FROM AQUEOUS SOLUTIONS BY SPARGING

INTRODUCTION

Nitric acid dissolution of Hanford irradiated uranium releases iodine, some of which is radioactive, into solution. About fifty percent of this iodine is evolved by the sparging action of gases released during dissolution and passes, with these gases, through a silver reactor where it is effectively removed. Before the iodine remaining in solution can be sent to a waste stream, about ten percent of it is evolved in subsequent operations, thus contaminating canyon ventilating air. Such contamination is undesirable because it increases the hazard to personnel working in the canyon building and because it contributes the major portion of the iodine discharged from the canyon stack. Treatment of the ventilation air to remove the iodine before discharge to the stack is impractical because of its large volume.

Removal of the residual iodine while the solution is still in the dissolver would serve to prevent contamination of the large volume of ventilation air. Since the dissolvers are already equipped with spargers and since the silver reactors are now installed in the dissolver effluent gas stream, sparging seemed the most promising way to effect the removal of iodine from dissolver solution.
This report concerns studies of the removal of iodine in various oxidation states by sparging from simulated dissolver solutions. The solutions were spiked with I$^{131}$ such that iodine removal could be followed by measurement of the gamma activity of this isotope. Consideration was given largely to sparging solutions as present in the dissolvers since only these vessels discharge gases through the silver reactors.
SUMMARY

Removal of iodine, added as iodide, iodine or iodate, from simulated dissolver solutions by sparging was studied as a function of several variables:

1. Temperature. Rate of removal of iodine, added as iodide, iodine or iodate is markedly increased with increased temperature. (Figures 4, 5 and 6).

2. Spargant. Rate of evolution is affected to a small degree by the spargant used. Oxygen, air and nitrogen are of increasing effectiveness in the order given when the iodine is added as iodine or iodate. The order is reversed for iodide. (Figures 7, 8 and 9).

3. Spargant flow-rate. Increasing the spargant flow-rate increases markedly the rate of evolution of iodine when added in any of the oxidation states studied. (Figures 10, 11 and 12).

4. Presence or absence of metallic uranium. Iodine, added as iodine or iodate, is more rapidly evolved at a given spargant flow-rate when the solution is in contact with metallic uranium than in its absence; iodide removal is slower when metallic uranium is present. (Figures 13, 14 and 15).

5. Nitric acid concentration. Acidity has a definite effect on the rate of iodine evolution for all of the oxidation states studied. Curves relating percent iodine remaining after three hours of air sparging at 1.7 cc/m/ml to acidity show broad minimums for each
oxidation state, ranging from 0.5 to 2.0, 0.1 to 0.7 and 0.0 to 0.5 M HNO₃, respectively, for iodide, iodine and iodate. (Figures 16 to 22 inclusive).

6. Uranyl nitrate concentration. The rate of iodine evolution is not influenced by uranyl nitrate concentration between 1.5 and 2.2 M for any of the three oxidation states studied. (Figures 23, 24 and 25).

At a spargant flow-rate of 0.4 cc/ml, removal of 65, 73 and 65 percent of iodine added as iodide, iodine and iodate, respectively, was achieved after three hours.
APPARATUS. A schematic diagram of the equipment used for these sparging studies is shown in Figure 1. Direction of gas flow was as indicated. Measurement of the spargant flow-rate was by the Venturi flow-meter (A). Vessel (B) contained the solutions to be sparged. Gases emerging from (B) passed through a reflux condenser (C) from which condensed nitrogen oxides and water vapor were returned to the sparging vessel. Passage of the non-condensed gases through the two sodium hydroxide traps (D & E) served to remove the iodine. Finally, the water aspirator served to draw the spargant gas through the system and to keep the system at a partial vacuum to prevent the active iodine from escaping to the atmosphere.

The sparging vessel is shown in more detail in Figure 2. A glass tube (G), sintered at the end and extending nearly to the bottom of the vessel, served to disperse the spargant. Two capillary side-arms (H & I) were connected to the side of the vessel below the surface of the liquid. One was used for the addition of solution containing active iodine and the other for sampling. Standard-taper ground glass joints, ring-sealed onto the extremities of the side-arms, served to hold one milliliter volumetric flasks. A pipette control (hypodermic syringe) was used to draw solution through the sample port. Glass ball-and-socket joints were used for all other connections.
REAGENTS. All reagents used, except the following, were prepared from commercially available reagent grade chemicals.

