MBX SYSTEMS, INC.

BIOREDUCTION AMENABILITY TESTING

OF

ACTINIDE CONTAMINATED SOILS

The Systems: Am^{241}-Pu^{238}, Am^{241}-$Pu^{239/40}$, U

BY

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2.0 INTRODUCTION

2.1 History: Laboratory testing to extract metals from ores by bioreductive processing was first initiated by MBX in 1988 at the University of Arizona. This initial research examined the release of silver from argentiferous pyrolusite [1]. During the summer of 1991 researchers at MBX predicted that the bioreductive treatment of plutonium hydrous oxide precipitates would reduce $Pu^{(+4)}$ to $Pu^{(+2)}$, the soluble form of Pu. The $Pu^{(+2)}$ thus solubilized from its solid form would report to the liquid fraction of a leach system.

2.2 Prior Testing: Upon securing a Confidentiality Agreement with Los Alamos National Laboratory (LANL), MBX demonstrated in early January 1992 that plutonium hydrous oxide could be biologically reduced. Initial solubilization of >90% was achieved on synthetically prepared plutonium hydrous oxide. This work was conducted by Dr. Patricia Rusin of MBX in cooperation with Dr. Jim Brainard of LANL [2]. United States Patents obtained by MBX support this technology [3], as well as the formulated biological growth medium [4] and bacterial inoculum [5].

During the early summer of 1993, MBX further advanced this bioreductive processing technology by conducting tests on Rocky Flats (RFP) soil samples [6]. These tests were sponsored by and conducted in collaboration with Lockheed Environmental Systems & Technologies Co. (LESAT) in Las Vegas, Nevada. The soil tests of 1993 demonstrated that 92% of the plutonium and 87% of the americium could be extracted from RFP soil within eight days using bioreductive bacteria in the presence of a chelator (nitrilotriacetic acid, NTA).

A third demonstration of bioreductive processing of actinide contaminated soil was initiated (this report) in September of 1994. Five sites containing different actinide contaminant compositions were selected to test the amenability of the MBX treatment systems to extract combinations and types of actinide contaminants (see Table I).

TABLE I: DESCRIPTION OF TEST SOILS

Site	Actinide Contaminant Type	Actinide Contaminant Concentration
Rocky Flats Project (RFP), CO	$Pu^{239/40}$-Am^{241}	2121 pCi/g
Los Alamos (LANL), NM	$Pu^{239/40}$-Am^{241}	140 pCi/g
Mound, OH	Pu^{238}-Am^{241}	511 pCi/g
Hanford, WA	Uranium	693 ppm (1483 pCi/g)
Fernald, OH	Uranium	408 ppm (873 pCi/g)

1.0 EXECUTIVE SUMMARY

Bioreductive processing of actinide contaminated soils can achieve extraction levels in excess of 97% for both plutonium and uranium contaminants. Reasonable reaction rates of 4 to 6 day resident times for Pu-Am have been demonstrated on 4 gram sample charges. Longer reaction times of 17 days required for uranium extraction can be improved by soil sample preconditioning and/or an increase in process reagent concentrations. The environmentally benign treatment process operates at pH 6 - 7, preserves the original soil matrix, and utilizes standard processing equipment. The process reagent components (inoculum SD-1 and biological growth medium PX100™) are available for utilization in an integrated system. Process techniques developed by MBX, involving graduated volume bioreactors have been proven to alleviate biological toxicity problems in treatment leachates. Bioreductive processing of actinide contaminated soils, preconditioning of soil charges, and recycling or vegetation of unacceptable tailings can be combined to provide an effective and environmentally attractive method of remediation.

The laboratory testing was completed during October, test assays were completed by December, and the report was finalized by January 1995.

3.0 TEST PROGRAM

The test program was conducted to determine how amenable the MBX bioremediation process is for the universal treatment of actinide contaminated soils. The testing of RFP soils is essentially a repeat of tests performed by MBX under contract to Lockheed Environmental Systems & Technologies Co.[6] during 1993, with the exception that the 1994 RFP test sample contained higher levels of total contaminants. Total Pu-Am and uranium solubilization, and time course for actinide extraction (reaction kinetics) were defined for all of the 1994 test samples and are analyzed and evaluated in this report.

3.1 Description: The 1994 five soil test program was designed to determine the applicability of the MBX bioreductive technology to solubilize Pu and Am from RFP, Mound & LANL soils and uranium from Hanford and Fernald soils. Rates of solubilization and total actinide removal were to be determined. The test results were to be compared and contrasted between sites as to the amenability of the technology to provide actinide remediation for varying soil matrix and contaminant compositions. Four tests on each soil site were conducted in triplicate to compare and contrast the treatment components: (1) inoculum plus chelator, (2) chelator alone, (3) inoculum plus chelator in the presence of native organisms, and (4) native organisms plus chelator. Reaction kinetics of actinide extraction, including test specific and total actinide extractions were to be determined.

All test results were examined as to their amenability for application to remediate each specific soil site. Evaluation and presentation of the test data is presented in a form which allows this processing technique to be compared to other decontamination methods.

3.2 Test Results:

3.2.1 General: Extractions of Pu-Am ranged from a high of 97.6% to a low of 64.5%. Extraction of uranium ranged from 97.7% to 73.8%. The remediation level (residual actinides) achieved by the most effective tests was 15 pCi/g of combined Pu and Am, and 7.8 ppm (17 pCi/g) of uranium. These results are regarded by MBX to be a clear demonstration of the efficiency and applicability of bioreduction to remediate contaminated soils of varying actinide and soil matrix compositions.

3.2.2 Sample Description: Vital data regarding soil matrix chemistry, actinide mineralogic compositions and actinide particle size were not made available for integration into the interpretation of the test results. However, reaction kinetics and efficiencies suggest that Pu-Am ratios, Pu isotope ratios, uniformity in the oxidation state of Pu, particle surface area, presence or absence of nuggets, and presence or absence of encapsulation by refractory substances (ie: silica) may have individually or in combination affected the test results. Consideration of these possible sample states will be presented, although not documented as part of the test program, in the interpretive discussion of the test results. For ease of discussion the Pu-Am test results will be discussed separately from the uranium test results.

3.2.3 Plutonium-Americium Extractions: Three of the five soil tests were performed on Pu-Am contaminated soils. Each site specific soil test is presented separately.

Rocky Flats (RFP): (Appendix A & B)
Test results indicate that inoculating RFP soil with SD-1 (Test 1) achieved the best total extraction of Pu-Am (average of 88.8% based on solutions), with the best reaction kinetics demonstrating 84.9% extraction within 6 days (See Table II). Extraction based on solids assays was 85.5%.

TABLE II: PERCENT EXTRACTION OF TOTAL ACTINIDES BY BIOREDUCTION

			% TOTAL ACTINIDES EXTRACTED*			
SOIL	**TEST**	**PARAMETER**	**DAY 2**	**DAY 4**	**DAY 6**	**FINAL**
RFP	1 A,B,C	Sterile + NTA + SD-1	62.8	79.2	84.9	**88.8**
RFP	2 A,B,C	Sterile + NTA	43.5	65.5	74.5	**86.0**
RFP	3 A,B,C	Native + NTA + SD-1	47.9	66.9	72.0	**76.7**
RFP	4 A,B,C	Native + NTA	43.8	74.9	83.7	**88.0**
LANL	1 A,B,C	Sterile + NTA + SD-1	61.8	75.8	76.1	**76.1**
LANL	2 A,B,C	Sterile + NTA	50.0	59.0	63.8	**72.5**
LANL	3 A,B,C	Native + NTA + SD-1	55.6	70.9	73.1	**74.7**
LANL	4 A,B,C	**Native + NTA**	**28.9**	58.5	67.7	**71.3**
MOUND	1 A,B,C	Sterile + NTA + SD-1	57.5	85.8	90.6	**92.1**
MOUND	2 A,B,C	Sterile + NTA	29.1	54.7	82.4	**89.3**
MOUND	3 A,B,C	Native + NTA + SD-1	63.1	89.7	93.7	**95.0**
MOUND	4 A,B,C	Native + NTA	49.0	85.0	92.1	**94.1**
HANFORD	1 A,B,C	Sterile + NTA + SD-1	20.7	34.3	56.7	**96.2**
HANFORD	2 A,B,C	Sterile + NTA	13.0	25.7	46.5	**93.8**
HANFORD	3 A,B,C	Native + NTA + SD-1	31.0	51.9	80.2	**96.9**
HANFORD	4 A,B,C	Native + NTA	25.5	48.9	74.7	**95.4**
FERNALD	1 A,B,C	Sterile + NTA + SD-1	51.8	70.4	79.3	**82.4**
FERNALD	2 A,B,C	Sterile + NTA	19.7	39.2	56.5	**95.5**
FERNALD	3 A,B,C	Native + NTA + SD-1	32.8	65.7	79.4	**82.1**
FERNALD	4 A,B,C	Native + NTA	34.3	59.2	73.1	**83.9**

*average of three replicates

BEST TEST

The second best treatment was achieved by native bacteria alone (Test 4: average extraction of 88.0% based on solutions) with average kinetics demonstrating 83.7% extraction in 6 days. Extraction based on solids was 81.5%. Although the spread between Tests 1 and 4 was close (88.8% vs. 88.0%), the overall remediation of the soil ranged from a final actinide residual of 307 pCi/g (Test 1 -SD-1) to 393 pCi/g (Test 4 - native bacteria) from an initial 2121 pCi/g total actinides.

Test results for treatments including SD-1 inoculum (Tests 1 & 3) exhibit closer agreement between assay head and calculated head determinations than do treatments without SD-1. This enhancement of test reliability was also demonstrated in LANL and Mound soils.

As was demonstrated on Mound soil, 97.6% extraction of Pu-Am is possible, but this was not achieved on RFP soil. Longer retention times with RFP soil might have reached

this level of extraction, but at the average extraction rate of 100 pCi/g/day, a 2000 pCi/g reactor charge would have to be in residence for 20 days. This suppressed extraction of RFP actinides may be due to one or a combination of the following:

1) presence of Am nuggets
2) a portion of the $Pu^{239/40}$ exists as metallic particles
3) $Pu^{239/40}$ present as large granules or aggregates of particles

The assay data (Appendix B) suggests that RFP soils contain nuggets of Americium. The R5B head sample analysis of 6.3 pCi/g of Am^{241} is less than all twelve tails assays for Tests 1 - 4. If all of the Am was present in this quantity, Test 1 results could be reduced by 25.9 pCi/g. The adjusted total extraction could have been 86.7%, an increase of 1.2%.

The basis for suggesting that the $Pu^{239/40}$ is refractory (items 2 & 3 above) is subjective. The original soil sample was screened to 100% passing 2mm (2,000 μ). This large screen size would readily allow large nuggets or aggregates of Pu to be present within the test sample, significantly biasing the sample due to the small charge size of 4 g. The triplicate test data illustrate finite levels of extraction which vary for each test (replicates A,B,C). These characteristic curves are believed to represent the break between the oxidized and uniform particle size Pu that is more easily solubilized (curve portion of graph) versus the presence of refractory Pu (flat portion of graph). The same characteristic extraction curves are illustrated in the LANL tests.

Note the RFP and LANL samples are predominantly contaminated by $Pu^{239/40}$. As shown in Table III, in both RFP and LANL soils the ratio of $Pu^{239/40}$ to Pu^{238} is high (79:1 & 466:1, respectively), whereas in Mound soil isotope 238 predominates. Greater extraction of both total actinides and of Pu $^{239/40}$ appears possible when less $Pu^{239/40}$ is present in the sample, suggesting some undetermined refractory characteristic of this isotope.

TABLE III: ISOTOPE RATION AND ACTINIDE EXTRACTION FROM TEST SOILS

Site	Isotope Ratio $Pu^{239/40}$: Pu^{238}	Average % Extraction (by Test) $Pu^{239/40}$ 1	2	3	4	Total Actinides 1	2	3	4
RFP	79 : 1	87	83	81	84	86	81	79	82
LANL	466 : 1	79	78	78	77	78	78	78	77
Mound	1 : 17	95	86	95	94	92	88	93	92

Los Alamos (LANL): (Appendix A & B)

Test results indicate that inoculating LANL soil with SD-1 (Test 1) achieved the best total extraction of Pu-Am (average of 76.1% based on solutions), with enhanced reaction kinetics demonstrating 75.8% extraction within 4 days (see Table II). Extraction based on solids assays was 78.4%.

The second best treatment was achieved by native bacteria inoculated with SD-1 (Test 3) resulting in an average extraction of 74.7% (based on solutions), with average reaction kinetics showing 73.1% extraction in 6 days. Extraction based on solids was 78.3% (see Table II).

The spread between the two best tests (76.1% vs. 74.7% extraction) correlates well with the final overall soil remediation. Residual actinide levels of 30.2 pCi/g (SD-1 in four days) and 30.5 pCi/g (natives plus SD-1 in 6 days) were achieved from an initial contaminant level of 140 pCi/g. The best reaction kinetics (4 days) was achieved through the use of the inoculum SD-1.

As indicated in the discussion of RFP soils, the data suggests that LANL soils also contain nuggets of americium (Appendix B). Note that the L3C tail sample (0.49 pCi/g) is higher than either of the duplicate americium head assays (0.27pCi/g and 0.19 pCi/g).

As with the RFP soils, the ratio of $Pu^{239/40}$:Pu^{238} is high (466:1). Although optimal actinide extraction was not reached with LANL soils, the rapid reaction kinetics (4 days) surpassed the 6 day retention required of the soils in which Pu^{238} predominates. This suggests that LANL soils, like RFP soils, contain refractory $Pu^{239/40}$ particles. The reaction curves of LANL soils suggest that high extraction levels, possibly 97.6%, were reached on the available (non-refractory portion) of the $Pu^{239/40}$, while the total actinide extraction is only 76% to 78%. This is shown by the shape of the reaction curves which dramatically maximize after 4 days. It should also be noted that each of the three replicates in Test 1 has the same characteristic reaction kinetics curve. The spread between extractions ranges from a low of 65.8% to 84.0% with an average of 76.1%. Again, this suggests that the extraction process is limited by the concentration of refractory $Pu^{239/40}$ present within a specific sample. The suspected refractory $Pu^{239/40}$ is believed to be in the form of non-oxidized metallic particles or nuggets (see L1B: Pu^{238} on RAD Data Report of Analyses Appendix B).

Mound: (Appendix A & B)

Test results indicate that inoculation of nonsterilized Mound soil with SD-1 (Test 3) achieved the best average Pu-Am extraction (95.0% based on solutions), with reaction kinetics demonstrating 93.7% extraction in 6 days (See Table I). Extraction based on solids assays was 93.3%.

The second best treatment was achieved by native bacteria alone (Test 4: average extraction of 94.1% based on solutions) with reaction kinetics showing 92.1% extraction in 6 days. Extraction based on solids was 92.2%. Test 3 replicates showed the most consistent extraction (94.2%, 95.6% and 95.2%) as compared to the second best (Test 4) which showed a wide range of extractions (96.5%, 88.2% and 97.6%). The spread between the best and second best test is only 0.9%, well within analytical error. In addition, the consistently high extractions of Test 3 and the close correlation of extraction based on solids vs solutions (93.3% vs. 95.0%) suggests that Test 3 is the most valid and effective treatment.

The RAD Data Report of Analysis (Appendix B) for Mound soil indicates one tail assay which demonstrates the presence of americium nuggets (Sample M2A). The Mound sample is predominantly comprised of Pu^{238}, which does not display any characteristics of being refractory to bioreductive treatment.

The highest extraction for any individual replicate of all tests on all soils evaluated was 97.6% (Mound Test 4C). This effectively establishes the basis for successful bioreductive treatment of Pu-Am contaminated soil.

3.2.4 Uranium Extractions: Two of the five soil tests were performed on uranium contaminated soils. Each site specific soil test is presented separately.

Hanford: (Appendix C & D)

Test results indicate that inoculating nonsterilized Hanford soil with SD-1 extracted 96.9% (based on solutions) of the uranium, with average reaction kinetics demonstrating 96.9% in 17 days.

The second best treatment was Test 1 (SD-1 inoculated in sterile soil), resulting in an extraction of 96.2% in 17 days. The residual uranium in the samples after

remediation averaged 12.2 ppm (26.1 pCi/g) for Test 3 and 13.3 ppm (28.5 pCi/g) for Test 1.

The best single test, achieving 97.7% extraction of uranium, was H2B (sterile soil plus 0.05M NTA). The data suggest that accelerated extraction of uranium in this treatment occurred after day 4, when biological contamination of the test samples was observed. The autoclave used for ore sterilization proved to be inadequate as demonstrated by the re-appearance of native bacteria (see Appendix C, E & G). However, the total extraction after 17 days was 97.6%, leaving a residual uranium content of 37.2 ppm. Partial sample sterilization may have future application for sample pretreatment processing as discussed in section 4.2. Reaction kinetics curves for all biocontaminated NTA tests (Hanford 2A,B,C & Fernald 2A,B,C) indicate that slow extractions through day 4 were followed by a slightly accelerated extraction at the date that biocontamination was recognizable (see break in curves, Tests 2B & 2C, Appendix C). The accelerated extraction is believed to be due to the chelation by NTA of some unknown constituent present within the Hanford soil sample, which was inhibitory to the extraction synergism between the rapidly growing native bacterial populations and the NTA. This phenomenon was also observed in the Fernald tests, but to a much more pronounced degree. A second explanation, which may apply to the Hanford soils, for the Test 2 reaction kinetics is presented in the discussion of the Fernald Test results.

