Iodine Speciation Across the Length of the Hanford 200-UP-1 Operable Unit Radioiodine Plume and Biogeochemical Drivers of Speciation– 17270

Brady Lee *, Hope Lee *, John McDonald **, Shelby Brooks *, Michael Truex *, Nikolla Qafoku *, Jim Szecsody *
* Pacific Northwest National Laboratory
** CH2M Hill PRC

ABSTRACT

In 1943, construction began on the first of nine nuclear reactors at the Hanford Site to produce plutonium for the development of atomic weapons for the Manhattan Project during World War II and throughout the Cold War. Over a production period lasting from 1944 to 1987, approximately 110,000 tons of nuclear fuel was processed. During the production period, billions of gallons of liquid nuclear waste and millions of tons of solid waste were produced. Approximately 4.7 Ci of radioiodine (I-129) was discharged to liquid disposal sites, during disposition of the waste. Following percolation of the liquid waste through the vadose zone, three large I-129 groundwater plumes have formed beneath Central Plateau Facilities including both 200 East and 200 West Areas.

Analysis of I-129 plumes in the 200-ZP-1 Operable Unit (OU) (200 West Area) showed iodine speciation that was dominated by iodate even though iodide was thought to be dominant species in waste. Experimental results demonstrated that iodate interacts with calcite via a co-precipitation and/or adsorption mechanism. From sorption experiments performed on Hanford sediments, iodate interacted more strongly than iodide during adsorption experiments. These results would indicate that iodate migration would be retarded compared to iodide, but results from groundwater samples obtained from eight wells in the 200 ZP-1 OU did not support this hypothesis.

Due to different chemical processes used during plutonium processing, iodine species in other plumes such as in the 200-UP-1 OU (200 West Area) may be different. In addition, species distribution may change longitudinally between the source area and the distal end of the plume. Groundwater samples will be taken at a location near the source, in the middle of the plume and at the distal end of the plume. These samples will be analyzed for iodine speciation using ion chromatography coupled to an inductively coupled plasma mass spectrometer. Results from the different samples will be compared to give an initial determination of species distribution at different locations along the plume.

Data generated from these samples can then be used to inform the conceptual model that is being developed for iodine as part of an evaluation of remediation options for the 200-UP-1 OU.

INTRODUCTION

In 1943, construction began on the first of nine nuclear reactors at the Hanford Site to produce plutonium for the development of atomic weapons for the Manhattan Project during World War II and throughout the Cold War. Over a

production period lasting from 1944 to 1987, approximately 110,000 tons of nuclear fuel was processed (Gephart 2003). During the production period, billions of gallons of liquid nuclear waste and millions of tons of solid waste were produced. Isotopes of iodine were generated during plutonium production within the nine production reactors at the Hanford Site. The short half-life ^{131}I was released from the fuel into the atmosphere during the dissolution process (when the fuel was dissolved) in the Hanford Site 200 Area, is no longer present at concentrations of concern in the environment.

The primary sources known or suspected to have contributed to contamination in the 200-UP-1 OU include liquid process wastes and wastewater generated during historical operations of S Plant (REDOX) Plant, U Plant, S-SX Tank Farm, and U Tank Farm (U.S. DOE 2014). The contaminants observed in groundwater within the 200-UP-1 OU resulted from planned releases of these process liquid wastes and wastewater to the soil via discharge to engineered structures (cribs, trenches, ditches, ponds, leach fields, or injection wells). Unplanned releases resulted from inadvertent releases of the same or similar waste materials from tanks, pipelines, or other waste storage or conveyance components. Most of the liquid waste and wastewater that contributed to observed groundwater contamination migrated downward through the soil column by gravity to reach the underlying groundwater. Vadose zone flux is continuing to contribute contaminants to the groundwater. Additional investigation of vadose zone contamination will be conducted before a final remedy is selected for the 200-UP-1 OU.

The total amount of ^{129}I generated at the Hanford Site during reactor operations is well known: 49.4 Ci of ^{129}I was produced during reactor operations according to ORIGEN2 fuel activity estimates (Watrous et al. 2002). However, the distribution of that well-defined inventory to storage or environmental releases is very uncertain. The inventory has been distributed among the following mechanisms:

- Stored in single-shell and double-shell tanks
- Discharged to liquid disposal sites (e.g., cribs and trenches)
- Released to the atmosphere during fuel reprocessing operations
- Captured by off-gas absorbent devices (silver reactors) at chemical separations facilities (PUREX, B-Plant, T-Plant, and REDOX)

Once ^{129}I and other mobile contaminants reached the aquifer, they spread, producing large-scale plumes. Three ^{129}I plumes in groundwater at the Hanford Site cover an area greater than 50 km^2. In general, the plume emanating from the 200 East Area is larger because of differences in subsurface geology. The water table beneath the 200 East Area and extending to the Columbia River is within more-permeable sediments. In the 200 West Area, the water table is primarily within the lower permeability Ringold Formation. This results in faster groundwater flow and shorter travel times in the 200 East Area than in the 200 West Area (Freshley and Graham 1988). The largest ^{129}I plume extends toward the southeast from the 200 East Area. A smaller arm of the plume has moved toward the northwest between Gable Mountain and Gable Butte. The largest ^{129}I plume associated with the 200 West Area is in the 200-UP-1 OU.