Radioactive iodine $^{131}I$. Active iodine $^{131}I$ was obtained from Oak Ridge National Laboratory. It is stated to be carrier free and is shipped as iodide in a slightly basic sodium bisulfite solution. The actual basicity varied from shipment to shipment and was in the range of 0.02 to 0.08 M.

Uranyl nitrate. Uranyl nitrate solution was prepared by dissolving $\text{UO}_3$ in nitric acid, evaporating the resulting solution to remove excess acid, and diluting to the appropriate volume with distilled water. The solution so prepared had a residual acidity of 0.1 M.

Metallic uranium. Machined pieces of metallic uranium, pretreated for thirty minutes with a five percent nitric acid solution, were used where indicated. The pretreatment served to remove oil film and uranium oxide coatings.

PREPARATION OF ACTIVE SPIKE SOLUTION. The following procedures were used to prepare solutions containing radioactive and inactive iodine in the various oxidation states studied. Aliquots of these solutions were added to simulated dissolver solutions immediately prior to sparging.

Iodide. Seven hundred lambda of radioactive iodine solution (as received from Oak Ridge) was placed in a one milliliter volumetric flask. Two hundred lambda of $1.0 \text{ M NaHSO}_3$ and 38 lambda of
0.10 M KI were added and the mixture was diluted to one milliliter. Final KI concentration was 0.0038 M.

Iodine. Seven hundred lambda of radioactive iodine solution (as received from Oak Ridge) was placed in a two milliliter flask. Seventy-five lambda of 0.10 M KI, 100 λ of 5 M NaOH, 200 λ of 4 M NaNO₂, 1000 λ of CCl₄ and 200 λ of 5 M H₂SO₄ were added. The flask was stoppered immediately to prevent loss of iodine and shaken vigorously for two minutes. It was then centrifuged to effect phase separation. Eight hundred lambda of the CCl₄ layer was transferred to another two milliliter volumetric flask. One thousand lambda of 0.05 M NaOH was added, the flask stoppered and shaken vigorously until the violet color of iodine in carbon tetrachloride disappeared. Eight hundred lambda of the aqueous phase was transferred to another volumetric flask and diluted to one milliliter. Final total iodine concentration was about 0.0019 M. It is recognized that iodine disproportionates in basic solution to iodide and iodate. However, when the solution is acidified, as was the case when it was spiked into solutions to be sparged, it reverts to iodine. To handle an acid solution of the iodine without loss of activity would have been very difficult.

Iodate. Two hundred lambda of 5 M NaOH and 38 λ of 0.10 M KIO₃ were added to 700 λ of Oak Ridge I⁻¹³¹ solution. One drop of liquid bromine was added and the solution heated to 90°C for two hours. After acidification with 5 M HNO₃ the solution was again heated to
drive off the excess bromine. The resulting solution was then diluted to one milliliter giving an iodate concentration of about 0.0038 M.

These stock solutions were then tested for oxidation state of the iodine as follows: Twenty-five lambda of each solution was acidified with 50 \( \lambda \) of 5 M \( \text{H}_2\text{SO}_4 \), diluted to 500 \( \lambda \) and contacted with an equal volume of carbon tetrachloride. Total gamma activity and the gamma activity present in the carbon tetrachloride layer were measured in each case. Less than one percent of the activity extracted into carbon tetrachloride from the iodide and iodate solutions. About 85 percent extracted from the iodine solution. This latter figure agrees well with results reported by Raben (8, p. 481) for the extraction of iodine into carbon tetrachloride under similar conditions.

ANALYSES. Measurement of the iodine gamma activity in the various solutions concerned was done with a Shonka counter. Although this instrument does not yield results which can be readily transformed into curies, it does give readings which are directly proportional to the gamma activity present in the sample. It was particularly useful in these studies since, to make the measurements, it is not necessary to remove the iodine from solution or to evaporate the solution to dryness. Much time and tedious analytical effort was thus saved. Also, it is likely that the results obtained are more dependable since there is always the hazard of losing iodine through volatilization in a separation procedure or in evaporating a sample to dryness. Since uranium equilibrium products also emit gamma activities it was
necessary to correct for this background when uranium was present.