Fernald: (Appendix C & D)

Test results indicate that treatment of sterilized Fernald soil with NTA (Test 2) was the most effective, resulting in 95.5% extraction of uranium by day 17. No other treatment in this series compares to Test 2. All others achieved ≤90% extraction, with reactions kinetics stabilizing after day 9.

Test 2 shows a unique reaction kinetics curve which demonstrates that excellent extraction began after day 4, along with biological contamination. The extraction curve shows continuing extraction at day 17. Pretreatment of sterile soil with NTA may chelate a soil component that is either inhibitory to the bacteria or that diminishes the carrying capacity of the available NTA. By complexing this inhibitor before the bacteria begin to solubilize the uranium, a more favorable bioreductive environment may become established which could result in more efficient uranium extractions (94% - 96%). Analysis of the sample as to soil matrix,

chemistry, particle size and uranium mineralogy will be necessary in order to address this issue. Bioreductive efficiency may also be enhanced if the NTA concentration is increased to 0.1M. This will also increase the holding capacity of the leachate. SD-1 can tolerate this higher concentration [8] whereas many native bacteria cannot.

Without access to the baseline soil matrix data, one can only speculate as to the nature of the observed reaction inhibitor. However, based on the Test 2 reaction curves a case is established for an increase in NTA concentration or pretreatment of the soil prior to contacting with an inoculum. Pretreating with more concentrated NTA may complex the inhibitor, but at the same time prove toxic to bacteria. Proper balancing of NTA concentration and inoculum is predicted to improve uranium reaction kinetics.

3.2.5 Biological and Chelator Test Parameters: Four comparative tests, conducted in triplicate, were designed to collect data which could be correlated and compared as to the contribution of each test parameter to the efficiency of the process (Appendix E).

Discussion: The purpose of knowing the relative contribution of each test parameter to the total process was to determine which parameter(s) could be manipulated to enhance the process efficiencies should the test results not achieve the desired extractions. Sterilization of the soil eliminates contributing or hindering effects of the indigenous or native bacteria. The method of sterilization chosen for this study was autoclaving. Unfortunately, the degree of sterilization achieved by the sub-standard autoclave available at the test laboratory only provided a partial kill of the native bacteria. Other methods of sterilization, such as those utilizing chemical treatments, were not considered due to the undesirable effect of modifying the test soil matrix. The test parameters investigated were: 1) pure inoculum (sterile soil plus SD-1 + NTA), 2) pure chelator (0.05M NTA) addition to sterile soil, 3) inoculum addition to native bacteria (SD-1 plus non-sterile soil + NTA), and 4) native bacteria alone (non-sterile soil + NTA). As discussed in the previous section 3.2 and compiled in the Appendix A, process efficiencies proved to be very close in their overall total actinide extractions. Variations were noticeable in reaction kinetics and indicated a potential need for preconditioning of certain Pu-Am and uranium contaminated soils. Preconditioning could prove advantageous, since complete sterilization cannot practically be achieved

under field conditions. Partial sterilization by soil preconditioning could result in essentially the same conditions achieved in the tests of this reporting.

Evaluation: Table II illustrates the relative contribution of the process components. For the RFP and LANL soils, SD-1 extracted the most contaminants with the best reaction kinetics. The Mound and Hanford soils were best remediated with native bacteria plus SD-1. Lack of quantification and identification of native bacterial types hinders exact interpretation of the test results, but clearly SD-1 with or without native organisms provides the best remediation treatment. Since complete sterilization and thereby prevention of native organisms from entering into the sterile soil tests was not achieved, hence, one may conclude that there is little or no difference between Tests 1 or 3. However, partial sterilization through sample preconditioning is the process likely to be utilized in the applied field remediation. Maintaining SD-1 inoculum in populations greater than native populations should yield the best process efficiencies (Appendix E). Inoculum of SD-1 can be provided by an inoculum bioreactor supplemental to the process bioreactors.

The best treatment for Fernald uranium remediation was NTA addition to sterile soil (Test 2). The total extraction of 95.5% required 17 days. The best initial reaction kinetics were achieved by addition of SD-1 to sterile soil (Test 1). Why Tests 1,3, and 4 were limited as to total extraction is not known at this reporting. It is possible that biological toxicity may have restricted these reactions. As discussed in other sections of this report, soil preconditioning with a higher concentration of NTA, followed by an SD-1 inoculated bioleach may enhance both reaction kinetics as well as total actinide extraction.

Test result statistics (Section 3.3) further demonstrate greater reproducibility and consistency for those tests utilizing SD-1 as an inoculum.

3.3 Statistical Analysis of Test Results: (Appendix F)
The data were analyzed by single factor analysis of variance (ANOVA) to determine if differences noted among the replicate means of the various tests were significant at the 95% confidence level ($p<0.05$). Further analysis to investigate potentially significant differences among the means was carried out by the T-Method. This provided for calculation of minimum significant differences among the means and allowed graphical representation of the means comparisons. Generally, any differences noted were most pronounced during the first 4

- 6 days of testing. Samples taken after this period showed little difference between the five tests. Contamination of the tests in the laboratory may account for this. Contamination, as indicated by bacterial growth in the sterile soil tests, was generally noted after the fourth day of testing. Based on these observations, initial rates of actinide solubilization were determined by regression analysis of the percent extracted from day 0 - 4. Subsequent sample points were not used for this analysis.

3.3.1 **ROCKY FLATS** - Results and Discussion: Analysis of variance showed no significant difference among the tests after two days of incubation. T-Method analysis showed that there was a slightly higher extraction for the SD-1 + NTA treatment (Test 1). This difference was significant at the 0.14 level (86%). Initial rates of actinide extraction calculated over the first four days showed that SD-1 extracted 22% per day whereas the second best treatment, native organisms (Test 4), extracted 19.4% per day.

3.3.2 **LOS ALAMOS** - Results and Discussion: Analysis of variance showed a significant difference between the tests ($p<0.05$) after two days. The difference was explained by a significantly lower extraction from soil treated with native organisms + NTA (Test 4). This difference became less pronounced with increasing incubation time and was gone entirely after 17 days. Once again, T-Method analysis showed that there was a slightly higher extraction for the SD-1 + NTA treatment (Test 1) over the next best treatment, SD-1 + native organisms + NTA (Test 3). Initial rates of actinide extraction calculated over the first four days showed that SD-1 extracted 21.3% per day whereas the second best treatment, Test 3, extracted 19.7% per day.

3.3.3 **MOUND** - Results and Discussion: Analysis of variance showed a very significant difference between the tests ($F=8.4$, $F_{CRIT}=4.1$, $p<0.05$) after two days. The difference was explained by a significantly lower extraction from soil treated with NTA only (Test 2). T-Method analysis showed that treatment with SD-1, either alone or in combination with native organisms led to higher extraction of actinides than did treatment with native bacteria or NTA alone. Initial rates of actinide extraction calculated over the first four days showed that SD-1 extracted 22.9% per day whereas SD-1 + native organisms extracted 24.2% per day. Native organisms (Test 4) and NTA (Test 2) extracted 21.9% and 13.8% per day, respectively.

3.3.4 **HANFORD** - Results and Discussion: There was a significant difference between the tests after two days. Actinide extraction by SD-1 + native organisms was significantly higher than extraction by NTA only. Although not significant, extraction by SD-1 alone and native organisms alone was lower than for SD-1 + native organisms. Initial extraction rates over the first four days showed that SD-1 + native organisms extracted 13.5% per day, natives only extracted 12.3% per day and SD-1 extracted 8.9% per day.

3.3.5 **FERNALD** - Results and Discussion: Analysis of variance showed a highly significant difference between the tests ($F=56.4$, $F_{CRIT}=4.1$, $p<0.05$) after two days. T-Method analysis showed that extraction of uranium by SD-1 alone (Test 1) was significantly higher than any other treatment. There was not a significant difference between extraction by native and SD-1 + native organisms alone but these were, in turn, significantly higher than NTA alone. Initial rates of uranium extraction calculated over the first four days showed that SD-1 extracted 19.3% per day whereas native organisms and SD-1 + native organisms extracted 15.3% and 16.4% per day respectively.

Additionally, ANOVA demonstrated a significant difference between the tests in this series after 17 days incubation ($F=4.3$, $F_{CRIT}=4.1$, $p<0.05$). T-Method analysis showed that this difference was due to significantly higher uranium extraction by the soil treated with NTA alone whereas there was no difference among the remaining tests. This, along with the observations presented in section 3.2.4, supports the idea that pretreatment with NTA could enhance bioreductive solubilization of uranium by complexing some inhibitory substance present in the soil. Speculating about the identity of this substance without more extensive information regarding the chemical composition of the soil and the uranium contaminants would be fruitless at this point.

4.0 PROCESS COMPONENTS EVALUATION

The process amenability tests have demonstrated high levels of extraction at reasonable to unacceptable retention times (4 - 17 days). The process extracted Pu, Am, and uranium from all five test samples.

4.1 Process Components-General: A basic bioreduction process system would be comprised of the following:

1) Soil receiving hopper
2) Screen deck - wet or dry (to be determined)

3) Three stage bioreactor section, with separate inoculum bioreactor
4) Multi stage thickener section
5) Ion-exchange or similar pregnant leach solution strip unit
6) Fresh water pond, pregnant pond, barren solution pond, re-cycle and storage pond
7) Lined tailings disposal site if tails require plant sequestering remediation

The method of screening the soil (item 2) will affect the other process components. If the soil can be wet screened then native bacteria can be utilized in the reactor section. If heat drying is required to screen the soil, then an inoculum bioreactor will be required (item 3). Most of the preferred test results favored inoculation with SD-1, so this process component would be an integral part of the reactor section. The number of stages comprising the reactor section (item 3) must be determined by particle retention time. Bioreductive leaching must deal with leachate toxicity problems, hence a graduated volume bioreactor cell configuration [7] should be considered. This configuration for 72 hour resident processing would consist of a conditioning cell, a leach cell and a polishing cell.

Should extended retention time be required, the design of the thickener section (item 4) could accommodate additional retention. Generally, a single primary thickener would provide the required liquid-solid separation capacity. The liquid or pregnant leach solution (PLS) would report to the strip section, while the dewatered thickener tails would report to a second wash thickener. Wash solutions and dewatered tails from this last stage, wash thickener, would comprise the major components of the process system.

4.1.1 Process Reagent Components: The main process additives consist of: inoculation bacteria, chelators, and biological growth media. Each of these process reagents should be optimized in Process Simulation testing (see Section 5.1.1).

Reducing Bacteria: The majority of the test results indicate that utilization of the MBX inoculum SD-1 provides the most efficient, consistent, and most reproducible test results. Other process reagents which can increase the process efficiencies are looked to for improvement and modification of the process system.

Chelators: The chelator NTA, which was utilized for all tests, requires careful handling due to the following characteristics: 1) NTA used in concentrations greater than 0.1M can be toxic to process bacteria (NTA

tolerances[8] are known for SD-1), and 2) NTA is an expensive chelator, hence efficient use should be evaluated. Recycling of process solutions and regeneration of NTA by pH adjustment precipitation would affect costs.

Biological Growth Media: The growth media used for all tests was Tryptic Soy Broth (TSB), a common laboratory growth media. Use of this media in a multi thousand gallon field reactor system would be costly and unnecessary. PX100™[4] is a substitute commercial growth media. This product is deliverable in 5,000 gal. tanker lots and can be specifically formulated for a particular bioreductive system [9]. Optimal formulation and use concentrations can be determined during Process Simulation testing.

4.2 Process System Modifications: The five soil program tested the amenability of the bioreductive process for treatment of different soils containing varying actinide contaminants. Soils of high $Pu^{239/40}$ may require pretreatment to counter the suspected refractory nature of this actinide, as demonstrated with RFP and LANL soils. The extraction inhibitor present in the uranium contaminated samples (Fernald and Hanford) may also require a pretreatment modification of the soil charge as part of the applied treatment system. All of the treatments may need to include tailings remediation should closure standards not be achieved through primary processing.

4.2.1 Pretreatment: Suggested pretreatment methods to maximize extraction efficiencies include an initial NTA leaching to complex a suspected inhibitor in uranium contaminated soils, and an oxidizing conditioning of $Pu^{239/40}$ content soils in order to oxidize possible metallic Pu particles. Each of these preconditioning procedures will have to be carefully tested to avoid potentially unfavorable conditions for second stage bioreductive processing.

Preconditioning with increased concentrations of NTA could result in high levels of NTA being sent to, and accumulating in, the first stage bioreactor, resulting in potentially toxic conditions for the inoculum as well as native bacteria. The preconditioning of the suspected refractory Pu contaminated soils with strong oxidants could have a similar effect. These preconditioning systems can be designed to be effective and in balance with the total process by thorough testing.

4.2.2 Tailings Remediation: Remediated soils from this test program had residual Pu-Am levels in the test

tailings ranging from 15 pCi/g to 559 pCi/g (RFP, LANL, and Mound), and residual uranium levels of 58 ppm (124.1 pCi/g) to 8 ppm (17.1 pCi/g) as found in Hanford and Fernald soils. Although these limits are the result of first phase testing, they suggest that a field process system might have difficulty in reaching allowable closure limits. At this writing it is not known what residual limits of contaminants would be allowed. A proposed tailings remediation system is briefly presented in order to address the issue of optimum remediation.

Condition of Leached Tails: Bioreductively leached soils will be minimally affected as to their original contained nutrients. The pH of the leach system is near neutral, and the addition of the PX100™, an organic carbon source, as well as the biological processes operative within the bioleach system will add nutrients and thereby enhance and support vegetation of the leached tailings.

Actinide Sequestering by Plants: The ability of specific plants to sequester actinides has long been recognized. Early uranium and vanadium prospectors sought out dense growth of rattle weed as an indicator of these ore minerals. Actinide sequestering by re-vegetation of impounded tailings is offered as a second stage of remediation. The harvested plants could be incinerated, and the resulting ash recycled back into the bioreactor section. Should incineration not be an option due to possible emissions of the airborne contaminants, then recycling of ground plant material directly into the bioreactor section should be considered. Either of these two systems will provide secondary recovery and capture of the residual tailing contaminants. Plant selection will depend on many factors including response to specific soil type and site climatic conditions.

5.0 RECOMMENDATIONS

All five soil tests demonstrate the efficiency of bioreduction as a remediation process for the removal of actinides from contaminated soils. Initial levels of soil contamination, type, residual concentrations, and soil sites are illustrated in Table IV below:

TABLE IV: RESIDUAL ACTINIDES AND SUGGESTED REMEDIATION METHOD

SITE	ACTINIDE TYPE	CONTAMINATION INITIAL - RESIDUAL	BIOREDUCTIVE PROCESS
RFP	$Pu^{239/40}$	2121-307 pCi/g	SD-1
LANL	$Pu^{239/40}$	140-30 pCi/g	SD-1
MOUND	Pu^{238}	511-34 pCi/g	Native + SD-1
HANFORD	Uranium	693-12 ppm (26pCi/g)	Native + SD-1
FERNALD	Uranium	408-10 ppm (21pCi/g)	NTA + Native

Preconditioning of soil combined with residual contaminant sequestering by plants and secondary bioreductive processing could greatly lower or eliminate residual actinide levels.

5.1 Phase II - Process Development Testing:

5.1.1 Laboratory: Process Simulation studies to be conducted in 2 liter bioreactors on 300g soil samples.

5.1.2 Location: To be conducted at the remediation site in order to facilitate materials handling.

Test Equipment:
1) 2 liter bioreactors modified to MBX specifications
2) SD-1 inoculum and PX100™ growth media to be provided by MBX
3) Bioreactors remain at site of remediation (expendables)

Process Parameters to be Evaluated:
1) Preconditioning of $Pu^{239/40}$ and uranium rich soils (effects and retention times)
2) Retention time, NTA concentration, pulp density, growth media concentration, and reaction kinetics to be determined. Required thickener retention times can be determined from 2 liter bioreactor data

Test Procedure:
1) MBX graduated volume bioleaching: This processing simulates continuous flow-through processing as would be utilized in full scale operations. This process also allows for minimum materials handling

by technicians and minimizes build-up of biologically toxic factors in the leachate.

2) Analytical balances would be maintained on solutions from preconditioning and primary leach cells to thickener treatment. Heads and tails analyses of solids would provide the basis for final metallurgical balances, as well as for the evaluation of plant sequestering of residuals from tails as a final remediation component.

5.2 Phase III - Process Development - Final Design:

5.2.1 Evaluation: Results of the above testing (2 liter - 300g), will be evaluated in order to design a 100kg third stage test as outlined above.

The 100kg test program will simulate Pilot or Full Scale Field Operations. Process components to be evaluated in the 100kg test are as follows:

1) Soil process screening
   a) wet
   b) dry
   c) screen type
2) Preconditioning materials handling
   a) agitation conditioning and slurry transport to primary reactor section
   b) retention time and solution management studies
3) Primary bioreductive treatment in three stage, graduated volume reactors
   a) retention time, pulp density
   b) slurry flow, solution management
   c) chelator management
      1) recycle
      2) consumption
   d) inoculum bioreactor
      1) growth rates
      2) recycle
4) Primary Thickener
   a) efficiency
   b) retention
   c) decantation of PLS
   d) solution recycle
   e) solids management
5) Wash Thickener
   a) Steps 1 - 5 above
6) Strip Processor
   a) selection
   b) efficiency testing
   c) solution recycling
   d) quality control
   e) solution and solids evaluation

7) Tailings
   a) evaluation (pass-fail)
   b) low level remediation by plant sequestering
   c) recycle through bioreductive reactor-thickener

5.3 APPROXIMATE TIMETABLE:

5.3.1 Phase II - Laboratory:

6 weeks: Per Test Sample (exclusive of sample acquisition, sample preparation, and solution and solids assaying)

5.3.2 Phase III - Pilot Testing:

9 months: Final Process Development (100kg) (exclusive of sample acquisition, sample preparation and assaying)
Detailed test designs, schedules, timetables and costs are available upon client request and the submittal of full test material identification and description.