The ^{129}I plumes in the Hanford Site Central Plateau are very large and dilute. The lengths of the leading edges of the plumes are on the scale of kilometers. The ^{129}I concentrations are all less than 50 pCi/L, with most less than 10 pCi/L, though

above the DWS of 1 pCi/L. Furthermore, natural stable iodine (^{127}I) is also present in the aquifer at much greater concentrations than ^{129}I. The presence of ^{127}I is important because most remediation technologies are not specific for a particular iodine isotope. In addition, ^{127}I and ^{129}I have the same chemical behavior in the subsurface, so the presence of ^{127}I will influence the biogeochemical processes for ^{129}I.

The subsurface behavior of radioiodine is complex because it can exist in multiple physical states (solid, liquid, or gas) and oxidation states (-1, 0, +1, +5, and +7) at environmentally relevant conditions (Zhang et al. 2013). Initial studies to understand iodine biogeochemistry in both groundwater and on mineral surfaces was performed using groundwater and soils from the Hanford 200 West Area [8-9]. Iodine speciation and isotope analysis was performed on groundwater from seven monitoring wells. Average total ^{127}I concentrations ranged from 8.4 to 75 µg/L, with an average of 30.8 µg/L. Iodate (IO_3^-) accounted for the bulk of the ^{127}I (22.6 µg/L), followed by organo-iodine (6.95 µg/L) and iodide (0.46 µg/L). Radioiodine concentrations were orders of magnitude lower, with an average concentration of 0.1 µg/L, which was calculated from IO_3^--associated ^{129}I concentrations because organo-iodine and I^- forms of ^{129}I were below detection limits. Although the mass-based ^{129}I concentrations are low, in the seven wells tested, ^{129}I activity ranged from 3.6 to 42.5 pCi/L, concentrations above the 1 pCi/L drinking water standard. One unexpected result from these studies was the formation of $CaCO_3$ precipitates in sample bottles used during the study. These precipitates had I concentrations averaging 107.6 mg/L and contained high amounts of both ^{127}I (74.0 µg/g) and ^{129}I (0.15 µg/g). These precipitates were thought to be formed during degassing of CO_2 when the groundwater was pumped to the surface. Precipitation of $^{127}I/^{129}I$-laden $CaCO_3$ could be stimulated by the addition of $CaCl_2$ and Na_2CO_3.

Aqueous-phase iodine species interact with sediments, allowing adsorption/surface complex formation, as well as transformation, depending on the geochemistry of the sediment used (Kengen et al. 1999). In the study by Xu et al. (2015), sequential extraction of the three sediments showed that there were strongly bound forms of iodine on the mineral surface. Only 0.4 to 6.6 wt% of the iodine was readily released, 0% to 1.2% was associated with Fe and Mn oxides, and 2.9% to 39.4% of the iodine was associated with $CaCO_3$ on the mineral surface. Organic carbon associated with the surface of the sediments was hypothesized to account for 57.1% to 90.6% of the total iodine present. Iodine adsorption isotherms indicated that IO_3^- was more strongly sorbed to the sediments than iodide. Likewise, desorption of iodine from the sediment surface was always greater than sorption, regardless of the species tested. These studies showed that even low organic carbon on the soils appeared to control iodine binding because as organic carbon concentration increased, greater values of uptake, desorption, and residual iodine were found for these sediments. One other interesting finding for these sediments was that IO_3^- was readily reduced, meaning the IO_3^- is sorbed and then reduced, yielding I^- which would desorb.

Microbes isolated from sediment traps incubated in monitoring wells within the ^{129}I the 200 West UP-1 OU showed the ability to transform both IO_3^- and I^-. Bacteria common to groundwater were shown to reductively transform IO_3^- to I^- when grown in the presence of simple carbon sources and nitrate. Likewise, a number of bacterial isolates, as well as mixed communities isolated from these

sediment traps, were able to oxidize I^- to I_2 when stimulated with a variety of carbon sources.

These biogeochemical drivers will effect fate and transport of ^{129}I in the subsurface, and may affect species distribution in these plumes. In this paper, iodine speciation across the ^{129}I plume in the 200-UP-1 OU will be discussed. In addition, the biogeochemical drivers, including biotic and abiotic transformation, as well as mechanisms for precipitation will be discussed and possible effects on species distribution will be determined.

METHODS

Groundwater samples were taken during drilling of a monitoring well (W22-114) in the iodine plume in the 200-UP-1 groundwater operable unit (Figure 1).