A schematic diagram of the Shonka counter is presented in Figure 3. An ion chamber under forty atmospheres pressure is surrounded by a 3/8 inch stainless steel shield to absorb beta radiation. The direct current produced when gamma-rays pass through the ion chamber is converted to alternating current by a vibrating reed electroscope. This current is then amplified and recorded on a Brown recorder. The results are recorded as amperes of current which are directly proportional to the gamma activity present in the sample.

**OPERATING PROCEDURE.** (See Figures 1 and 2). Introduce simulated dissolver solution and metallic uranium into the sparging vessel (B) through opening (J). Connect (B) to condenser (C). Adjust aspirator to produce a vacuum of ten inches of water in the system. Pipette an aliquot of one of the prepared iodine spike solutions into a one milliliter glass boat. Rinse pipette with distilled water and add the rinsings to the boat. Immerse the tip of the capillary extending from the spike port (I) below the surface of the spike solution in the boat. Since the system is under a negative pressure the spike solution is drawn into the simulated dissolver solution. Wash the capillary walls by flushing with a minimum amount of water. Immediately stopper the capillary by placing a one milliliter volumetric flask on the ground glass joint. This prevents additional sparging caused by air being forced through the capillary. Admit spargant at the desired flow-rate and re-adjust the vacuum to ten inches of water.
Continue sparging a specified time (generally three hours) taking one milliliter samples periodically from sample port (H). Measure the gamma activity in the samples.
DISCUSSION

Eight iodine isotopes, 127, 129, 131, 132, 133, 134, 135 and 136, which have half-lives greater than one minute, are produced in the irradiation of uranium either as fission products or as a result of the decay of fission products. Only three of these are of importance at the time the uranium is actually processed since the remainder are of very short half-life and decay to non-iodine isotopes. I\(^{127}\) is a stable isotope resulting from the decay of Sn\(^{127}\) and Te\(^{127}\). I\(^{129}\) has a half-life of greater than \(10^8\) years and is the end product in the decay scheme for both Sn\(^{129}\) and Te\(^{129}\). These two isotopes account for the major portion of the iodine present in the dissolver solution. For uranium processed under current plant conditions, dissolver solution is about \(10^{-5}\) M in iodine. I\(^{131}\) accounts for very little of the total iodine in dissolver solution but, being of short half-life (8.0 d), contributes most of the radioactivity due to iodine. Radioactivity in the dissolver solution due to this isotope is about 500 millicuries per liter.

At Hanford, irradiated uranium is dissolved in hot nitric acid. The dissolution process is continued until the solution is in uranyl nitrate. At this time it is also about 0.5 M in HNO\(_3\) and is in contact with excess metallic uranium. Water is then added to cool the solution, thus stopping the reaction, and to dilute it to prevent the precipitation of \(\text{UO}_2(\text{NO}_3)_2\cdot6\text{H}_2\text{O}\) from the cooled solution.
During dissolving, the gases generated are passed through a condenser from which condensible vapors are refluxed to the dissolver. Non-condensed vapors then pass through a silver reactor (a column of beryl saddles coated with solid silver nitrate) which very efficiently removes iodine. The remaining gases are then discharged to the atmosphere through a stack. Steam jets in the gas line serve to draw the gases through the condenser and the silver reactor and to maintain the dissolver under a partial vacuum. Because the dissolver lids are not tightly seated, considerable air leaks into the dissolver and mixes with the effluent gases. Rated capacity of the jet is about 200 cubic feet per minute. However, in actual operation its capacity is about 150 CFM. When the dissolvers are maintained at ten inches of water vacuum, leakage of air through the lids varies from 40 to 100 CFM depending on the dissolver. Hence, when not dissolving, the maximum sparging rate one could use would range from 50 to 110 CFM if the dissolver vacuum is to be maintained. These numbers apply to operation of the dissolvers prior to the installation of the silver reactors. The resistance to gas flow of these reactors is such as to reduce the flow, with the present jets, to about 25 CFM.