6.0 REFERENCES

1) Rusin,, P., Sharp, J., Arnold, R., Sinclair, N.A., and Young, T. 1992. Enhanced recovery of silver and other metals from refractory oxide ores through bioreduction. Mining Engineering. 44:1467-1471.

2) Rusin, P., Quintana, L., Brainard, J., et al., 1994. Solubilization of plutonium hydrous oxide by iron-reducing bacteria. Envir. Sci. & Tech, v. 28.

3) Patent 5,221,327. "Biological Processes for Recovering Heavy Metals". Rusin, P.A., Issued June 22, 1993.

4) Patent 5,248,329. "Biological Processes for Recovering Heavy Metals". Rusin, P.A., Sharp, J.E., Issued Sept. 28, 1993.

5) Patent Pending

6) Microbial Extraction of Americium and Plutonium from Rocky Flats Soil. 1993. MBX Technical Report to: Lockheed Environmental, Rocky Flats, CO.

7) Co-Ni-Cr Bioreductive - Acid leach Amenability Testing. 1994. MBX Technical Report.

8) SD-1 Tolerance to NTA. 1992. MBX Technical Report.

9) AIME, Dec. 1994 - MBX Open File Report

APPENDIX A – 1

ROCKY FLATS SOIL, TEST 1, IN TRIPLICATE (A,B,C)

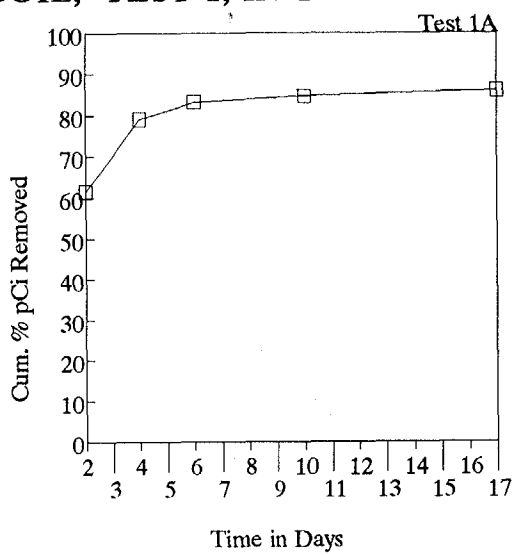
Pu–Am

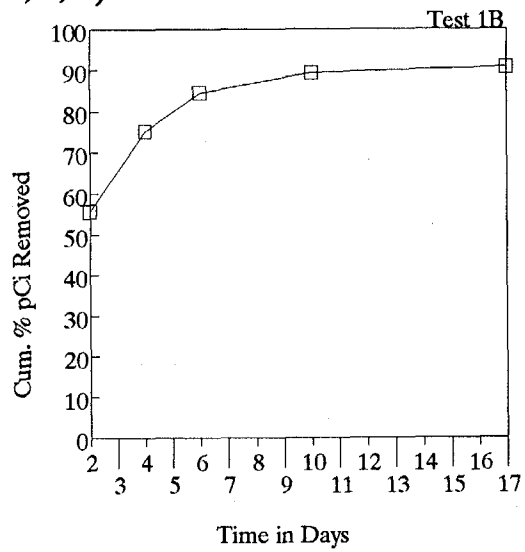
Test Standards for A,B,C

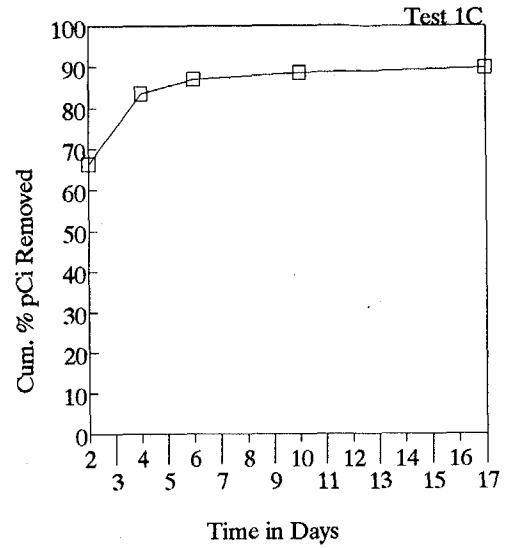
1) Sterile Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1

Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 + Native Orgs.
Test 4: Native Soil + NTA + Native Orgs.







TEST #1

A Gross Wt: 16.109 Tare Wt: 11.915 Net Wt: 4.194 Total Possible: 11897.820 Tails: 1663.15 Calc. Head: 11897.8

B Gross: 16.122 Tare: 11.978 Net: 4.144 Total Possible: 12217.210 Tails: 1131.01 Calc. Head: 12217.2

C Gross: 16.037 Tare: 11.943 Net: 4.094 Total Possible: 8762.73 Tails: 896.79 Calc. Head: 8,762.73

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng in Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
Sterile Soil + NTA + SD–1	09/30/94	0																								
	10/02/94	2	6.2	40	183.06	7.32	7322.40	7322.40	61.5	61.5		40	170.0	6.80	6800.00	6800.00	55.7	55.7		42	138.4	5.81	5814.48	5814.48	66.4	66.4
	10/04/94	4		41	50.80	2.08	2082.80	9405.20	17.5	79.0	5.9	40	59.7	2.39	2388.00	9188.00	19.5	75.2		41	36.6	1.50	1500.60	7315.08	17.1	83.5
	10/06/94	6		41	12.21	0.50	500.61	9905.81	4.2	83.3	6.3	41	27.7	1.14	1137.34	10325.34	9.3	84.5	6.4	40	7.7	0.31	306.80	7621.88	3.5	87.0
	10/10/94	10		43	4.02	0.17	172.86	10078.67	1.5	84.7		42	14.0	0.59	589.26	10914.60	4.8	89.3		42	3.2	0.13	133.56	7755.44	1.5	88.5
	10/17/94	17		78	2.00	0.16	156.00	10234.67	1.3	86.0		78	2.2	0.17	171.60	11086.20	1.4	90.7		65	1.7	0.11	110.50	7865.94	1.3	89.8

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
413.0 pCi/g	279.4 pCi/g	227.9 pCi/g	306.8 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	86.0 %	90.7 %	89.8 %	88.8 %
Basis: Assay Head (Solids)				85.5 %

APPENDIX A – 2

ROCKY FLATS SOIL, TEST 2, IN TRIPLICATE (A,B,C)

Pu–Am

Test Standards for A,B,C

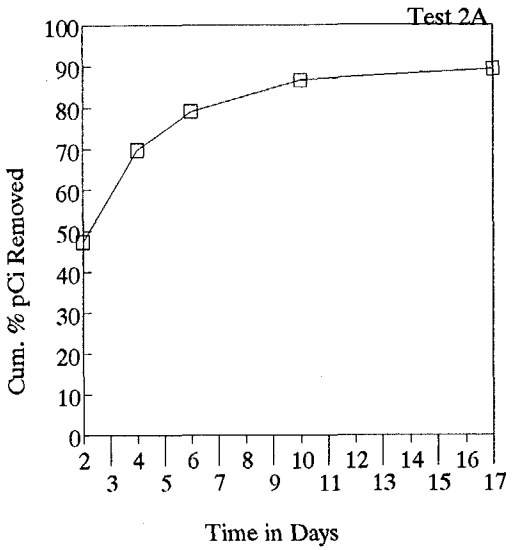
1) Sterile Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
8) 17–day retention
9) 26°C temp.

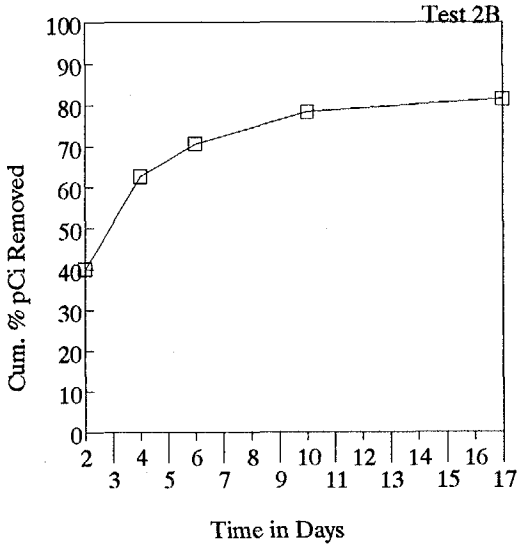
Test 1: Sterile Soil + NTA + SD–1

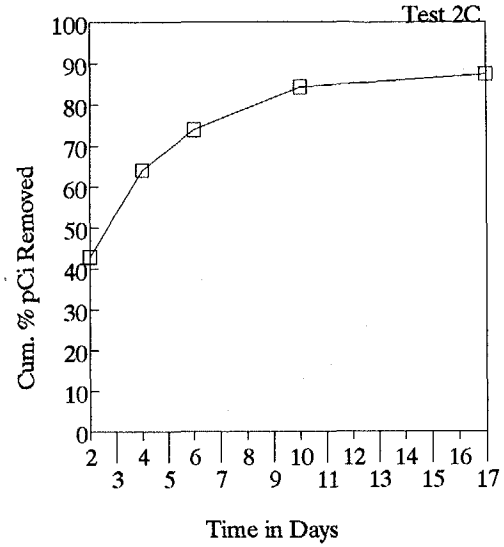
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #2

A Gross Wt: 16.018 Tare Wt: 11.912 Net Wt: 4.106 Total Possible: 10317.590 Tails: 1106.28 Calc. Head: 10317.5

B Gross Wt: 15.934 Tare Wt: 11.872 Net Wt: 4.062 Total Possible: 11865.480 Tails: 2205.15 Calc. Head 11865.4

C Gross Wt: 16.125 Tare Wt: 11.948 Net Wt: 4.177 Total Possible: 11574.020 Tails: 1461.39 Calc. Head: 11574.0

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
Sterile Soil + NTA	09/30/94	0																								
	10/02/94	2		42	116.65	4.90	4899.30	4899.30	47.5	47.5		40	118.98	4.76	4759.20	4759.20	40.1	40.1		41	121.4	4.98	4975.76	4975.76	43.0	43.0
	10/04/94	4		42	54.80	2.30	2301.60	7200.90	22.3	69.8		42	63.66	2.67	2673.72	7432.92	22.5	62.6		42	58.2	2.44	2443.56	7419.32	21.1	64.1
	10/06/94	6		40	23.95	0.96	958.00	8158.90	9.3	79.1		41	23.05	0.95	945.05	8377.97	8.0	70.6		41	27.7	1.14	1137.34	8556.66	9.8	73.9
	10/10/94	10		41	19.01	0.78	779.41	8938.31	7.6	86.6		42	21.83	0.92	916.86	9294.83	7.7	78.3		41	29.2	1.20	1195.97	9752.63	10.3	84.3
	10/17/94	17		91	3.00	0.27	273.00	9211.31	2.6	89.3		85	4.30	0.37	365.50	9660.33	3.1	81.4		80	4.5	0.36	360.00	10112.63	3.1	87.4

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
280.0 pCi/g	559.4 pCi/g	364.8 pCi/g	401.4 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	89.3 %	81.4 %	87.4 %	86.0 %
Basis: Assay Head (Solids)				81.1 %

APPENDIX A – 3

ROCKY FLATS SOIL, TEST 3, IN TRIPLICATE (A,B,C)

Pu–Am

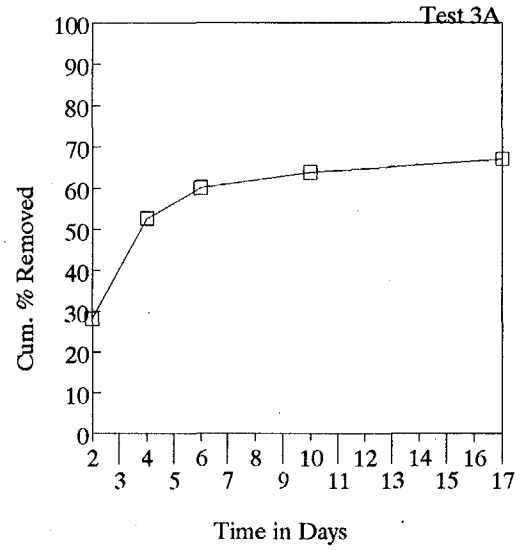
Test Standards for A,B,C

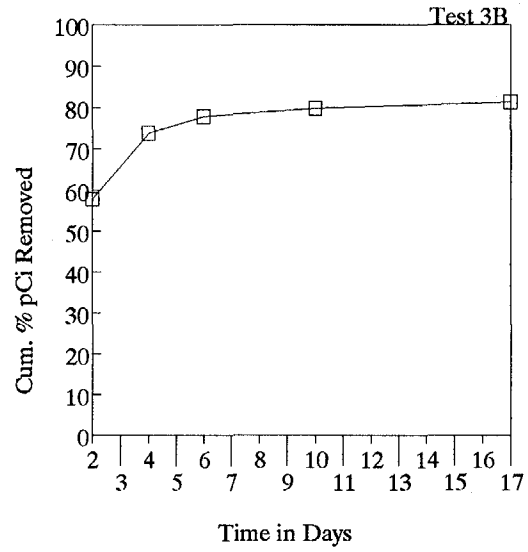
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
8) 17–day retention
9) 26°C temp.

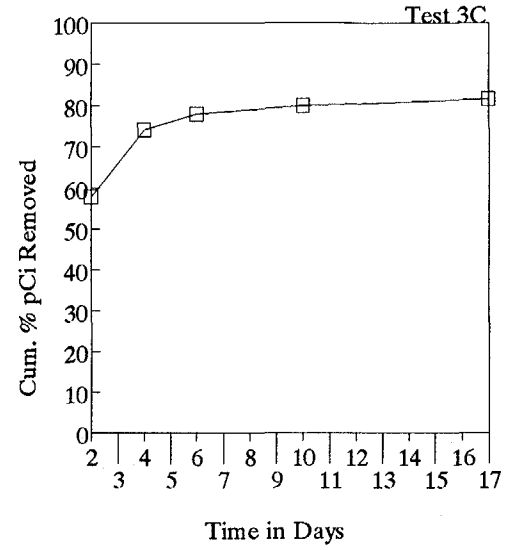
Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #3

A Gross Wt: 15.895 Tare Wt: 11.824 Net Wt: 4.071 Total Possible: 3910.930 Tails: 1285.16 Calc. Head: 3910.93

B Gross Wt: 15.938 Tare Wt: 11.835 Net Wt: 4.103 Total Possible: 11484.160 Tails: 2134.27 Calc. Head 11484.1

C Gross Wt: 16.129 Tare Wt: 11.948 Net Wt: 4.181 Total Possible: 10579.240 Tails: 1940.29 Calc. Head: 10579.2

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
Native Soil	09/30/94	0																								
+ NTA	10/02/94	2		42	26.19	1.10	1099.98	1099.98	28.1	28.1		42	158.0	6.63	6633.90	6633.90	57.8	57.8		41	149.3	6.12	6121.30	6121.30	57.9	57.9
+ SD–1	10/04/94	4	6.3	39	24.61	0.96	959.79	2059.77	24.5	52.7	6.3	40	46.3	1.85	1850.80	8484.70	16.1	73.9	6.3	40	43.2	1.73	1726.80	7848.10	16.3	74.2
+ Native Orgs.	10/06/94	6	6.3	40	7.30	0.29	292.00	2351.77	7.5	60.1	6.4	40	11.5	0.46	458.40	8943.10	4.0	77.9	6.5	41	9.9	0.41	407.13	8255.23	3.8	78.0
	10/10/94	10		40	3.62	0.14	144.80	2496.57	3.7	63.8		41	5.5	0.23	225.09	9168.19	2.0	79.8		41	5.1	0.21	209.92	8465.15	2.0	80.0
	10/17/94	17		76	1.70	0.13	129.20	2625.77	3.3	67.1		79	2.3	0.18	181.70	9349.89	1.6	81.4		79	2.2	0.17	173.80	8638.95	1.6	81.7

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
324.7 pCi/g	526.2 pCi/g	488.0 pCi/g	446.3 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	67.1 %	81.4 %	81.7 %	76.7 %
Basis: Assay Head (Solids)				78.9 %

APPENDIX A – 4

ROCKY FLATS SOIL, TEST 4, IN TRIPLICATE (A,B,C)