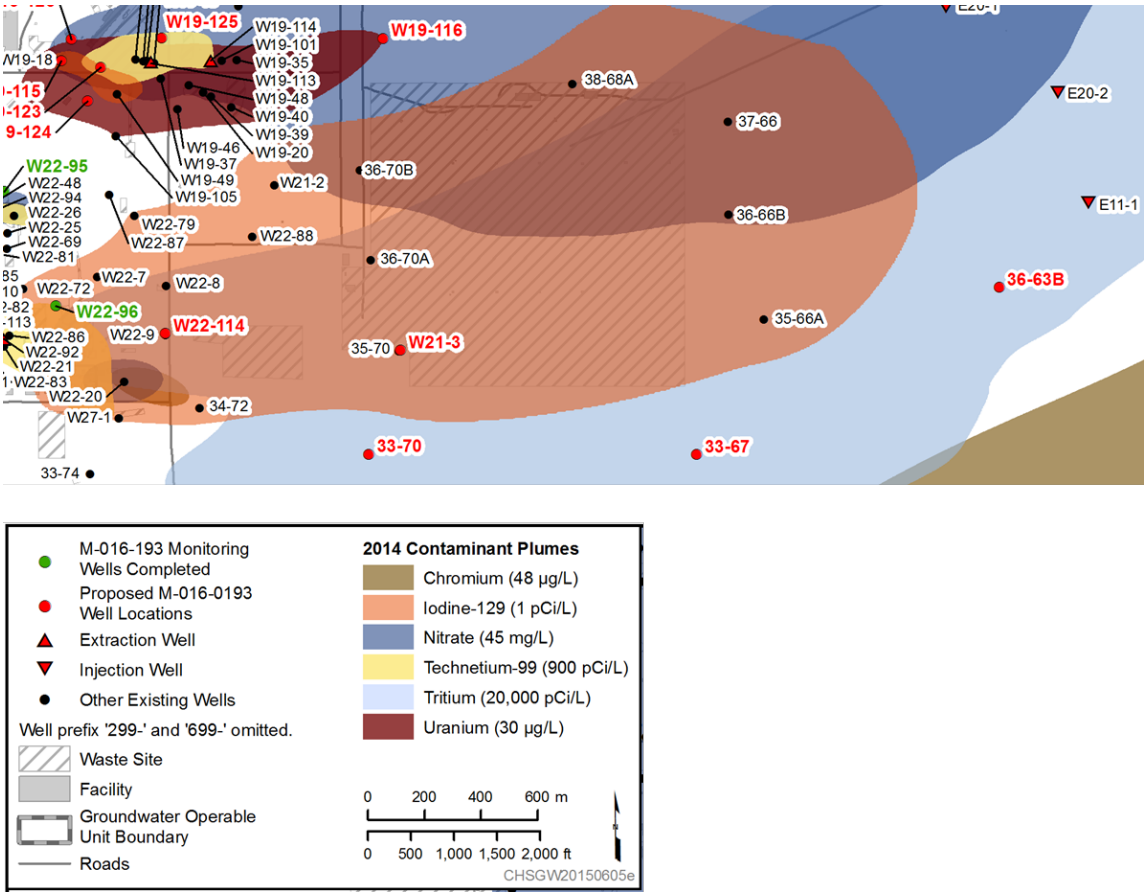

Figure 1. I-129 plume showing wells sampled for iodine speciation.

As drilling proceeded, samples were taken at seven depth intervals. In addition, groundwater was sampled from wells 36-70A, 35-66A and 36-66B and analyzed for iodine speciation. In addition, ^{129}I, along with other contaminants of concern were measured in the samples.

Total Iodine and Iodine Speciation Analysis

Total Iodine was measured quantitatively at mass 127 using a Perkin Elmer ELAN DRC II quadrupole Inductively Coupled Plasma-Mass Spectrometer (ICP-MS)

and an Elemental Scientific SC2 DX FAST auto-sampler interface. The instrument was calibrated using standards made by the High-Purity Standards Corporation to generate calibration curves. The seven calibration standards range from 0.05ppb to 5ppb.

Samples were separated into IO_3^- and I^- species using a chrom-FAST Iodine Speciation Kit (CF-KIT-I) and SC2-DX FAST auto sampler interface made by the Elemental Scientific Corporation (ESI). The speciation kit includes an in-line ion exchange column which separates Iodine into its constituent species for time resolved elution and subsequent ^{127}I quantification by ICP-MS. The solution used for column elution consisted of 2% Fisher Optima grade Nitric Acid and twice deionized water with resistivity no lower than 18.0 MΩ-cm as per the CF-KIT-I User Manual.

IO_3^- and I^- were analyzed quantitatively with a Perkin Elmer ELAN DRC II quadrupole Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) using time resolved data points where IO_3^- was eluted off the column at approximately 80-90 seconds and I^- was eluted off the column at approximately 260-280 seconds. Chromatographic peak areas were integrated using periSPEC Peak Area Finder software from the ESI Corporation. Peak areas were then recorded and used to generate calibration curves for both IO_3^- and I^-. The concentration of the calibration standards ranged from 0.1ppb to 50ppb for both Iodate and Iodide.

Understanding Controlling Processes

Iodate Carbonate Precipitation

IO_3^- precipitation during calcium carbonate precipitation was studied using a series of batch experiments. In summary, experiments were conducted by mixing stock solutions (0.1M or 1M) of $CaCl_2$ and $(NH_4)_2CO_3$ in equal amounts to form calcite 1) in the presence of IO_3^-at varying concentrations up to 500 µg/L and 2) for selected treatments in the presence of $IO_3^-$and chromate (up to 500 µg/L). In some experiments (referred to as “late-spike”), IO_3^- was added about a day after the calcite-forming solutions were mixed, after the precipitation of calcite appeared to be complete. The aqueous-phase concentration of IO_3^- was measured periodically over a period of 28 days.