Little is known of the oxidation state(s) of iodine in dissolver solution and no satisfactory analytical methods have been developed.
for their determination. It is possible that, during dissolution, iodine exists as iodide at the surface of the undissolved uranium. However, in the solution, the concentration of nitric acid is adequate to oxidize iodide to iodate in the early stages of the dissolution, and at least to iodine or perhaps even to iodate in the latter stages. One theory used to explain the fact that not all of the iodine is sparged out during dissolution is that it comes in contact with strong oxidizing conditions in the condenser and is therefore refluxed as iodate. Thus, predictions as to the oxidation state(s) of iodine during or following dissolution are indeed difficult.

The foregoing discussion points out some of the limitations which current plant conditions impose on the manner in which a sparging operation could be carried out and the reasons why certain variables and ranges of those variables were chosen for study.

Iodide, iodine and iodate were considered the most likely oxidation states of iodine in dissolver solution and hence were chosen for study. Although added in these oxidation states it is not possible to say what changes in state occurred during the actual sparging. Semilog plots showing percent iodine remaining versus sparging time for the variables studied are shown in Figures 4 to 25 inclusive. If the sparger had been operated such that the spargant was always in equilibrium with the solution and if a single species, as iodine, had been sparged, straight lines would have been obtained. Obviously this was not the case. It is almost certain that a sparger having as short
contact time as the one used in these studies was not operating at equilibrium. In general the curves (except for the cases where iodate was present in an acid deficient system and also not in contact with metallic uranium) can be resolved into three components having half-lives ranging from one to ten minutes for the most readily removed, fifteen to forty minutes for the next most readily removed and fifty minutes to infinity for the least easily removed component. The presence of the three components suggests that when iodine is added as iodide, iodine or iodate, it rapidly distributes itself among all three states.

The rate of iodine evolution (added as I⁻, I₂ or IO₃⁻) from simulated dissolver solution by air sparging at 1.7 cc/m/ml as a function of temperature is shown in Figures 4, 5 and 6. The trend toward more rapid removal at higher temperature was expected at least for I₂. The degree to which I⁻ and IO₃⁻ are evolved suggests that they are being converted to I₂ during the sparging since neither aqueous HI nor HIO₃ has a vapor pressure at the temperatures studied comparable to that of I₂.

Figures 7, 8 and 9 show iodine removal under similar conditions but as a function of the spargant used. Large rate differences were not observed. It is perhaps to be expected that I⁻ removal would be favored by potentially oxidizing spargants such as air and oxygen and that the reverse might be true for I₂ and IO₃.
Iodine removal as a function of the flow-rate of air as a spargant (as shown in Figures 10, 11 and 12) varies in a manner to be expected for I\(_2\) revolution. Again, the degree to which I\(^-\) and IO\(_3^-\) are removed indicates that they are being converted to I\(_2\). Conversion of I\(^-\) to I\(_2\) might conceivably be more rapid with more thorough contact with air although oxidation by the nitrate ion in solution seems the more probable. Reduction of IO\(_3^-\) to I\(^-\) by contact with metallic uranium and subsequent oxidation to I\(_2\) by nitrate ion would perhaps be aided by the more vigorous agitation due to more rapid sparging.

The storage tank to which dissolver solution is sent when removed from the dissolver is also equipped with a sparger. Gases from it do not pass through a scrubber or silver reactor but to canyon ventilation air. However, at some cost, it is possible to connect it to the corresponding dissolver effluent gas line such that gases coming from it would pass through a silver reactor. This plant modification might be considered if sparging of iodine from solutions not in contact with metallic uranium proved to be much more efficient than with the metal present. Figure 13 shows that sparging of iodine added as I\(^-\) is more rapid in the absence of metallic uranium than in its presence. These results would be expected in the absence of reducing agent uranium. Figure 14 shows that sparging of iodine added as I\(_2\) is more effective in
contact with metallic uranium than in its absence. If I₂ is oxidized to IO₃⁻ in the absence of metal, these results would be expected.

Figure 15 shows that IO₃⁻ is not evolved at all by air sparging in the absence of metallic uranium. These results indicate rather strongly that IO₃⁻ is evolved by sparging only after being reduced to I₂ or I⁻ which in turn is reoxidized to I₂.