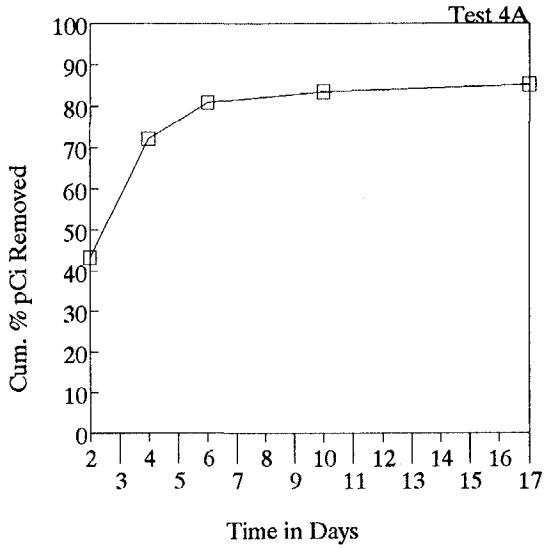
Pu–Am

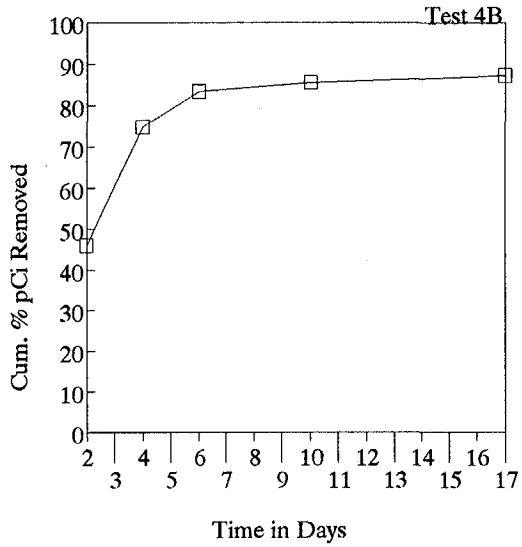
Test Standards for A,B,C

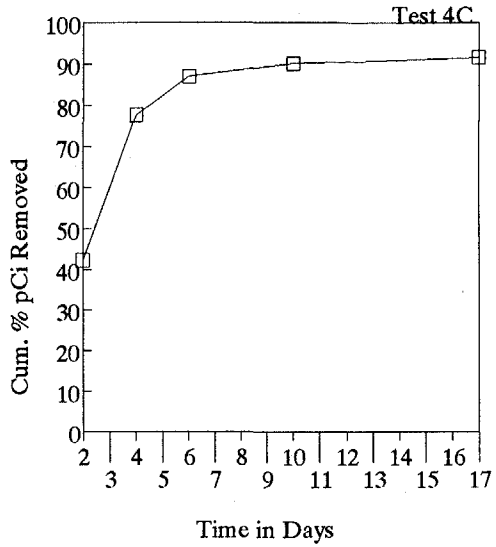
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #4

A Gross Wt: 16.153 | Tare Wt: 11.95 | Net Wt: 4.203 | Total Possible: 11339.580 | Tails: 1676.58 | Calc. Head: 11339.5

B Gross Wt: 15.959 | Tare Wt: 11.924 | Net Wt: 4.035 | Total Possible: 14515.400 | Tails: 1855.88 | Calc. Head 14515.4

C Gross Wt: 16.074 | Tare Wt: 11.92 | Net Wt: 4.154 | Total Possible: 13720.690 | Tails: 1153.32 | Calc. Head: 13720.6

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
	09/30/94	0																								
Native Soil	10/02/94	2		42	116.50	4.89	4893.00	4893.00	43.1	43.1		41	162.8	6.67	6674.80	6674.80	46.0	46.0		41	141.3	5.79	5792.07	5792.07	42.2	42.2
+ NTA	10/04/94	4		40	81.97	3.28	3278.80	8171.80	28.9	72.1		40	104.7	4.19	4186.00	10860.80	28.8	74.8		40	121.8	4.87	4871.60	10663.67	35.5	77.7
+ Native Orgs.	10/06/94	6		40	24.89	1.00	995.60	9167.40	8.8	80.8		40	31.1	1.25	1245.60	12106.40	8.6	83.4		40	31.8	1.27	1273.60	11937.27	9.3	87.0
	10/10/94	10		42	7.20	0.30	302.40	9469.80	2.7	83.5		41	7.7	0.32	316.52	12422.92	2.2	85.6		42	10.1	0.42	422.10	12359.37	3.1	90.1
	10/17/94	17		92	2.10	0.19	193.20	9663.00	1.7	85.2		91	2.6	0.24	236.60	12659.52	1.6	87.2		80	2.6	0.21	208.00	12567.37	1.5	91.6

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
415.2 pCi/g	476.6 pCi/g	285.9 pCi/g	392.6 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	85.2 %	87.2 %	91.6 %	88.0 %
Basis: Assay Head (Solids)				81.5 %

APPENDIX A – 5

LANL SOIL, TEST 1, IN TRIPLICATE (A,B,C)

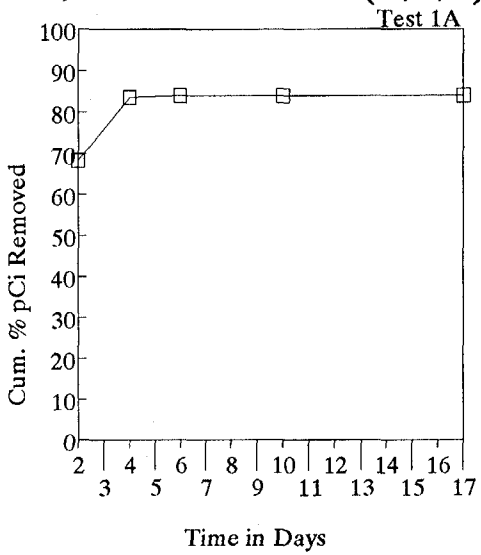
Pu–Am

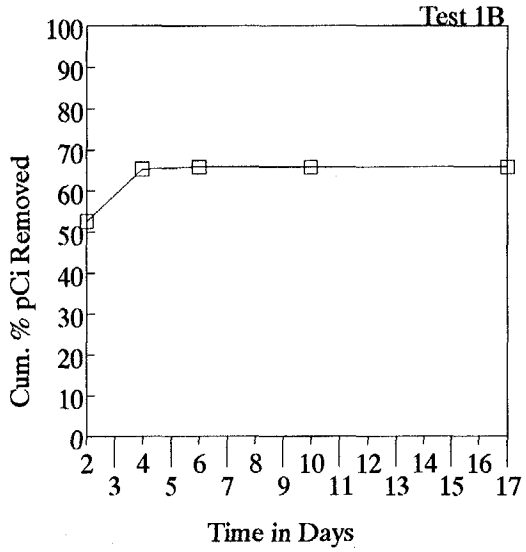
Test Standards for A, B, C

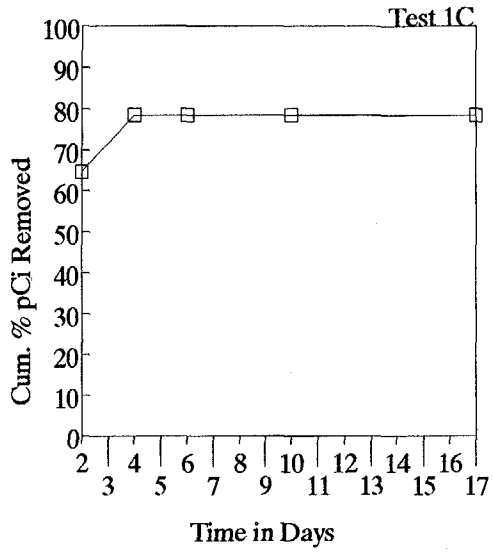
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1

Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 + Native Orgs.
Test 4: Native Soil + NTA + Native Orgs.







TEST #1

A Gross Wt: 16.050 Tare Wt: 11.902 Net Wt: 4.148 Total Possible: 438.475 Tails: 70.350 Calc. Head: 438.475

B Gross Wt: 16.088 Tare Wt: 11.908 Net Wt: 4.180 Total Possible: 557.286 Tails: 190.320 Calc. Head: 557.286

C Gross Wt: 15.883 Tare Wt: 11.849 Net Wt: 4.034 Total Possible: 474.380 Tails: 102.180 Calc. Head: 474.380

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
	09/30/94	0																								
	10/02/94	2		42	7.12	0.30	299.04	299.04	68.2	68.2		41	7.2	0.29	293.56	293.56	52.7	52.7		42	7.3	0.31	306.60	306.60	64.6	64.6
Sterile Soil	10/04/94	4	5.5	41	1.64	0.07	67.24	366.28	15.3	83.5	5.4	41	1.7	0.07	70.52	364.08	12.7	65.3	5.4	41	1.6	0.07	65.60	372.20	13.8	78.5
+ NTA	10/06/94	6	5.9	41	0.05	0.00	1.85	368.13	0.4	84.0	6.2	39	0.1	0.00	2.89	366.97	0.5	65.8	5.9	41	0.0		0.00	372.20	0.0	78.5
+ SD–1	10/10/94	10		42	0.00		0.00	368.13	0.0	84.0		38	0.0		0.00	366.97	0.0	65.8		42	0.0		0.00	372.20	0.0	78.5
	10/17/94	17		78	0.00		0.00	368.13	0.0	84.0		79	0.0		0.00	366.97	0.0	65.8		77	0.0		0.00	372.20	0.0	78.5

CALCULATIONS: pCi in Soln. = pCi/ml x Solution Vol. Removed
Calculated Head = Sum of pCi in Solution + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
17.3 pCi/g	48.7 pCi/g	25.4 pCi/g	30.5 pCi/g

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	84.0 %	65.8 %	78.5 %	76.1 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	78.4 %

APPENDIX A – 6

LANL SOIL, TEST 2, IN TRIPLICATE (A,B,C)

Pu–Am

Test Standards for A, B, C

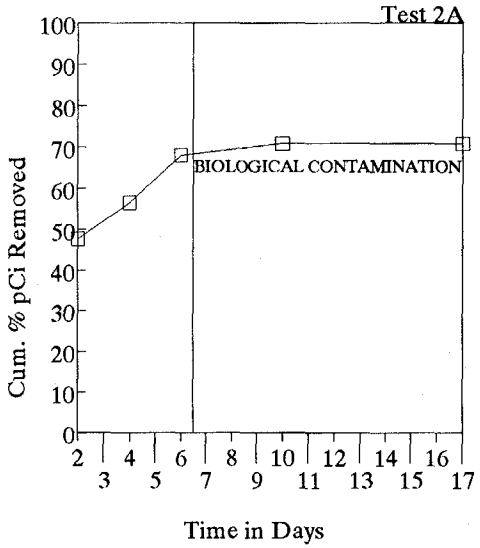
1) Sterile soil, 4g
2) Pulp ~ 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

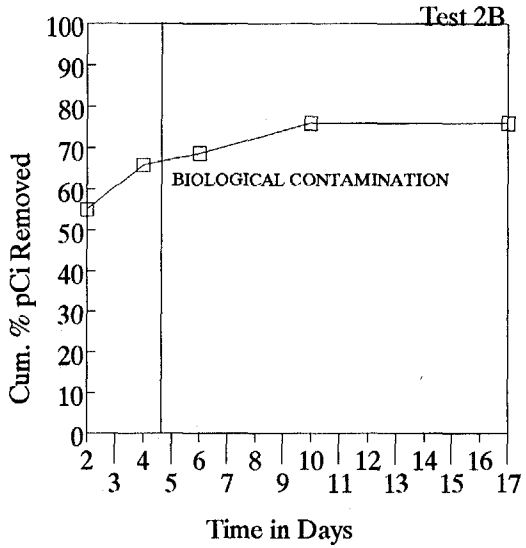
Test 1: Sterile Soil + NTA + SD–1

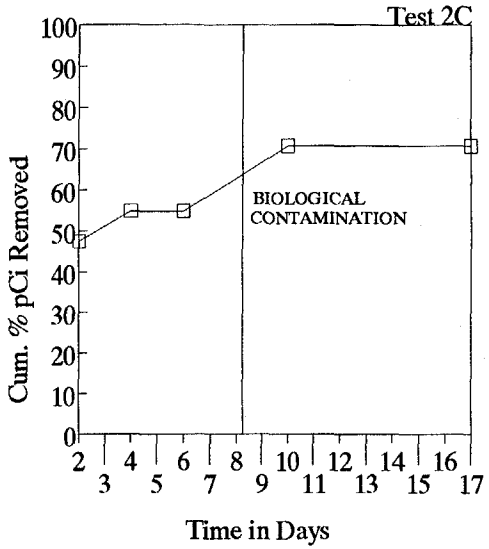
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #2

A Gross Wt: 16.054 | Tare Wt: 11.908 | Net Wt: 4.146 | Total Possible: 439.160 | Tails: 128.100 | Calc. Head: 439.160

B Gross Wt: 16.026 | Tare Wt: 11.891 | Net Wt: 4.135 | Total Possible: 408.209 | Tails: 98.160 | Calc. Head: 408.209

C Gross Wt: 16.023 | Tare Wt: 11.888 | Net Wt: 4.135 | Total Possible: 523.994 | Tails: 153.290 | Calc. Head: 523.994

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
	09/30/94	0																								
	10/02/94	2		40	5.23	0.21	209.20	209.20	47.6	47.6		41	5.47	0.22	224.27	224.27	54.9	54.9		41	6.1	0.25	248.46	248.46	47.4	47.4
Sterile Soil	10/04/94	4		42	0.92	0.04	38.64	247.84	8.8	56.4		42	1.05	0.04	44.10	268.37	10.8	65.7		40	1.0	0.04	38.66	287.12	7.4	54.8
+ NTA	10/06/94	6		42	1.21	0.05	50.82	298.66	11.6	68.0		41	0.28	0.01	11.44	279.81	2.8	68.5		41	0.0		0.00	287.12	0.0	54.8
	10/10/94	10		40	0.31	0.01	12.40	311.06	2.8	70.8		42	0.72	0.03	30.24	310.05	7.4	76.0		42	2.0	0.08	83.58	370.70	16.0	70.7
	10/17/94	17		86	0.00		0.00	311.06	0.0	70.8		81	0.00		0.00	310.05	0.0	76.0		85	0.0		0.00	370.70	0.0	70.7

CALCULATIONS: pCi in Soln. = pCi/ml x Solution Vol. Removed
Calculated Head = Sum of pCi in Solution + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
31.3 pCi/g	24.3 pCi/g	37.6 pCi/g	31.1 pCi/g

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	70.8 %	76.0 %	70.7 %	72.5 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	77.9 %

APPENDIX A – 7

LANL SOIL, TEST 3, IN TRIPLICATE (A,B,C)

Pu–Am

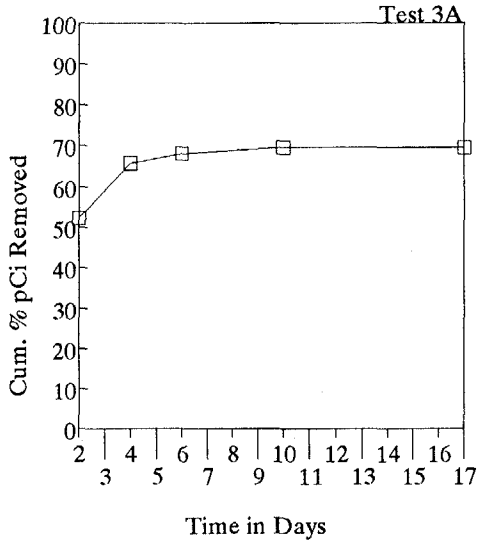
Test Standards for A, B, C

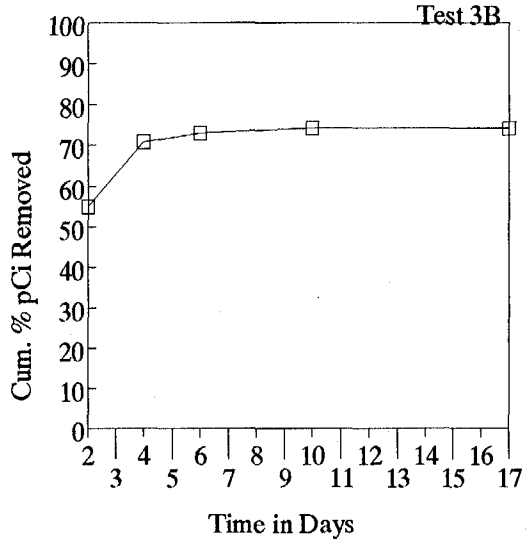
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

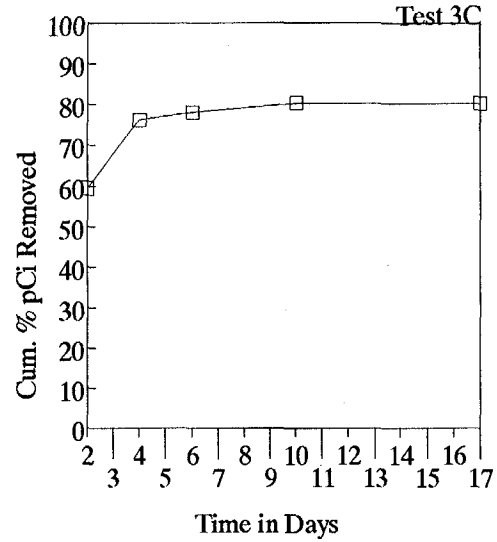
Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #3

A Gross Wt: 15.909 Tare Wt: 11.895 Net Wt: 4.014 Total Possible: 489.514 Tails: 149.130 Calc. Head: 489.514

B Gross Wt: 115.899 Tare Wt: 11.831 Net Wt: 104.068 Total Possible: 474.950 Tails: 122.420 Calc. Head: 474.950

C Gross Wt: 15.998 Tare Wt: 11.834 Net Wt: 4.164 Total Possible: 446.350 Tails: 87.480 Calc. Hea 446.350