Biotransformation of Iodine Species

In an effort to understand the impact of microbial activity on speciation of ^{129}I in the Hanford subsurface, a series of microcosms were set up to look at oxidation of iodide and reduction of iodate.

Iodate reduction capacity of Hanford bacterial isolates was performed using batch experiments with *Agrobacterium* species DVZ35 which was isolated from sediments incubated in an ^{129}I plume in the 200-ZP-1 OU. All incubations were carried out at 25°C in the absence of light throughout this study. 1/2R2A media with 200 µM iodate was used to subculture DVZ35. The growth medium used for iodate reduction was a minimal medium and contained (liter^{-1}): KH_2PO_4 (0.14 g), $MgCl_2 \cdot 6H_2O$ (0.20 g), $CaCl_2 \cdot 2H_2O$ (0.15 g), $Na_2SO_4 \cdot 10H_2O$ (0.14 g), $NaHCO_3$ (0.5 g), ATCC vitamin supplement (1.0 ml), ATCC trace mineral supplement (1.0 ml), bacto-tryptone (1.0 g) , NaCl (1.5 g), 10 mM $NaNO_3$, and 200 µM KIO_3. The pH was adjusted to 8.0 prior to autoclaving. To detect iodate-reducing capabilities,

isolates were grown aerobically overnight, harvested during log phase, washed twice with phosphate buffered saline (PBS), and diluted to an OD600 of 0.2 (corresponding to 0.14 mg protein ml^{-1}) and inoculated at 1%. Anaerobic cultures were supplemented with 10 mM lactate as electron donor and sparged with O_2 free N_2 for 10 min after inoculation to generate anoxic growth conditions.

Iodide oxidation experiments were performed with aerobic enrichments from the sediments discussed above. Bacteria enriched from materials incubated in ^{129}I plumes at the Hanford Site were screened for the ability to oxidize I- to the more oxidized iodine compounds, such as I_2 and IO_3^- (Table 1). Isolates were cultured aerobically in modified M9 minimal medium (2.27 mM ammonium sulfate, 0.02 M sodium chloride, 0.2 mM magnesium sulfate heptahydrate, 0.15g/L yeast extract, 0.012 M phosphate buffer, 3 mL/L Hutner's mineral solution, 0.2% glucose, pH 7.5) at 30°C and shaken at130 rpm. Pseudomonas putida strain mt-2 was used as a positive control, since laccase production has been demonstrated in this bacterium (Ahmad, Taylor et al. 2010).

Four isolates that demonstrated the greatest I- oxidation during screening were further tested to determine the effect of carbon source on I- oxidation, as well as production of multicopper oxidase enzymes previously associated with I- oxidation. Carbon sources tested were 0.2% (w/v) glucose, 0.2% (w/v) xylose, 10 mM acetate, and 10 mM lactate. Cultures were grown overnight (approximately 10-16 hours) and used to inoculate batch experiments at the end of the growth period. Experiments were performed in 125 mL Erlenmeyer flasks with a working volume of 50 mL, with 0.2 mM potassium iodide (KI) as the source of I-. Negative controls contained modified M9 medium without bacteria. Upon inoculation, the flasks were incubated at 30°C and shaken (130 rpm), and samples were taken every 24 hours for a total of 96 hours.

Iodine Sorption

Iodine adsorption is important to quantify for predicting iodine fate and transport. Iodine is generally characterized as a mobile contaminant in groundwater, and the observed large plumes at the Hanford site are consistent with this generalization. However, iodine transport behavior differs for each species. Studies of sorption were conducted for iodide and iodate to Ringold sediments obtained from borehole C9483 (depth interval 387-388 ft bgs), located downgradient of the ^{129}I plume in the 200-UP-1 operable unit. Adsorption was measured in batch experiments at different soil/water ratio and also during breakthrough in 1-D soil columns.

Sequential Liquid Extractions of Field Sediments.

Six sequential extractions used to characterize the iodine distribution associated with field-contaminated sediments included: 1) artificial groundwater (aqueous iodine species), 2) 0.5 M Mg(NO3)2 (adsorbed iodine species), 3) 1 M Na-acetate for 1 h to dissolve some carbonates (some iodine species associated with carbonates), 4) acetic acid, pH 2.3 for 5 days to dissolve most carbonates (most iodine species associated with carbonates), and 5) 0.1 M ammonium oxalate, 0.1 M oxalic acid (1 h) to dissolve Fe/Mn/Al oxides. The first two phases (aqueous, adsorbed) were clearly identified by these extractions. The remaining three extractions operationally defined progressively harder to extract iodide/iodate-

substituted mineral or coated surface phases, as the solutions more strongly dissolved phases.

RESULTS

Iodine Speciation in Groundwater

Groundwater samples were taken at seven depth intervals below the water table during drilling of an iodine plume monitoring well (W22-114) in the 200-UP-1 OU. Data from these analyses indicate that ^{129}I is present in the groundwater above the 1 pCi/L drinking water standard (DWS) in samples from the first three intervals down to a depth of ~320 ft bgs (Table 1). At the shallowest sample interval,

Table 1. Radioiodine and iodine speciation in groundwater samples taken during drilling of a monitoring well.