Sparging during the early stages of dissolving is not possible since the gases generated by the reaction are all that the jets can handle. Indeed, during peaks of dissolving it is sometimes impossible to maintain the desired vacuum in the dissolver. However, toward the end of a dissolving the reaction slows down considerably such that some sparging during these latter stages could be considered. Under these conditions the sparging would be done in a solution increasing in uranyl nitrate and decreasing in nitric acid concentrations. A study was made of iodine sparging efficiency as a function of nitric acid and uranyl nitrate concentrations. These results are shown in Figures 16 to 25. As can be seen, acidity (nitric acid) does have a pronounced effect on iodine removal whether added as I⁻, I₂ or IO₃⁻. Curves relating percent iodine remaining after three hours of sparging to acidity (Figure 22) all pass through broad minimums ranging from 0.5 to 2.0 M for I⁻, 0.1 to 0.7 M for I₂ and 0.0 to 0.5 M for IO₃⁻.
Tables 1, 2 and 3 give the percent iodine remaining when added initially as $I^-$, $I_2$ or $IO_3^-$ after three hours of sparging for all runs performed.
BIBLIOGRAPHY


3. Hanford works technical manual. Section C. HW-10475. May 1, 1944. 121lp.


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### TABLE 2

**Sparging Studies**

Initial iodine concentration: $5 \times 10^{-6} \text{ M I}_2$

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<th>Run Number</th>
<th>流速 Flow-率 (ml/ml)</th>
<th>温度 Temperature (°C)</th>
<th>水银温度 Utrum metal</th>
<th>浓度 Concentration, M</th>
<th>蒸余 Percent iodine remaining after three hours</th>
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### Sparging Studies

Initial iodate concentration: \(10^{-5} \text{ M KIO}_3\)

<table>
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<tr>
<th>Run Number</th>
<th>Sparging</th>
<th>Flow-rate cc/m³/m</th>
<th>Temperature °C</th>
<th>Uranium metal</th>
<th>Concentration, M</th>
<th>(\text{UO}_2(\text{NO}_3)_2)</th>
<th>(\text{HNO}_3)</th>
<th>Percent Iodine remaining after three hours</th>
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Note: The table contains data on sparging studies with various conditions and concentrations, including the percent iodine remaining after three hours.
SCHEMATIC DIAGRAM
OF THE SPARGING EQUIPMENT
SPARGING VESSEL

---

**Effluent Gases**
(to condenser)

- Sample port
- Spike port
- Sintered glass
- Sparging rod
- To pipette control

**Diagram Components:**
- B: Sparging Vessel
- G: Sintered Glass Sparging Rod
- H: Sample Port
- I: Spike Port
- J: To Pipette Control
- Diagram includes additional labeling for parts of the apparatus.
FIGURE 3

SCHEMATIC DIAGRAM OF THE SHONKA COUNTER

lead shield
ion chamber

D.C.  A.C.

amplifier

Brown recorder

vibrating reed
iodine present as I⁻
air sparged
sparging flow rate: 1.7 cc/min./ml.
metallic uranium present
solution: 1.5 M UNH, 0.3 M HNO₃, 10⁻⁵ M KI
iodine present as $I_2$
air sparged
sparging flow rate: 1.7 cc./min./ml.
metallic uranium present
solution: 1.5 M UNH, 0.3 M HNO$_3$, 5x10$^{-6}$ M $I_2$
iodine present as $10^{-3}$
air sparged
sparging flow rate: 1.7 cc/min./ml.
metallic uranium present
solution: 1.5 M UNH, 0.3 M HNO$_3$, $10^{-5}$ M KIO$_3$
iodine present as I⁻
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: 1.5M UNH, 0.3M HNO₃, 10⁻⁵M KI

FIGURE 7
RATE OF IODINE REMOVAL

PERCENT IODINE REMAINING

TIME IN MINUTES

air sparge
N₂ sparge
O₂ sparge
FIGURE 8
RATE OF IODINE REMOVAL

iodine present as I₂
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°- 100° C.
metallic uranium present
solution: 1.5 M UNH, 0.3 M HNO₃, 5x10⁻⁶ M I₂
Iodine present as $10^{-3}$
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: 1.5 M UNH, 0.3 M HNO$_3$, $10^{-5}$ M KIO$_3$
Figure 10

Rate of Iodine Removal

Iodine present as $I^-$
Air sparged
Temperature: 95° - 100° C.
Metallic uranium present
Solution: 1.5 M UNH, 0.3 M HNO$_3$, $10^{-5}$ M KI

0.4 cc./min./ml.
1.2 cc./min./ml.
3.4 cc./min./ml.