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
Native Soil	09/30/94	0																								
+ NTA	10/02/94	2		40	6.40	0.26	256.00	256.00	52.3	52.3		40	6.5	0.26	261.20	261.20	55.0	55.0		40	6.64	6.64	265.60	265.60	59.5	59.5
+ SD–1	10/04/94	4	6.0	40	1.64	0.07	65.60	321.60	13.4	65.7	6	40	1.9	0.08	75.20	336.40	15.8	70.8	6	41	1.82	8.46	74.62	340.22	16.7	76.2
+ Natve Orgs.	10/06/94	6	6.3	41	0.28	0.01	11.64	333.24	2.4	68.1	6.5	41	0.3	0.01	10.25	346.65	2.2	73.0	6.3	40	0.21	8.67	8.40	348.62	1.9	78.1
	10/10/94	10		42	0.17	0.01	7.14	340.38	1.5	69.5		42	0.1	0.01	5.88	352.53	1.2	74.2		41	0.25	8.92	10.25	358.87	2.3	80.4
	10/17/94	17		76	0.00		0.00	340.38	0.0	69.5		88	0.0		0.00	352.53	0.0	74.2		75	0.00	8.92	0.00	358.87	0.0	80.4

CALCULATIONS: pCi in Soln. = pCi/ml x Solution Vol. Removed
Calculated Head = Sum of pCi in Solution + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
37.3 pCi/g	30.4 pCi/g	23.9 pCi/g	30.5 pCi/g

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	69.5 %	74.2 %	80.4 %	74.7 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	78.3 %

APPENDIX A – 8

LANL SOIL, TEST 4, IN TRIPLICATE (A,B,C)

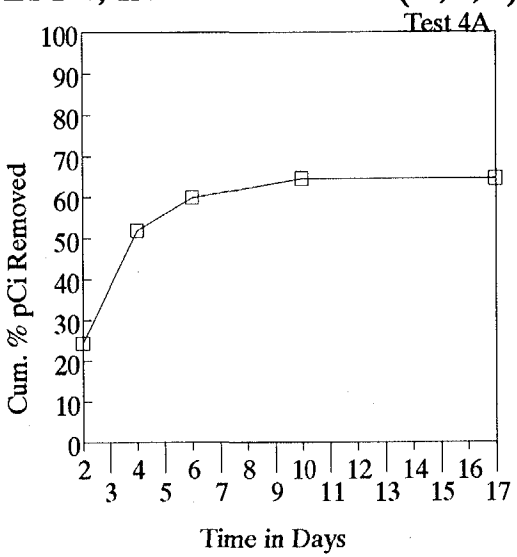
Pu–Am

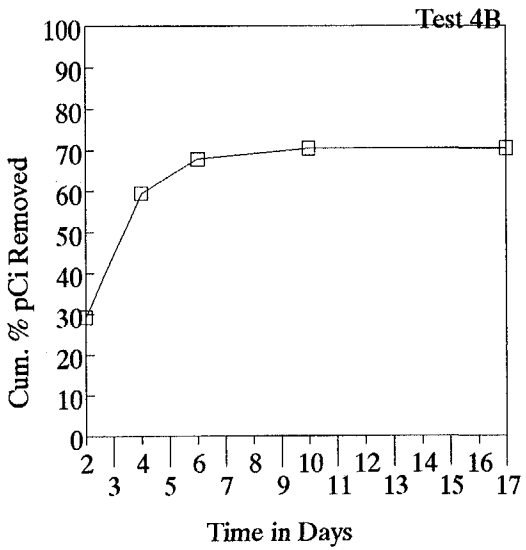
Test Standards for A, B, C

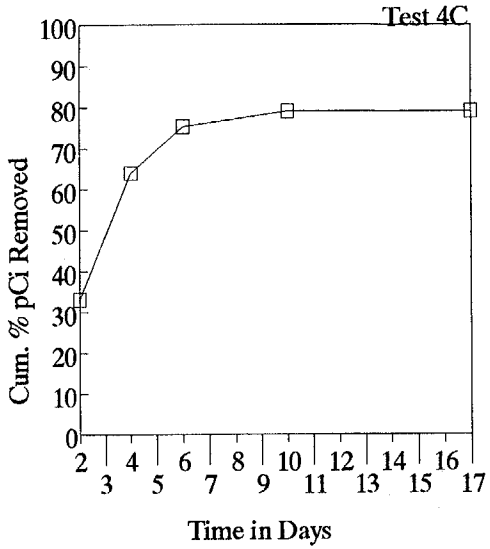
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Natve Orgs.







TEST #4

A Gross Wt: 16.013 Tare Wt: 11.844 Net Wt: 4.169 Total Possible: 499.540 Tails: 177.260 Calc. Head: 499.540

B Gross Wt: 16.003 Tare Wt: 11.924 Net Wt: 4.079 Total Possible: 440.150 Tails: 130.370 Calc. Head: 440.150

C Gross Wt: 16.089 Tare Wt: 11.982 Net Wt: 4.107 Total Possible: 417.600 Tails: 87.480 Calc. Head: 417.600

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
	09/30/94	0																								
Native Soil	10/02/94	2		40	3.05	0.12	122.00	122.00	24.4	24.4		41	3.1	0.13	128.74	128.74	29.2	29.2		40	3.5	0.14	138.40	138.40	33.1	33.1
+ NTA	10/04/94	4		40	3.44	0.14	137.60	259.60	27.5	52.0		40	3.3	0.13	133.20	261.94	30.3	59.5		40	3.2	0.13	128.80	267.20	30.8	64.0
+ Native Orgs.	10/06/94	6		40	1.00	0.04	40.00	299.60	8.0	60.0		41	0.9	0.04	36.08	298.02	8.2	67.7		46	1.0	0.05	47.38	314.58	11.3	75.3
	10/10/94	10		42	0.54	0.02	22.68	322.28	4.5	64.5		42	0.3	0.01	11.76	309.78	2.7	70.4		42	0.4	0.02	15.54	330.12	3.7	79.1
	10/17/94	17		88	0.00		0.00	322.28	0.0	64.5		83	0.0		0.00	309.78	0.0	70.4		89	0.0		0.00	330.12	0.0	79.1

CALCULATIONS: pCi in Soln. = pCi/ml x Solution Vol. Removed
Calculated Head = Sum of pCi in Solution + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
42.9 pCi/g	32.6 pCi/g	21.8 pCi/g	32.4 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	64.5 %	70.4 %	79.1 %	71.3 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	76.8 %

APPENDIX A – 9

MOUND SOIL, TEST 1, IN TRIPLICATE (A,B,C)

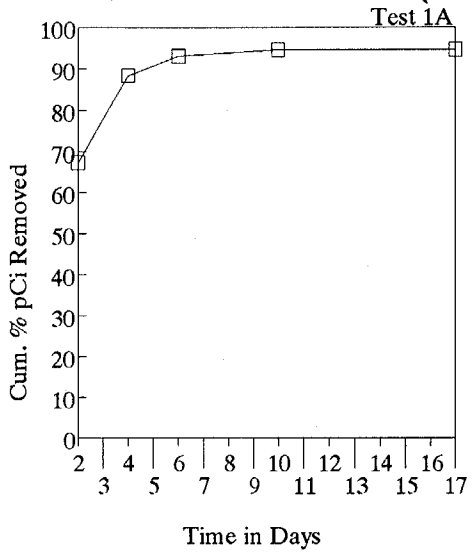
Pu–Am

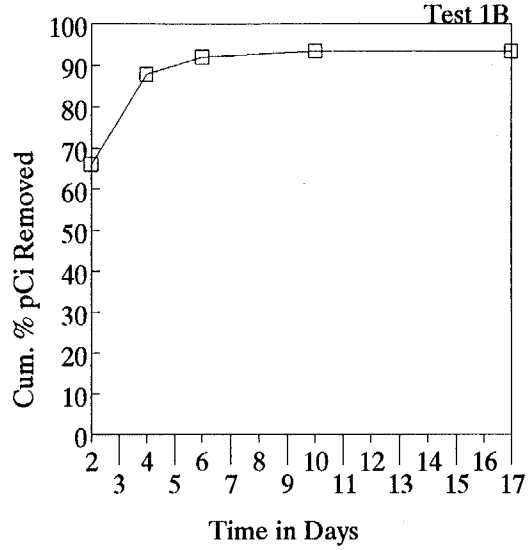
Test Standards for A, B, C

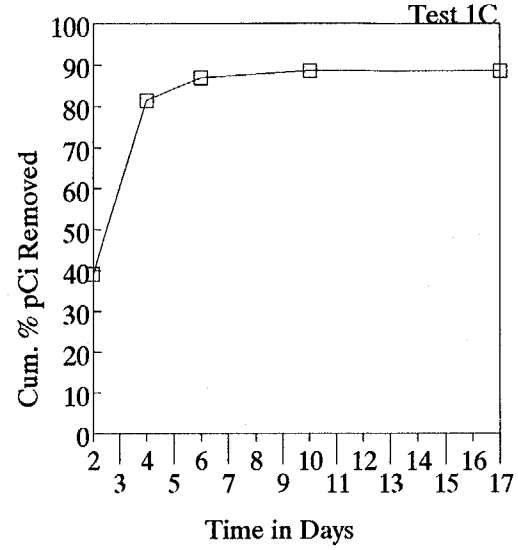
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1

Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 + Native Orgs.
Test 4: Native Soil + NTA + Native Orgs.







TEST #1

A Gross Wt: 16.026 Tare Wt: 11.903 Net Wt: 4.123 Total Possible: 2,385.150 Tails: 130.220 Calc. Head: 2,385.150

B Gross Wt: 16.138 Tare Wt: 11.948 Net Wt: 4.190 Total Possible: 2,461.980 Tails: 163.140 Calc. Head: 2,461.980

C Gross Wt: 16.081 Tare Wt: 11.947 Net Wt: 4.134 Total Possible: 1,225.580 Tails: 140.720 Calc. Head: 1,225.580

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
	09/30/94	0																								
	10/02/94	2		42	38.20	1.60	1604.40	1604.40	67.3	67.3	6.7	41	39.7	1.63	1627.70	1627.70	66.1	66.1		42	11.4	0.48	479.22	479.22	39.1	39.1
Sterile Soil	10/04/94	4		41	12.23	0.50	501.43	2105.83	21.0	88.3	6.7	42	12.7	0.53	533.40	2161.10	21.7	87.8		41	12.7	0.52	518.65	997.87	42.3	81.4
+ NTA	10/06/94	6	6.4	42	2.70	0.11	113.40	2219.23	4.8	93.0	6.5	41	2.5	0.10	104.14	2265.24	4.2	92.0	6.5	41	1.6	0.07	66.83	1064.70	5.5	86.9
+ SD–1	10/10/94	10		42	0.85	0.04	35.70	2254.93	1.5	94.5		42	0.8	0.03	33.60	2298.84	1.4	93.4		42	0.5	0.02	20.16	1084.86	1.6	88.5
	10/17/94	17		77	0.00		0.00	2254.93	0.0	94.5		78	0.0		0.00	2298.84	0.0	93.4		78	0.0		0.00	1084.86	0.0	88.5

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
37.3 pCi/g	46.4 pCi/g	42.5 pCi/g	42.1 pCi/g

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	94.5 %	93.4 %	88.5 %	92.1 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	91.8 %

APPENDIX A – 10

MOUND SOIL, TEST 2, IN TRIPLICATE (A,B,C)

Pu–Am

Test Standards for A, B, C

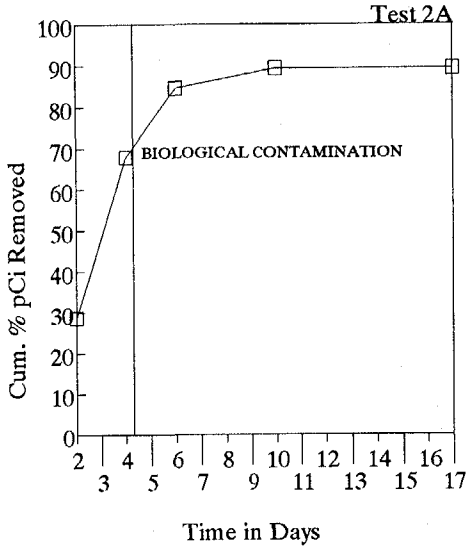
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17-day retention
9) 26°C temp.

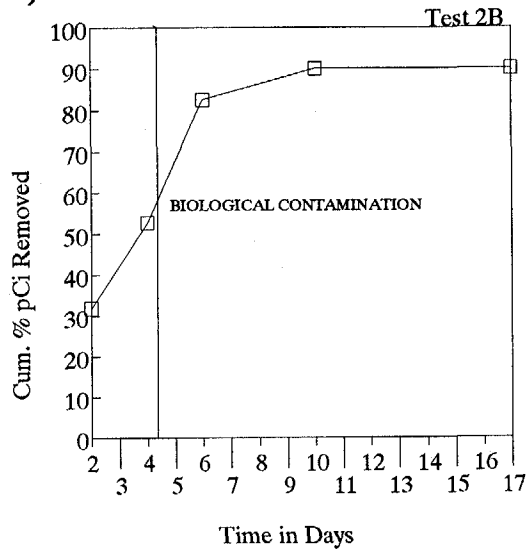
Test 1: Sterile Soil + NTA + SD–1

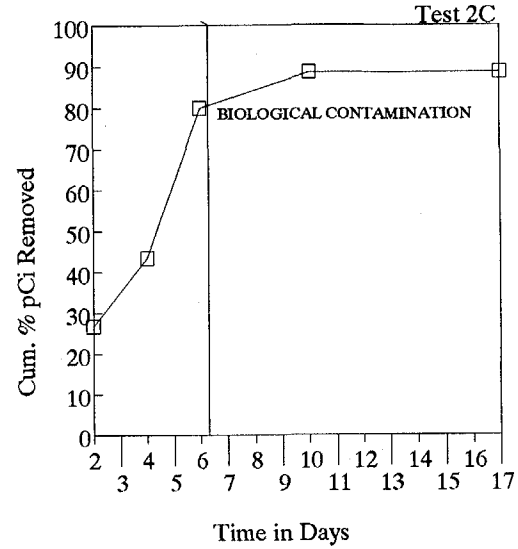
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #2

A Gross Wt: 16.069 Tare Wt: 11.924 Net Wt: 4.145 Total Possible: 2,214.440 Tails: 236.600 Calc. Head: 2,214.440

B Gross Wt: 15.904 Tare Wt: 11.845 Net Wt: 4.059 Total Possible: 2,054.250 Tails: 204.470 Calc. Head: 2,054.250

C Gross Wt: 16.072 Tare Wt: 11.956 Net Wt: 4.116 Total Possible: 2,193.840 Tails: 249.470 Calc. Head: 2,193.840

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
Sterile Soil + NTA	09/30/94	0																								
	10/02/94	2		41	15.50	0.64	635.50	635.50	28.7	28.7		42	15.60	0.66	655.20	655.20	31.9	31.9		40	14.7	0.59	588.00	588.00	26.8	26.8
	10/04/94	4		41	21.14	0.87	866.74	1502.24	39.1	67.8		42	10.20	0.43	428.40	1083.60	20.9	52.7		42	8.7	0.37	365.40	953.40	16.7	43.5
	10/06/94	6		41	9.03	0.37	370.23	1872.47	16.7	84.6		40	15.28	0.61	611.20	1694.80	29.8	82.5		41	19.5	0.80	800.73	1754.13	36.5	80.0
	10/10/94	10		41	2.57	0.11	105.37	1977.84	4.8	89.3		41	3.78	0.15	154.98	1849.78	7.5	90.0		41	4.6	0.19	190.24	1944.37	8.7	88.6
	10/17/94	17		62	0.00		0.00	1977.84	0.0	89.3		87	0.00		0.00	1849.78	0.0	90.0		84	0.0		0.00	1944.37	0.0	88.6

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
63.0 pCi/g	56.5 pCi/g	68.8 pCi/g	62.8 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	89.3 %	90.0 %	88.6 %	89.3 %
Basis: Assay Head (Solids)	. . . . .			87.7 %

APPENDIX A – 11

MOUND SOIL, TEST 3, IN TRIPLICATE (A,B,C)

Pu–Am

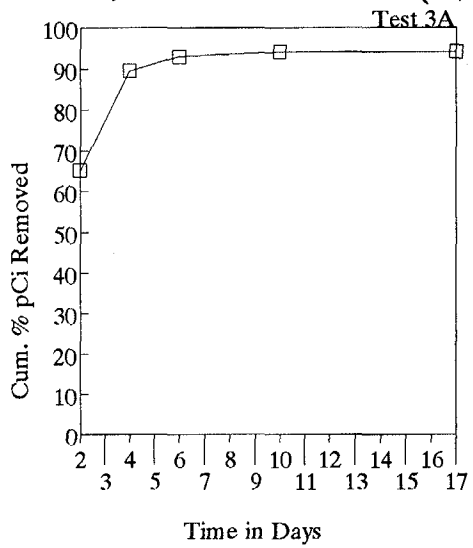
Test Standards for A, B, C

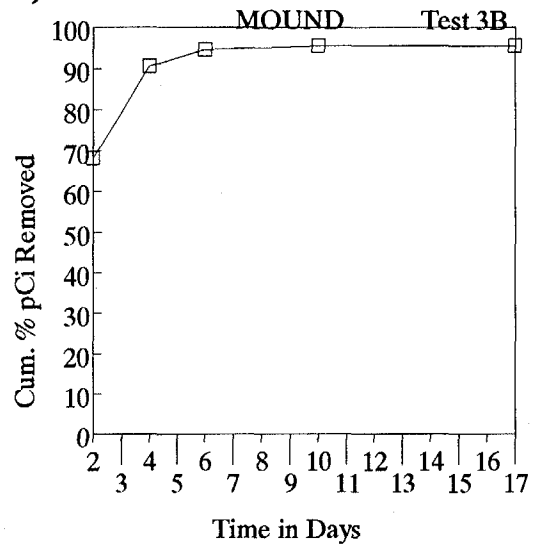
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