Depth (ft bls)	Depth (ft bwt)	I-129 (pCi/L)	Iodate (µg/L)	Iodide (µg/L)	Nitrate (mg/L)
257.5	7.59	4.01	2.81	3.55	79.7
284	34.09	1.73	17.8	ND	5.31
317.2	67.29	1.49	14.5	ND	4.38
347.6	97.69	ND	17.1	ND	3.5
377.6	127.69	ND	17.6	ND	3.9
427.5	177.59	ND	21.8	ND	6.2
447.2	197.29	ND	22.4	ND	7.53

the concentration was 4.01 pCi/L. Nitrate concentrations were also elevated at this sample interval and also exceeded the drinking water standard (45 mg/L). With the exception of the shallowest depth interval, iodine speciation was dominated by iodate. Using the IC-ICP-MS method for analysis, iodide in six of the seven samples was below detection. The Method Detection Limit for the analytical method used for iodide is 0.25 µg/L. At the sample interval at 7.6 feet below the water table, iodide concentration was slightly higher than iodate. Overall total iodine concentrations were the least at this sample interval. For these analyses, total iodine, iodate and iodide analyses were based on ^{127}I measurements, which would also account for ^{129}I in the samples. Analyses of 200-ZP-1 groundwater indicated that ^{127}I concentrations were approximately 200 times higher than ^{129}I in the groundwater (Zhang et al. 2013).

Precipitation of Iodate with Calcite

Results show a decrease of IO_3^- concentration correlated with the starting IO_3^- concentration and the molarity of the starting solutions (Figure 2). Removal of IO_3^- from solution appears to occur by adsorption and precipitation. Late-spike experiments showed less IO_3^- removal from solution than when IO_3^- was added at same time as the calcite-forming solutions (Figure 3). These results suggest that IO_3^- incorporation in precipitates occurred during the calcite precipitation process and late-spike removal of IO_3^- was by adsorption. The results of these recent experiments demonstrate IO_3^- precipitation concurrently with calcite precipitation and that the water chemistry affects this process. Thus, the results extend the

observations of iodate-calcite interactions by others (e.g., Zhang et al. 2013). Future efforts to determine the solubility of precipitates incorporating iodate in comparison to the solubility of calcite and other carbonate precipitates would enable interpretation of the iodate precipitation phenomena in terms of how it attenuates iodate transport.

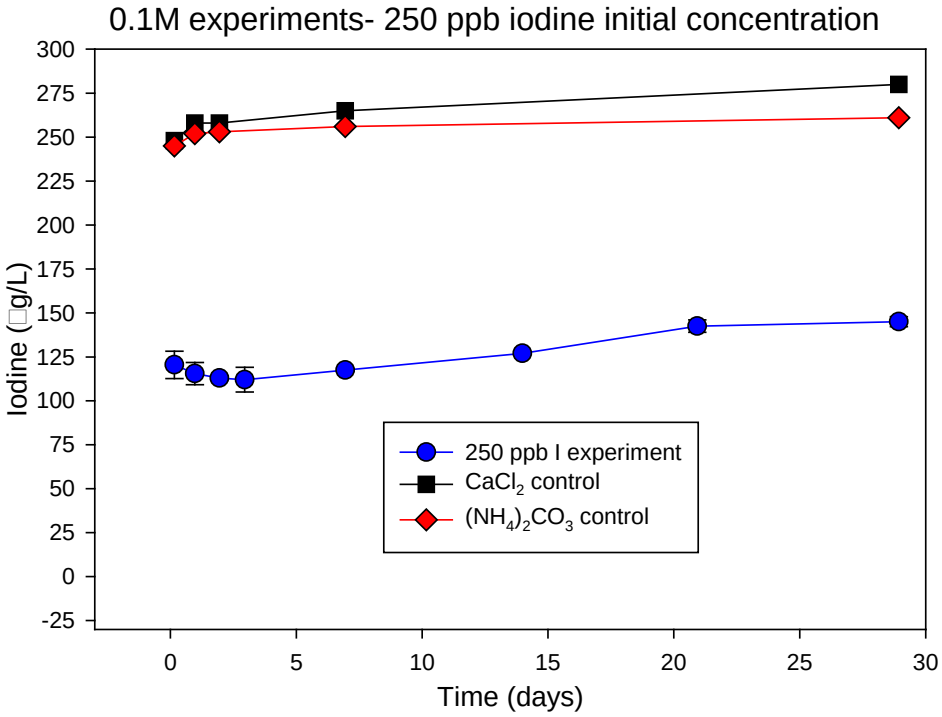

Figure 2. Iodate concentrations over time for the experiment when iodate was added at the same time (time zero) at the initial concentration of 250ppb in 0.1M calcite-forming solutions.