Percent Iodine Remaining

Time in Minutes
iodine present as I₂
air sparged
temperature: 95°-100° C.
metallic uranium present
solution: 1.5 M UNH, 0.3 M HNO₃, 5x10⁻⁶ M I₂
iodine present as $10^{-3}$
air sparged
temperature: $95^\circ - 100^\circ$ C.
metallic uranium present
solution: $1.5$ M UNH, $0.3$ M HNO$_3$, $10^{-5}$ M KIO$_3$
iodine present as I
air sparged
sparging flow rate: 1.7 cc./ min./ ml.
temperature: 95°- 100° C.
solution: 1.5 M UNH, 0.3 M HNO₃, 10⁻⁵ M KI

metallic uranium present
metallic uranium absent
FIGURE 14
RATe OF IODINE REMOVAL

iodine present as I₂
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100°C.
solution: 1.5 M UNH, 0.3 M HNO₃, 5x10⁻⁶ M I₂
FIGURE 15
RATE OF IODINE REMOVAL

metallic uranium absent

metallic uranium present

iodine present as $10^{-3}$
air sparged
sparging flow rate: 1.7 cc/min./ml.
temperature: 95° - 100° C.
solution: 1.5 M UNH, 0.3 M HNO$_3$, 10$^{-5}$ M KIO$_3$
iodine present as $I^-$
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: 1.5 M UNH, HNO$_3$, 10$^{-5}$ M KI
iodine present as $I^-$
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: $95^\circ - 100^\circ$ C.
metallic uranium present
solution: 1.5 M UNH, HNO$_3$, $10^{-5}$ M KI

FIGURE 17
RATE OF IODINE REMOVAL

PERCENT IODINE REMAINING

TIME IN MINUTES
iodine present as I₂
air sparged
sparging flow rate: 1.7 cc/min/ml.
temperature: 95°-100° C.
metallic uranium present
solution: 5M UNH, HNO₃, 5x10⁻⁶ M I₂
iodine present as I₂
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100°C.
metallic uranium present
solution: 1.5 M UNH, HNO₃, 5x10⁻⁶ M I₂

FIGURE 19
RATE OF IODINE REMOVAL

PERCENT IODINE REMAINING

TIME IN MINUTES

4.0 M HNO₃
1.0 M HNO₃
0.3 M HNO₃
iodine present as $10^{-3}$
air sparge
sparging flow rate: 1.7 cc/min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: 1.5 M UNH, HNO$_3$, $10^{-5}$ M KIO$_3$
iodine present as $10^{-3}$
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: 1.5M UNH, HNO$_3$, $10^{-5}$ M KIO$_3$
FIGURE 22
EFFECT OF HNO₃ CONCENTRATION

air sparged
sparging flow rate: 1.7 cc/min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: 1.5 M UNH, HNO₃

- 10⁻⁵ M KI
- 5x10⁻⁶ M I₂
- 10⁻⁵ M KIO₃

PERCENT IODINE REMAINING AFTER THREE HOURS

NITRIC ACID MOLARITY
iodine present as $I^-$
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: UNH, 0.3 M HNO$_3$, $10^{-5}$ M KI
FIGURE 24

RATE OF IODINE REMOVAL

iodine present as I₂
air sparged
sparging flow rate: 1.7 cc./min./ml.
temperature: 95°-100° C.
metallic uranium present
solution: UNH, 0.3M HNO₃, 5x10⁻⁶ M I₂

PERCENT IODINE REMAINING

TIME IN MINUTES
iodine present as $10^{-3}$
air sparged
sparging flow rate: 1.7 cc/min/ml.
temperature: 95°–100° C.
metallic uranium present
solution: UNH, 0.3 M HNO₃, $10^{-5}$ M KIO₃