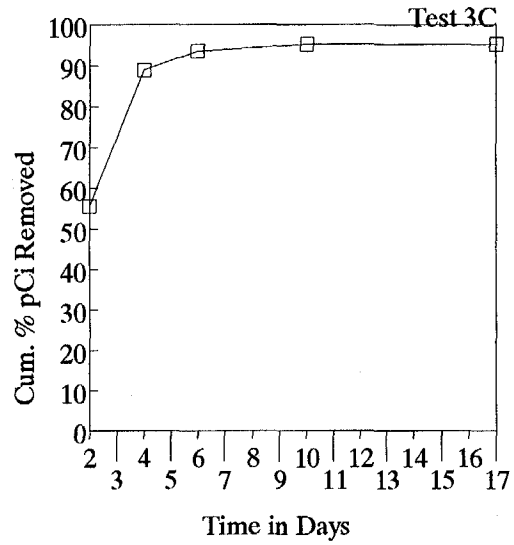
Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #3

A Gross Wt: 16.119 Tare Wt: 11.925 Net Wt: 4.194 Total Possible: 2,348.020 Tails: 136.870 Calc. Head: 2,348.020

B Gross Wt: 15.947 Tare Wt: 11.847 Net Wt: 4.100 Total Possible: 2,228.890 Tails: 97.600 Calc. Head: 2,228.890

C Gross Wt: 16.105 Tare Wt: 11.954 Net Wt: 4.151 Total Possible: 2,184.700 Tails: 104.420 Calc. Head: 2,184.700

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng in Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % in Soln.	A Cum. % in Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng in Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % in Soln.	B Cum. % in Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng in Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % in Soln.	C Cum. % in Soln.
Native Soil	09/30/94	0																								
+ NTA	10/02/94	2		42	36.50	1.53	1533.00	1533.00	65.3	65.3		41	37.1	1.52	1521.10	1521.10	68.2	68.2		40	30.4	1.22	1216.00	1216.00	55.7	55.7
+ SD–1	10/04/94	4	6.6	41	13.89	0.57	569.49	2102.49	24.3	89.5	6.7	41	12.2	0.50	498.97	2020.07	22.4	90.6	6.7	41	17.7	0.73	726.93	1942.93	33.3	88.9
+ Native Orgs.	10/06/94	6	6.3	40	2.04	0.08	81.60	2184.09	3.5	93.0	6.3	41	2.2	0.09	89.38	2109.45	4.0	94.6	6.2	41	2.5	0.10	101.68	2044.61	4.7	93.6
	10/10/94	10		41	0.66	0.03	27.06	2211.15	1.2	94.2		42	0.5	0.02	21.84	2131.29	1.0	95.6		41	0.9	0.04	35.67	2080.28	1.6	95.2
	10/17/94	17		73	0.00		0.00	2211.15	0.0	94.2		80	0.0		0.00	2131.29	0.0	95.6		61	0.0		0.00	2080.28	0.0	95.2

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
41.8 pCi/g	29.3 pCi/g	31.8 pCi/g	34.3 pCi/g

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	94.2 %	95.6 %	95.2 %	95.0 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	93.3 %

APPENDIX A – 12

MOUND SOIL, TEST 4, IN TRIPLICATE (A,B,C)

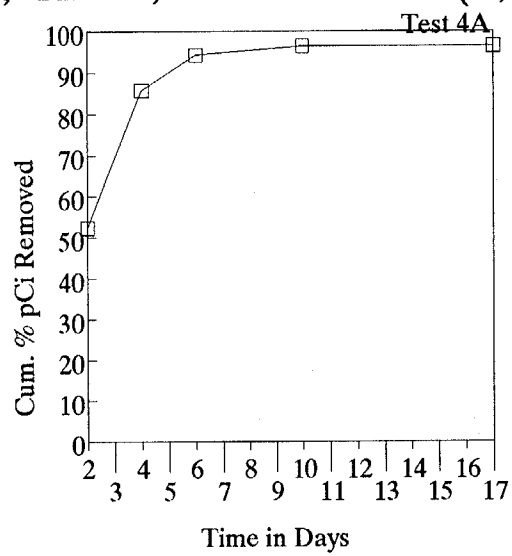
Pu–Am

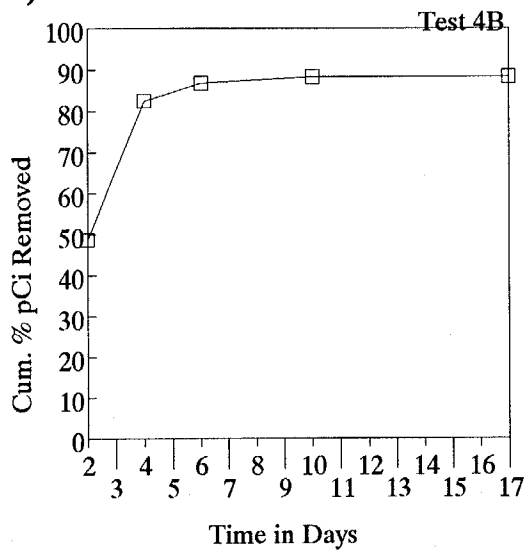
Test Standards for A, B, C

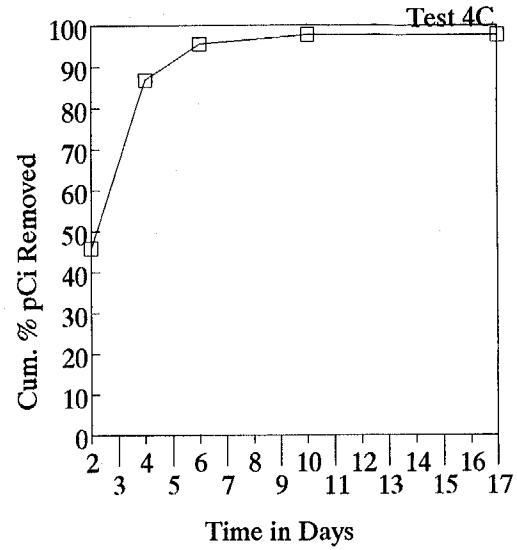
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #4

A Gross Wt: 15.975 Tare Wt: 11.855 Net Wt: 4.120 Total Possible: 2,207.590 Tails: 78.170 Calc. Head: 2,207.590

B Gross Wt: 15.966 Tare Wt: 11.865 Net Wt: 4.101 Total Possible: 2,238.600 Tails: 263.040 Calc. Head: 2,238.600

C Gross Wt: 15.975 Tare Wt: 11.909 Net Wt: 4.066 Total Possible: 2,064.840 Tails: 49.510 Calc. Head: 2,064.840

	DATE	DAY #	A pH	A Vol. (ml) Removed	A pCi/ml	A ng In Soln.	A pCi in Soln.	A Cum pCi in Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B pCi/ml	B ng In Soln.	B pCi in Soln.	B Cum pCi in Soln.	B % In Soln.	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C pCi/ml	C ng In Soln.	C pCi in Soln.	C Cum pCi in Soln.	C % In Soln.	C Cum. % In Soln.
	09/30/94	0																								
Native Soil	10/02/94	2		41	28.20	1.16	1156.20	1156.20	52.4	52.4		40	27.3	1.09	1092.00	1092.00	48.8	48.8		41	23.1	0.95	947.10	947.10	45.9	45.9
+ NTA	10/04/94	4		40	18.40	0.74	736.00	1892.20	33.3	85.7		40	18.9	0.75	754.00	1846.00	33.7	82.5		40	21.1	0.85	845.60	1792.70	41.0	86.8
+ Native Orgs.	10/06/94	6		40	4.68	0.19	187.20	2079.40	8.5	94.2		41	2.3	0.10	95.12	1941.12	4.2	86.7		41	4.4	0.18	178.35	1971.05	8.6	95.5
	10/10/94	10		41	1.22	0.05	50.02	2129.42	2.3	96.5		42	0.8	0.03	34.44	1975.56	1.5	88.2		41	1.1	0.04	44.28	2015.33	2.1	97.6
	10/17/94	17		83	0.00		0.00	2129.42	0.0	96.5		80	0.0		0.00	1975.56	0.0	88.2		80	0.0		0.00	2015.33	0.0	97.6

CALCULATIONS: pCi in Soln. = (pCi/ml x Vol Removed)
CALCULATED HEAD = Sum of pCi in Soln. + Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
24.3 pCi/g	78.1 pCi/g	15.4 pCi/g	39.2 pCi/g

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	96.5 %	88.2 %	97.6 %	94.1 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	92.2 %

APPENDIX B – 1: RAD DATA Report of Analyses

Lockheed Analytical Laboratory, Las Vegas, Nevada

RFP

Pu–Am

			CONSTITUENT ACTIVITY									Combined	
	Description	Description	Am–241			Pu–238			Pu–239/240			TOTAL	pCi/g
Sample No.	ID	Weight(grams)	pCi/g	Error	MDA	pCi/g	Error	MDA	pCi/g	Error	MDA	pCi	% Extracted
R5A	Head	8.25	**155.00**	18.00	3.00	**33.00**	35.00	48.00	**1770.00**	160.00	29.00	1,958.00	
R5B	Head	9.39	**6.30**	6.50	9.70	**19.00**	28.00	37.00	**2240.00**	210.00	22.00	2,265.30	
TOTAL:		17.646											
Weighted Avg.			75.85			25.55			2020.18				2121.58
R1A	Tail	4.03	**49.30**	8.70	5.20	**8.70**	4.60	4.20	**355.00**	28.00	2.80	413.00	
R1B	Tail	4.05	**34.90**	5.70	3.40	**5.50**	2.30	1.60	**239.00**	18.00	1.00	279.40	
R1C	Tail	3.94	**12.00**	11.00	6.70	**4.90**	2.90	2.60	**211.00**	18.00	1.70	227.90	
TOTAL:		12.01											
Weighted Avg.			32.23			6.38			268.72				307.32
% Extracted:				**57.5%**			**75.0%**			**86.7%**			**85.5%**
R2A	Tail	3.95	**39.10**	6.60	2.40	**3.90**	2.00	1.70	**237.00**	17.00	1.10	280.00	
R2B	Tail	3.94	**86.00**	15.00	5.30	**6.40**	4.50	4.40	**467.00**	38.00	3.50	559.40	
R2C	Tail	4.01	**60.40**	6.40	2.20	**4.40**	2.00	1.40	**300.00**	21.00	1.00	364.80	
TOTAL:		11.90											
Weighted Avg.			61.81			4.90			334.41				401.11
% Extracted:				**20.4%**			**82.8%**			**83.4%**			**81.1%**
R3A	Tail	3.96	**42.90**	4.50	1.60	**4.80**	1.90	1.20	**277.00**	19.00	1.10	324.70	
R3B	Tail	4.06	**81.00**	11.00	6.10	**9.20**	6.00	5.40	**436.00**	41.00	3.80	526.20	
R3C	Tail	3.98	**68.80**	8.90	4.30	**7.20**	3.70	2.90	**412.00**	32.00	2.20	488.00	
TOTAL:		11.99											
Weighted Avg.			64.38			7.08			375.55				447.02
% Extracted:				**15.1%**			**71.8%**			**81.4%**			**78.9%**
R4A	Tail	4.04	**57.00**	11.00	7.50	**5.20**	4.80	5.20	**353.00**	32.00	3.30	415.20	
R4B	Tail	3.89	**80.30**	7.80	1.90	**7.30**	2.00	1.00	**389.00**	23.00	0.82	476.60	
R4C	Tail	4.03	**40.80**	4.90	2.00	**3.10**	2.00	1.90	**242.00**	18.00	1.10	285.90	
	TOTAL:	11.97											
Weighted Avg.			59.12			5.18			327.29				391.59
% Extracted:				**22.1%**			**87.9%**			**83.8%**			**81.5%**

Anomalous Reading:

APPENDIX B – 2: RAD DATA Report of Analyses

Lockheed Analytical Laboratory, Las Vegas, Nevada

LANL

Pu–Am

			CONSTITUENT ACTIVITY									Combined	
	Description	Description	Am–241			Pu–238			Pu–239/240			TOTAL	pCi/g
Sample No.	ID	Weight(grams)	pCi/g	Error	MDA	pCi/g	Error	MDA	pCi/g	Error	MDA	pCi	% Extracted
L5A	Head	9.76	**0.27**	0.09	0.06	**0.00**	0.91	1.80	**121.00**	11.00	1.40	121.27	
L5B	Head	9.56	**0.19**	0.10	0.04	**0.60**	1.60	2.40	**159.00**	12.00	1.40	159.79	
TOTAL:		19.313											
Weighted Avg.			0.23			0.30			139.80				140.33
L1A	Tail	4.06	**0.00**	0.25	0.40	**0.31**	0.35	0.49	**17.00**	1.80	0.40	17.31	
L1B	Tail	3.91	**0.00**	0.41	0.74	**1.60**	1.20	1.50	**47.10**	4.70	0.73	48.70	
L1C	Tail	4.02	**0.00**	0.44	0.74	**0.20**	0.37	0.55	**25.20**	2.30	0.25	25.40	
	TOTAL:	12.00											
Weighted Avg.			0.00			0.69			29.56				30.25
% Extracted:				**100.0%**			**–133.5%**			**78.9%**			**78.4%**
L2A	Tail	4.09	**0.09**	0.80	1.20	**0.00**	0.55	1.00	**31.20**	3.00	0.50	31.29	
L2B	Tail	4.04	**0.15**	0.26	0.37	**0.06**	0.18	0.28	**24.10**	1.70	0.18	24.31	
L2C	Tail	4.08	**0.05**	0.25	0.39	**0.13**	0.16	0.22	**37.40**	2.40	0.15	37.58	
	TOTAL:	12.21											
Weighted Avg.			0.10			0.06			30.92				31.08
% Extracted:				**58.1%**			**78.7%**			**77.9%**			**77.9%**
L3A	Tail	4.00	**0.00**	0.37	0.63	**0.13**	0.15	0.20	**37.20**	2.40	0.15	37.33	
L3B	Tail	4.03	**0.00**	0.29	0.52	**0.00**	0.16	0.28	**30.40**	2.10	0.19	30.40	
L3C	Tail	4.04	**0.49**	0.47	0.64	**0.17**	0.39	0.60	**23.20**	2.30	0.43	23.86	
	TOTAL:	12.06											
Weighted Avg.			0.16			0.10			30.24				30.51
% Extracted:				**28.8%**			**66.3%**			**78.4%**			**78.3%**
L4A	Tail	4.13	**0.07**	0.27	0.42	**0.12**	0.17	0.25	**42.70**	3.00	0.19	42.89	
L4B	Tail	4.00	**0.00**	0.42	0.73	**0.00**	0.50	0.80	**32.60**	3.20	0.53	32.60	
L4C	Tail	4.02	**0.11**	0.16	0.22	**0.14**	0.19	0.25	**21.50**	1.60	0.13	21.75	
	TOTAL:	12.15											
Weighted Avg.			0.06			0.09			32.36				32.51
% Extracted:				**73.9%**			**70.7%**			**76.9%**			**76.8%**

Anomalous Reading:

APPENDIX B – 3: RAD DATA Report of Analyses

Lockheed Analytical Laboratory, Las Vegas, Nevada

MOUND

Pu–Am

			CONSTITUENT ACTIVITY									Combined	
	Description	Description	Am–241			Pu–238			Pu–239/240			TOTAL	pCi/g
Sample No.	ID	Weight(grams)	pCi/g	Error	MDA	pCi/g	Error	MDA	pCi/g	Error	MDA	pCi	% Extracted
M5A	Head	7.30	**0.79**	0.27	0.21	**447.00**	42.00	12.00	**27.70**	9.00	5.40	475.49	
M5B	Head	6.87	**0.91**	0.25	0.13	**520.00**	65.00	28.00	**28.00**	17.00	18.00	548.91	
TOTAL:		14.17											
Weighted Avg.			1.06			605.13			34.70				511.07
M1A	Tail	3.49	**0.00**	0.16	0.26	**36.00**	2.30	0.13	**1.27**	0.27	0.08	37.27	
M1B	Tail	3.52	**0.20**	0.37	0.55	**44.80**	3.50	0.38	**1.40**	0.48	0.24	46.40	
M1C	Tail	3.31	**0.21**	0.24	0.34	**39.90**	2.90	0.32	**2.43**	0.55	0.19	42.54	
TOTAL:		10.32											
Weighted Avg.			0.14			40.25			1.69				42.07
% Extracted:				**87.3%**			**93.3%**			**95.1%**			**91.8%**
M2A	Tail	3.76	**1.46**	0.76	0.83	**59.00**	4.50	0.47	**2.55**	0.71	0.27	63.01	
M2B	Tail	3.62	**0.44**	0.44	0.59	**51.50**	4.00	0.43	**4.56**	0.95	0.30	56.50	
M2C	Tail	3.63	**0.30**	2.50	4.20	**60.50**	6.10	1.20	**8.00**	2.00	0.72	68.80	
TOTAL:		11.00											
Weighted Avg.			0.74			57.03			5.01				62.78
% Extracted:				**30.2%**			**90.6%**			**85.6%**			**87.7%**
M3A	Tail	3.27	**0.74**	0.33	0.33	**38.40**	4.00	1.50	**2.69**	0.99	0.74	41.83	
M3B	Tail	3.330	**0.71**	0.59	0.76	**27.40**	6.40	5.50	**1.20**	1.80	2.70	29.31	
M3C	Tail	3.29	**0.00**	0.23	0.38	**30.00**	2.30	0.56	**1.73**	0.46	0.31	31.73	
TOTAL:		9.89											
Weighted Avg.			0.48			31.90			1.87				34.26
% Extracted:				**54.5%**			**94.7%**			**94.6%**			**93.3%**
M4A	Tail	3.22	**0.00**	0.32	0.65	**22.80**	2.20	0.67	**1.46**	0.53	0.45	24.26	
M4B	Tail	3.37	**0.60**	0.60	0.79	**74.50**	7.90	2.80	**3.00**	1.60	1.70	78.10	
M4C	Tail	3.22	**0.35**	0.31	0.41	**13.70**	2.10	1.20	**1.31**	0.68	0.67	15.36	
TOTAL:		9.81											
Weighted Avg.			0.32			37.56			1.94				39.82
% Extracted:				**69.8%**			**93.8%**			**94.4%**			**92.2%**