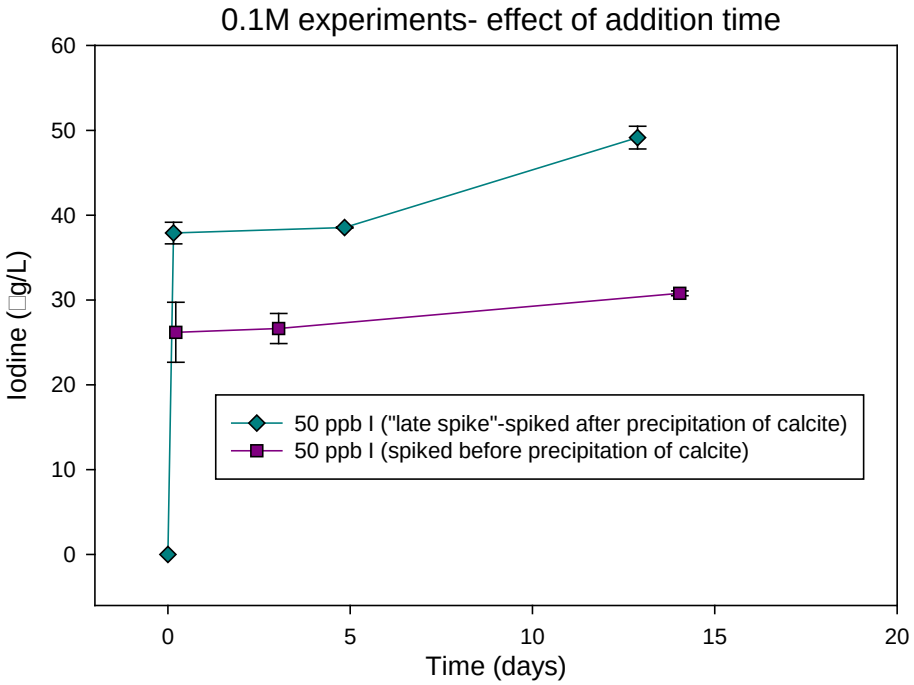

Figure 3. Iodate concentrations over time for experiments when iodate was added at the same time (time zero) as the 0.1M calcite-forming solutions (square) and for the same conditions except that iodate was added about a day after the calcite-forming solutions were mixed, i.e., after the precipitation of calcite appeared to be complete (late spike) (diamond).

Iodine Biotransformation

Hanford isolate *Agrobacterium* species DVZ35 has shown the ability to reduce iodate when nitrate is also present as an electron acceptor. Iodate was completely reduced to iodide, while nitrate was reduced to products other than nitrite. Most *Agrobacterium tumefaciens* species have enzymes allowing denitrification through nitric oxide, but do not have nitrous oxide reductase, so the absence of nitrate is not surprising (Kampschreur et al. 2012). These studies also showed that *Agrobacterium* DVZ35 was able to maintain iodate reduction, when after nitrate depletion; additional nitrate was spiked into the medium (Data not shown). Iodate reduction did not occur when nitrate was absence from the growth medium.

A number of bacteria isolated from sediments incubated in I-129 contaminated Hanford groundwater were tested for the ability to oxidize iodide (Table 2). Nine of the fourteen isolates demonstrate iodide oxidation through the formation of molecular iodine, as an oxidation intermediate. Four isolates were selected to look at iodide oxidation, as well as the ability to oxidize 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS), a substrate for multi-copper oxidases which have been shown to be involved in iodide oxidation (Kulys et al. 2005; Suzuki et al. 2012; Ihssen eta al. 2014). Preliminary results showed that all four isolates were able to oxidize iodide when grown on a variety of sugars and

organic acids. Addition of glucose appeared to stimulate the most growth, enzyme production and iodide oxidation (Figure 4). Since the amount of molecular iodine measured in the experiments is typically less than the amount of iodide added to the experiments, the reaction may continue to more oxidized forms of iodine, such as hypoiodous acid or iodate, or other reactions, such as volatilization or accumulation may be occurring.

Table 2. Hanford isolates tested for iodide oxidation.

Strain	Affiliation (accession number)
DVZ17	*Ralstonia* sp. PNP11 (DQ887520.1)
DVZ23	*Pseudomonas frederiksbergensis* strain DSM 13022 (NR_117177.1)
DVZ18	*Pseudomonas* sp. PAMC 26822 (KF011696.1)
DVZ27	*Pseudomonas mandelii* strain NF22-1 (KF151354.1)
DVZ60	*Cupriavidus necator* strain N-1 (NR_028766.1)
DVZ21	*Arthrobacter ilicis* strain ICMP 2608 (NR_104950.1)
DVZ35	*Agrobacterium tumefaciens* strain IAM 12048 (NR_041396.1)
DVZ24	*Pseudomonas mosselii* strain CFML 90-83 (NR_024924.1)
DVZ52	*Lysobacter niastensis* strain GH41-7 (NR_043868.1)
DVZ47	*Shinella kummerowiae* strain CCBAU 25048 (NR_044066.1)
DVZ6	*Pseudomonas mosselii* strain CFML 90-83 (NR_024924.1)
DVZ2	*Bacillus thuringiensis* strain IAM 12077 (NR_043403.1)
DVZ29	*Enterobacter hormaechei* strain 0992-77 (NR_042154.1)
DVZ19	*Microbacterium invictum* strain DC-200 (NR_042708.1)

Iodine Sorption

For iodide, batch sorption experiments over a range of sediment/water ratio showed very little sorption (Kd < 0.01 mL/g) over a time scale of 46 h (Figure 5). No oxidation of iodide to iodate was observed during these studies.