Anomalous Reading:

APPENDIX C – 1

HANFORD SOIL, TEST 1, IN TRIPLICATE (A,B,C)

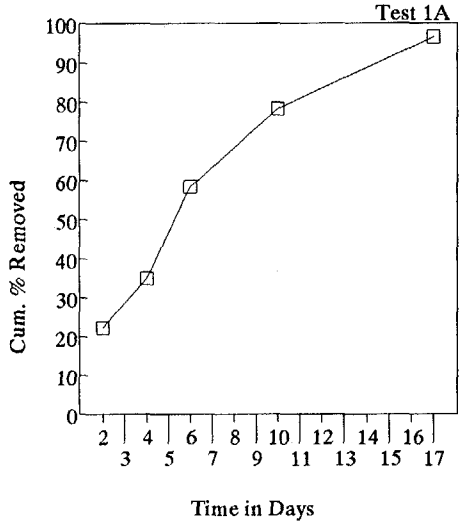
Uranium

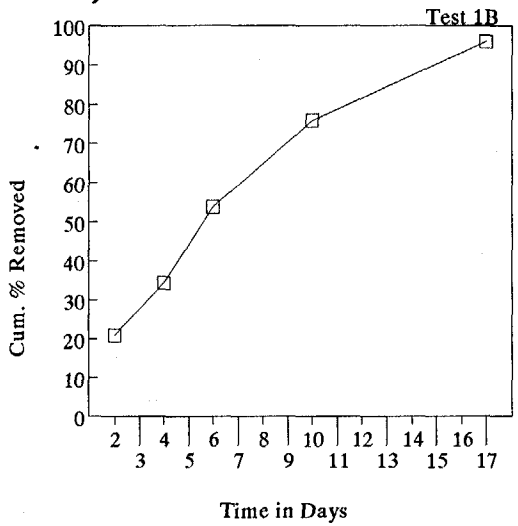
Test Standards:

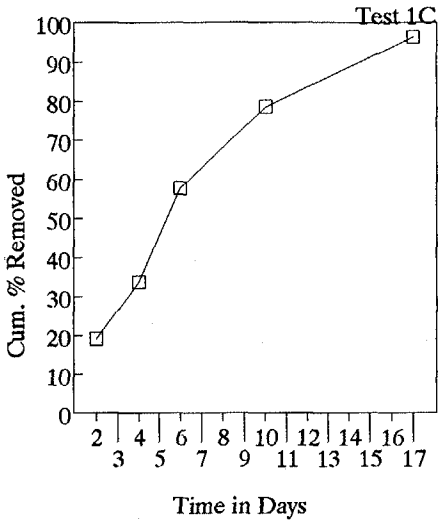
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1

Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 +Native Orgs.
Test 4: Native Soil + NTA +Native Orgs.







	A	B	C
Gross	16.035	16.051	16.204
Tare	11.861	11.897	12.016
Net Wt./g	4.174	4.154	4.188
TOTAL mg POSSIBLE:	1.584	1.377	1.467
Tails:	0.056	0.056	0.055
Cal. Head:	1.584	1.377	1.467

TEST #1

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0							0														
	10/02/94	2		42	8.4	0.35	0.35	22.2	22.2		40	7.2	0.29	0.29	20.9	20.9		41	6.8	0.28	0.28	19.1	19.1
Sterile Soil	10/04/94	4		42	4.8	0.20	0.56	12.8	35.0		41	4.5	0.18	0.47	13.4	34.3		42	5.1	0.21	0.49	14.6	33.7
+ NTA	10/06/94	6		41	9.0	0.37	0.93	23.4	58.5		41	6.5	0.27	0.74	19.5	53.8		41	8.6	0.35	0.85	24.0	57.8
+ SD–1	10/10/94	10		40	7.9	0.31	1.24	19.9	78.3		42	7.2	0.30	1.05	22.1	76.0		41	7.4	0.30	1.15	20.8	78.5
	10/17/94	17		85	3.4	0.29	1.53	18.2	96.5		79	3.5	0.28	1.32	20.0	95.9		83	3.1	0.26	1.41	17.7	96.2

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG
13.3 ppm	13.4 ppm	13.2 ppm	13.3 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	96.5 %	95.9 %	96.2 %	96.2 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	99.1 %

APPENDIX C – 2

HANFORD SOIL, TEST 2, IN TRIPLICATE (A,B,C)

Uranium

Test Standards:

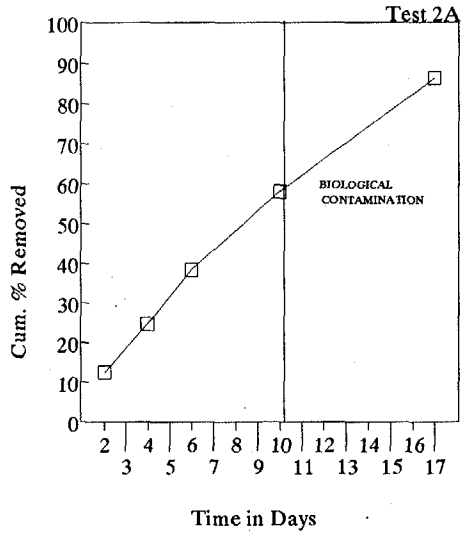
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

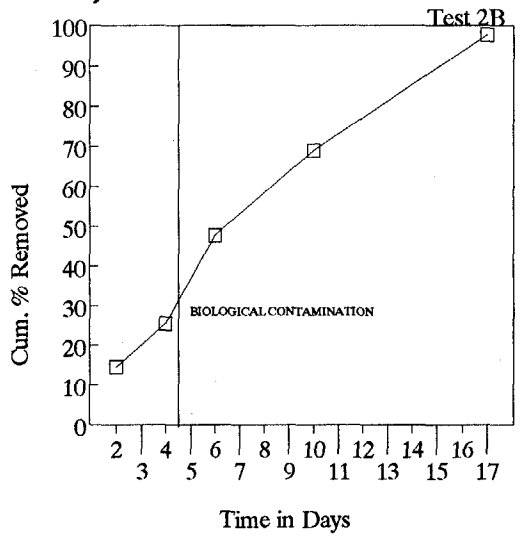
Test 1: Sterile Soil + NTA + SD–1

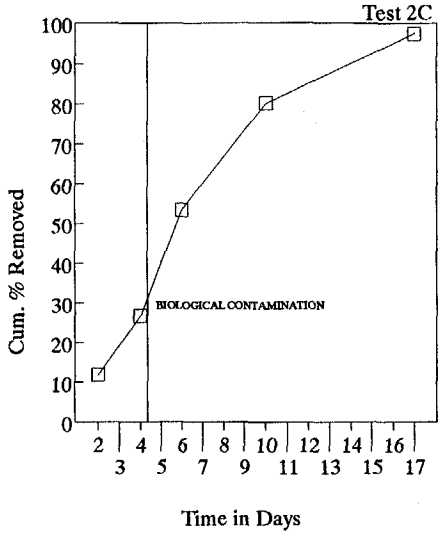
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 +Native Orgs.

Test 4: Native Soil + NTA +Native Orgs.







TEST #2

	A	B	C
Gross	15.903	16.04	15.965
Tare	11.852	11.836	11.911
Net Wt./g	4.051	4.204	4.054
TOTAL mg POSSIBLE:	1.307	1.441	1.279
Tails:	0.179	0.033	0.031
Cal.Head:	1.307	1.441	1.279

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0																					
	10/02/94	2		41	4.0	0.16	0.16	12.5	12.5		41	5.1	0.21	0.21	14.6	14.6		41	3.7	0.15	0.15	11.8	11.8
Sterile Soil	10/04/94	4		42	3.8	0.16	0.32	12.3	24.8		41	3.9	0.16	0.37	11.0	25.6		40	4.8	0.19	0.34	14.9	26.8
+ NTA	10/06/94	6		41	4.3	0.18	0.50	13.6	38.4		40	8.0	0.32	0.69	22.1	47.7		41	8.3	0.34	0.68	26.7	53.4
	10/10/94	10		42	6.1	0.26	0.76	19.7	58.1		42	7.3	0.31	0.99	21.3	69.0		42	8.1	0.34	1.02	26.7	80.1
	10/17/94	17		88	4.2	0.37	1.13	28.2	86.3		88	4.7	0.41	1.41	28.7	97.7		80	2.8	0.22	1.25	17.4	97.5

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
*Negative data reported as 0.
Calc. Head = Cum. mg removed + mg in Tails

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
44.3 ppm	58.4 ppm	7.8 ppm	36.8 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.	
Basis: Calc. Head (Soln + Solid)	86.3 %	97.7 %	97.5 %	93.8 %	
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	. . . . .	97.6 %

APPENDIX C – 3

HANFORD SOIL, TEST 3, IN TRIPLICATE (A,B,C)

Uranium

Test Standards:

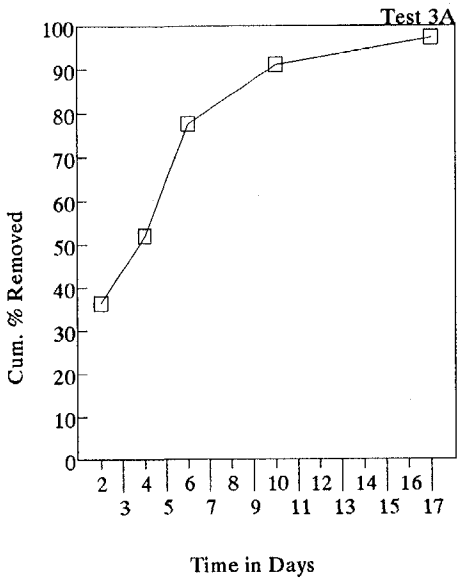
1) Native soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

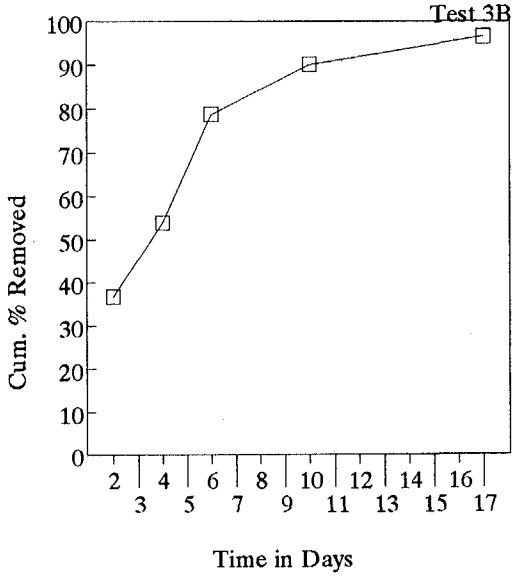
Test 1: Sterile Soil + NTA + SD–1

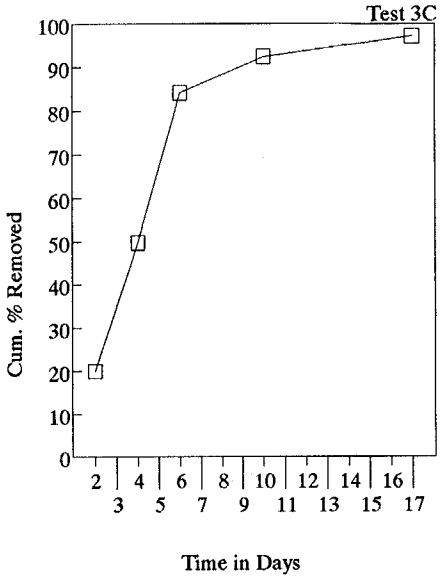
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #3

	A	B	C
Gross	16.042	16.011	16.045
Tare	11.934	11.868	11.892
Net Wt./g	4.108	4.143	4.153
TOTAL mg POSSIBLE:	1.360	1.444	2.206
Tails:	0.038	0.051	0.063
Cal.Head:	1.360	1.444	2.206

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0																					
	10/02/94	2		41	12.1	0.50	0.50	36.4	36.4		41	12.9	0.53	0.53	36.7	36.7		40	11.0	0.44	0.44	20.0	20.0
Native Soil	10/04/94	4	6.5	40	5.3	0.21	0.71	15.5	51.9	6.5	40	6.2	0.25	0.78	17.1	53.9	6.5	40	16.4	0.66	1.10	29.8	49.8
+ NTA	10/06/94	6		41	8.6	0.35	1.06	25.8	77.6		40	9.0	0.36	1.14	24.9	78.8		40	19.0	0.76	1.86	34.4	84.2
+ SD–1	10/10/94	10		42	4.4	0.18	1.24	13.5	91.1		41	4.0	0.16	1.30	11.3	90.1		42	4.3	0.18	2.04	8.2	92.4
+ Native Orgs.	10/17/94	17		74	1.1	0.08	1.32	6.2	97.2		71	1.3	0.09	1.39	6.4	96.5		78	1.3	0.10	2.14	4.7	97.1

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
9.1 ppm	12.4 ppm	15.2 ppm	12.2 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	97.2 %	96.5 %	97.1 %	96.9 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	99.2 %

APPENDIX C – 4

HANFORD SOIL, TEST 4, IN TRIPLICATE (A,B,C)

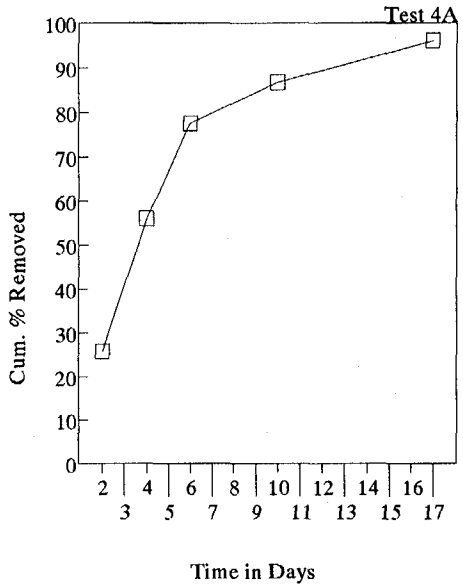
Uranium

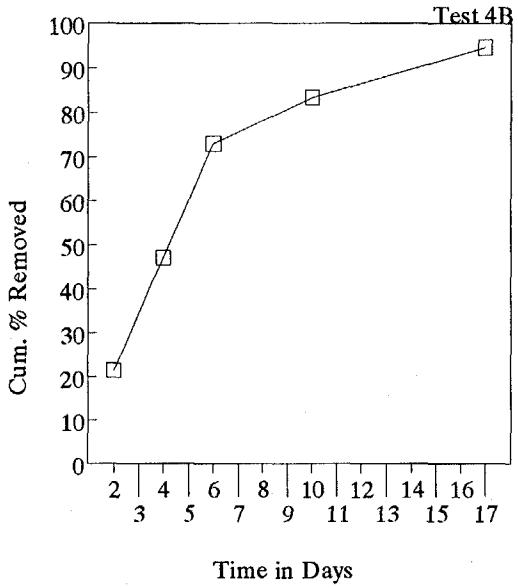
Test Standards:

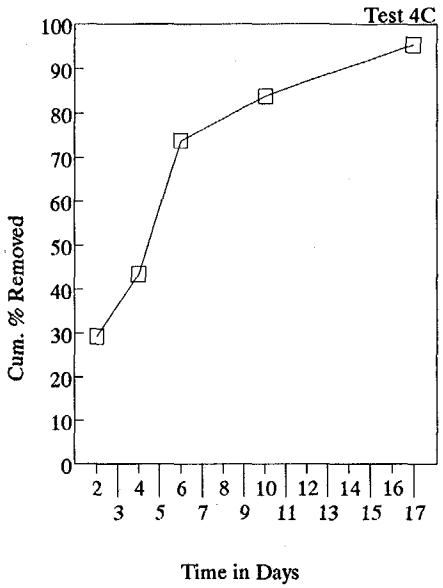
1) Native soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17-day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD-1
Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD-1 +Native Orgs.

Test 4: Native Soil + NTA +Native Orgs.