Iodate sorption was difficult to measure due to relatively rapid biotic/abiotic iodate reduction to iodide that occurred in the sediment. Thus, limited batch experimental data could be used to quantify sorption. From studies of iodate transformation and sorption at different soil water ratios, a Kd of 0.9 mL/g was estimated (Figure 6). These experiments resulted in an estimated Kd of 0.3 to 1.2 mL/g.

Sequential Extraction of Iodine from Sediments

Sequential Extractions show that significant (>90%) iodine mass is associated with precipitated in sediment, with a small amount aqueous and adsorbed (Figure 7). The two carbonate extractions used to remove a small fraction (orange in Figure 7) or most carbonates (yellow in Figure #) indicate that most of the iodine (50 to 70%) may be associated with or incorporated into carbonates, which is consistent with calcite precipitation studies (Figure 2 and 3). Iodine speciation shows > 70% is iodate.

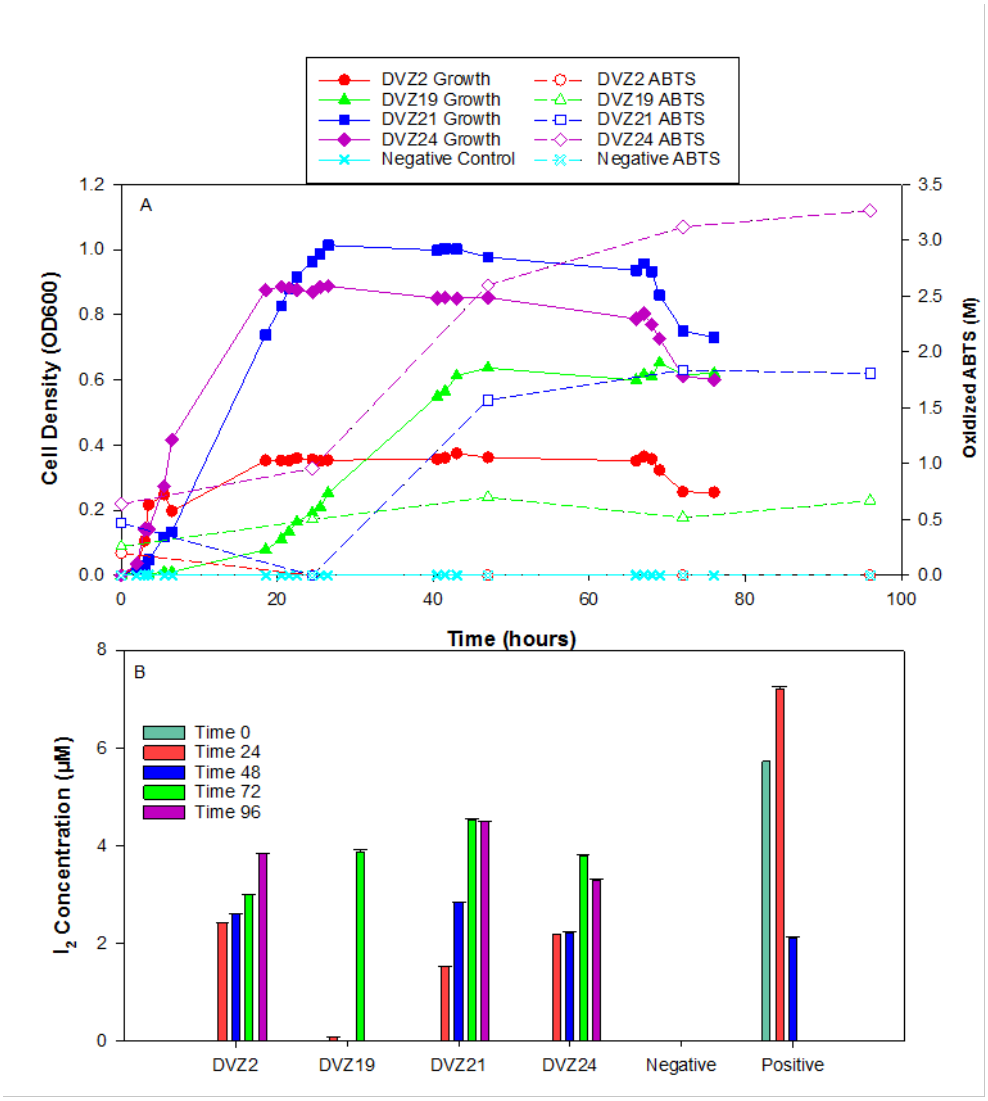

Figure 4. A) Growth and ABTS oxidation by different Hanford bacterial isolates; B) Molecular iodine concentration, as an indicator for iodide oxidation.

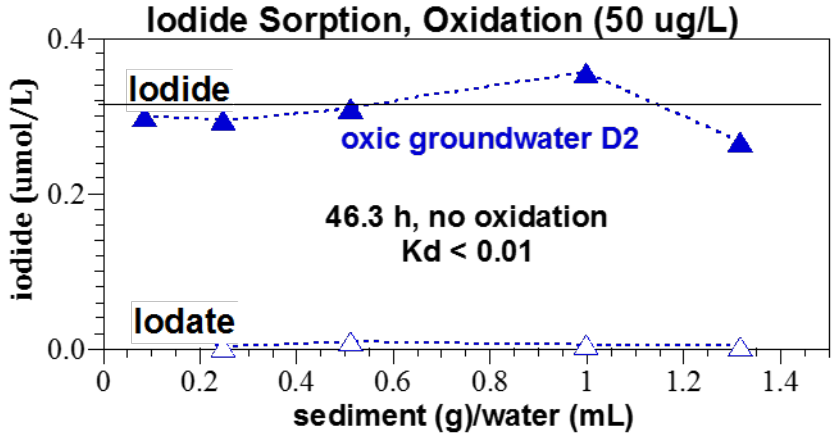

Figure 5. Iodide sorption to Hanford sediments.

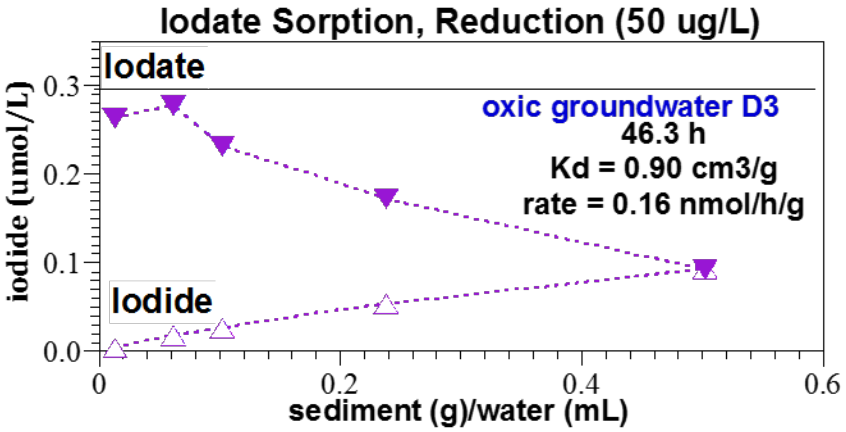

Figure 6. Iodate adsorption to Hanford sediments.

CONCLUSIONS

Radioiodine speciation in Hanford groundwater is dominated by iodate, when Eh and pH in the aquifer would indicate iodide would be the primary species. In addition, when comparing migration of tritium to ^{129}I, there are attenuation processes occurring as the iodine moves away from source zones. Sampling of the groundwater in the 200-UP-1 iodine plume showed that, like the groundwater in the 200-ZP-1 OU, iodate dominated speciation in the groundwater. These results indicate that whether iodine originated from T-Complex waste sites, or S-Complex, iodate is the dominant species in 200 West groundwater.

Potential attenuation mechanisms for iodine in the Hanford subsurface include geochemical drivers such as adsorption and precipitation, as well as biological drivers of redox chemistry. Results from studies to understand factors affecting transport of iodine in the subsurface showed adsorption, biotic and abiotic transformation, and precipitation with calcite affected iodate concentrations in laboratory experiments. Sequential extraction results from Hanford sediments support these mechanisms of incorporation. Importantly, along with reduction of iodate, Hanford bacteria were also able to oxidize iodide to molecular iodine.

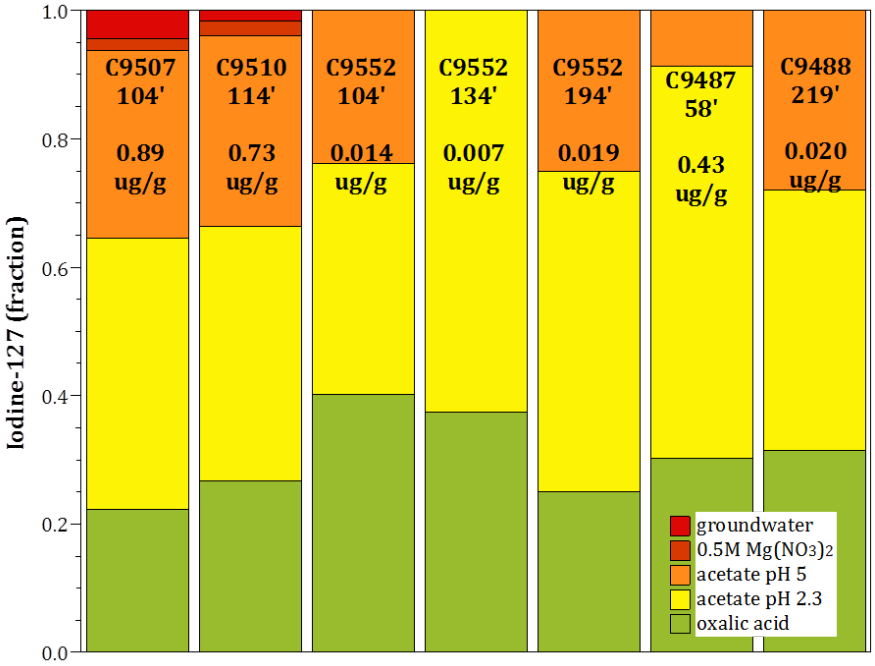

Figure 7. Total Iodine-127 distribution in field contaminated sediments based in sequential liquid extractions.

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