TEST #4

A

Gross	16.104
Tare	11.932
Net Wt./g	4.172
TOTAL mg POSSIBLE:	1.730
Tails:	0.068
Cal.Head:	1.730

B

Gross	16.095
Tare	11.904
Net Wt./g	4.191
TOTAL mg POSSIBLE:	1.710
Tails:	0.093
Cal. Head:	1.710

C

Gross	16.065
Tare	11.893
Net Wt./g	4.172
TOTAL mg POSSIBLE:	1.365
Tails:	0.062
Cal. Head:	1.365

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0																					
	10/02/94	2		42	10.6	0.45	0.45	25.8	25.8		41	8.9	0.37	0.37	21.4	21.4		40	10.0	0.40	0.40	29.3	29.3
Native Soil	10/04/94	4		42	12.5	0.52	0.97	30.2	56.0		40	11.0	0.44	0.81	25.7	47.1		40	4.8	0.19	0.59	14.2	43.5
+ NTA	10/06/94	6		41	9.1	0.37	1.34	21.5	77.5		42	10.5	0.44	1.25	25.8	72.9		42	9.8	0.41	1.01	30.2	73.7
+ SD-1	10/10/94	10		41	3.9	0.16	1.50	9.2	86.7		42	4.2	0.18	1.43	10.4	83.3		42	3.3	0.14	1.14	10.1	83.8
+Native orgs.	10/17/94	17		100	1.6	0.16	1.66	9.4	96.1		98	2.0	0.19	1.62	11.2	94.6		91	1.7	0.16	1.30	11.6	95.4

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
16.3 ppm	22.1 ppm	14.9 ppm	17.8 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	96.1 %	94.6 %	95.4 %	95.4 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	98.9 %

APPENDIX C – 5

FERNALD SOIL, TEST 1, IN TRIPLICATE (A,B,C)

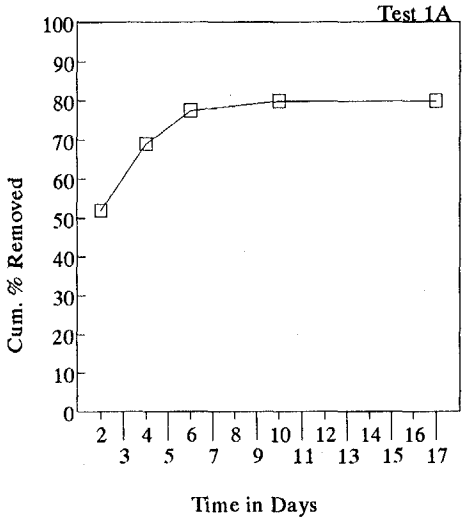
Uranium

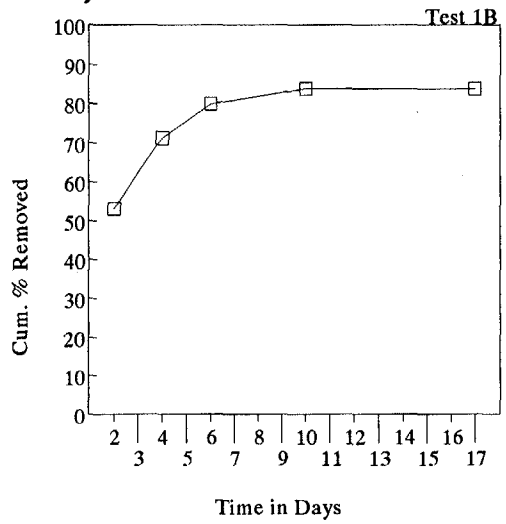
Test Standards for A, B, C

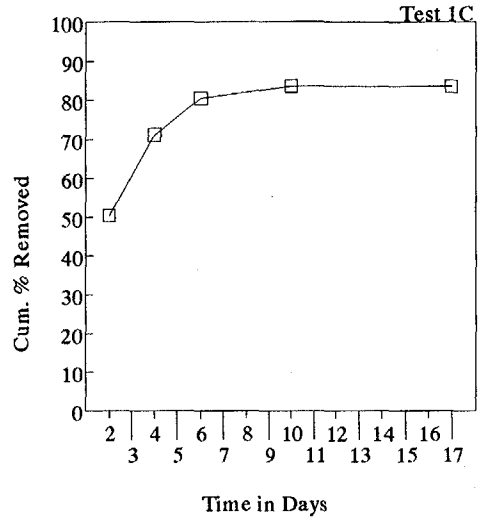
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1

Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 +Native Orgs.
Test 4: Native Soil + NTA +Native Orgs.







TEST #1

A		B		C	
Gross	16.020	Gross	16.042	Gross	16.006
Tare	11.998	Tare	11.951	Tare	11.94
Net Wt./g.	4.022	Net/g.	4.091	Net/g.	4.066
TOTAL POSSIBLE/mg.:	1.551	TOTAL POSSIBLE/mg.:	1.375	TOTAL POSSIBLE/mg.:	1.290
TAILS/mg.:	0.311	Tails/mg.:	0.223	Tails/mg.:	0.211
Cal. Head:	1.551	Cal. Head:	1.375	Cal. Head:	1.290

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B Vol. (ml) pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C Vol. (ml) pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0																					
	10/02/94	2		42	19.2	0.81	0.81	51.9	51.9		41	17.8	0.73	0.73	53.0	53.0		42	15.5	0.65	0.65	50.5	50.5
Sterile Soil	10/04/94	4		42	6.3	0.26	1.07	17.0	69.0		41	6.1	0.25	0.98	18.2	71.2		42	6.3	0.27	0.92	20.7	71.1
+ NTA	10/06/94	6		42	3.1	0.13	1.20	8.5	77.5		41	2.9	0.12	1.10	8.7	79.9		40	3.0	0.12	1.04	9.4	80.5
+ SD–1	10/10/94	10		41	0.9	0.04	1.24	2.5	79.9		41	1.3	0.05	1.15	3.9	83.8		42	0.9	0.04	1.08	3.1	83.6
	10/17/94	17		74	0.0		1.24	0.0	79.9		76	0.000		1.15	0.0	83.8		75	0.0		1.08	0.0	83.6

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails = Total Possible/mg.
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG
77.4 ppm	54.5 ppm	52.0 ppm	61.3 ppm

SUMMARY DATA:

% Solubilization

	TEST A	TEST B	TEST C	AVG
Basis: Calc. Head (Soln + Solid)	79.9 %	83.8 %	83.6 %	82.4 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	80.5%

APPENDIX C – 6

FERNALD SOIL, TEST 2, IN TRIPLICATE (A,B,C)

Uranium

Test Standards for A, B, C

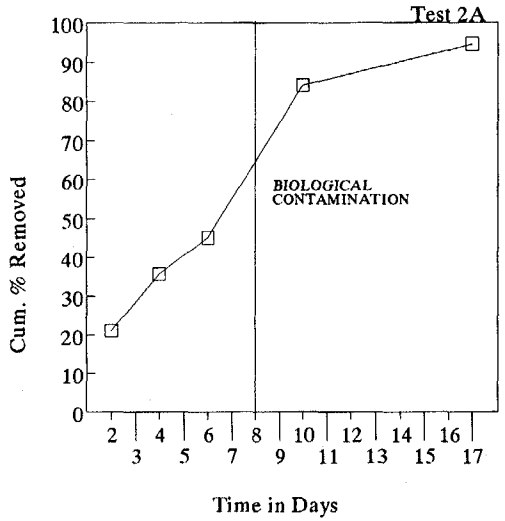
1) Sterile soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inocculum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

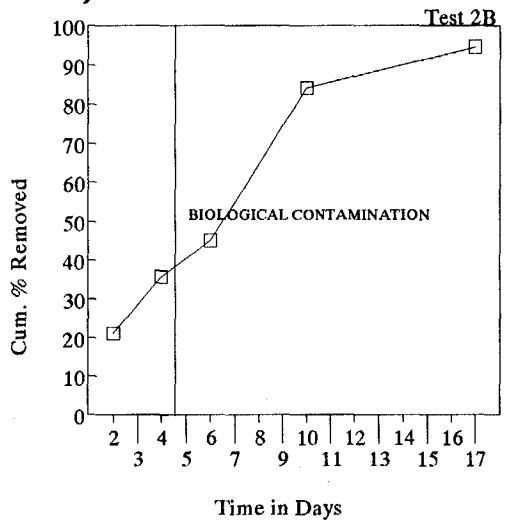
Test 1: Sterile Soil + NTA + SD–1

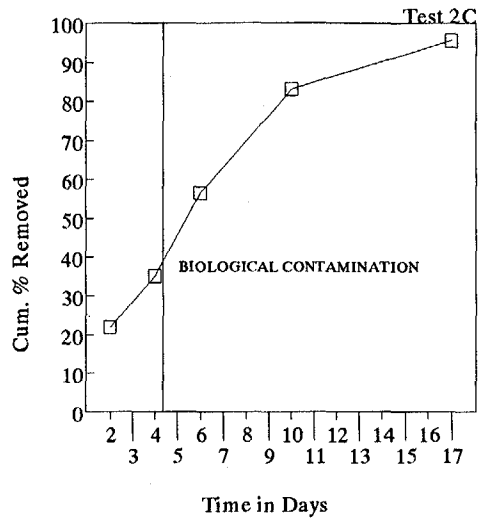
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 + Native Orgs.

Test 4: Native Soil + NTA + Native Orgs.







TEST #2

A		B		C	
Gross	16.018	Gross	15.9	Gross	16.179
Tare	11.921	Tare	11.862	Tare	11.983
Net Wt.	4.097	Net Wt.	4.038	Net Wt./g.	4.196
TOTAL POSSIBLE/mg.:	0.846	TOTAL POSSIBLE/mg.:	0.917	TOTAL POSSIBLE/mg.:	0.937
Tails/mg.:	0.046	Tails/mg.:	0.033	TAILS/mg.	0.042
Cal. Head:	0.846	Cal. Head:	0.917	Cal. Head:	0.937

			A							B							C						
	DATE	DAY #	pH	Vol. (ml) Removed	U (ppm) In Soln.	mg In Soln.	Cum mg In Soln.	% In Soln.	Cum. % In Soln.	Vol. (ml) pH	Vol. (ml) Removed	U (ppm) In Soln.	mg In Soln.	Cum mg In Soln.	% Solub	Cum. % In Soln.	Vol. (ml) pH	Vol. (ml) Removed	U (ppm) In Soln.	mg In Soln.	Cum mg In Soln.	% Solub	Cum. % In Soln.
Sterile Soil + NTA	09/30/94	0																					
	10/02/94	2		41	4.34	0.18	0.18	21.0	21.0		40	3.8	0.15	0.15	16.4	16.4		42	4.9	0.20	0.20	21.8	21.8
	10/04/94	4		41	3.01	0.12	0.30	14.6	35.6		41	6.8	0.28	0.43	30.5	46.9		41	3.0	0.12	0.33	13.2	35.1
	10/06/94	6		40	1.99	0.08	0.38	9.4	45.0		41	4.7	0.19	0.62	21.0	67.9		41	4.9	0.20	0.53	21.4	56.5
	10/10/94	10		41	8.05	0.33	0.71	39.0	84.1		41	5.3	0.22	0.84	23.9	91.8		41	6.1	0.25	0.78	26.6	83.1
	10/17/94	17		83	1.07	0.09	0.80	10.5	94.5		87	0.5	0.04	0.88	4.6	96.4		85	1.4	0.12	0.90	12.5	95.6

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails = Total Possible/mg.
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
11.3 ppm	8.2 ppm	9.9 ppm	9.8 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	94.5 %	96.4 %	95.6 %	95.5 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	97.0%

APPENDIX C – 7

FERNALD SOIL, TEST 3, IN TRIPLICATE (A,B,C)

Uranium

Test Standards for A, B, C

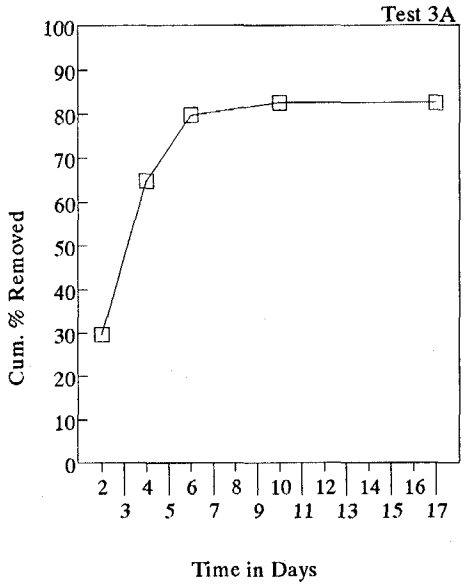
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoculum: – SD–1
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

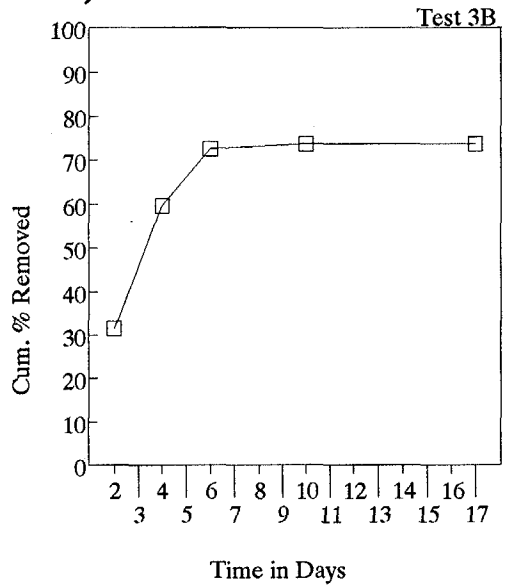
Test 1: Sterile Soil + NTA + SD–1

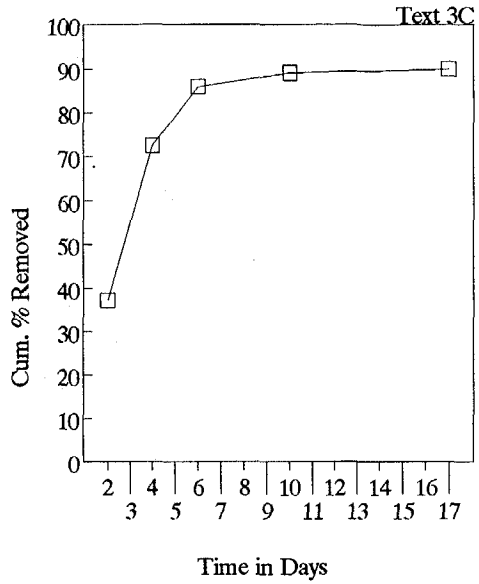
Test 2: Sterile Soil + NTA

Test 3: Native soil + NTA + SD–1 +Native Orgs.

Test 4: Native Soil + NTA +Native Orgs.







TEST #3

A			B			C		
Gross	16.078	TOTAL POSSIBLE/mg.: 1.116	Gross	15.925	TOTAL POSSIBLE/mg.: 1.069	Gross	16.053	TOTAL POSSIBLE/mg.: 1.213
Tare	11.867	TAILS/mg.: 0.195	Tare	11.851	TAILS/mg.: 0.280	Tare	11.897	TAILS/mg. 0.121
Net Wt./g.	4.211	Cal. Head: 1.116	Net Wt./g.	4.074	Cal. Head: 1.069	Net Wt./g.	4.156	Cal. Head: 1.213

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B Vol. (ml) pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C Vol. (ml) pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0																					
	10/02/94	2	6.1	41	8.1	0.33	0.33	29.6	29.6	6.1	40	8.4	0.34	0.34	31.5	31.5	6.1	41	11.0	0.45	0.45	37.2	37.2
Native Soil	10/04/94	4	6.4	41	9.6	0.39	0.72	35.2	64.8	6.5	41	7.3	0.30	0.64	28.1	59.6	6.4	40	10.8	0.43	0.88	35.5	72.7
+ NTA	10/06/94	6		41	4.1	0.17	0.89	14.9	79.7		40	3.5	0.14	0.78	13.0	72.7		41	3.9	0.16	1.04	13.3	85.9
+ SD–1	10/10/94	10		41	0.8	0.03	0.92	2.8	82.6		41	0.3	0.01	0.79	1.1	73.8		41	0.9	0.04	1.08	3.2	89.1
+Native Orgs.	10/17/94	17		85	0.0		0.92	0.0	82.6		67	0.0		0.79	0.0	73.8		67	0.2	0.01	1.09	0.9	90.0

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails = Total Possible/mg.
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
46.2 ppm	68.8 ppm	29.2 ppm	48.1 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	82.6 %	73.8 %	90.0 %	82.1 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	83.4%

APPENDIX C – 8

FERNALD SOIL, TEST 4, IN TRIPLICATE (A,B,C)

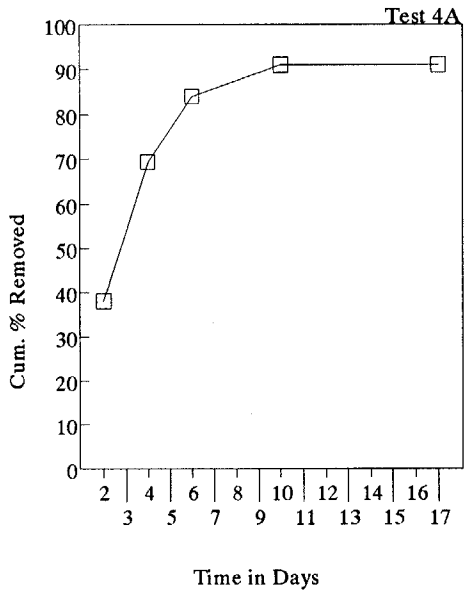
Uranium

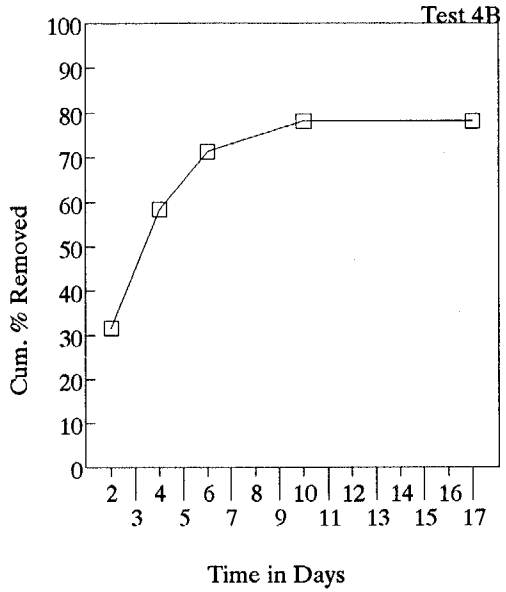
Test Standards for A, B, C

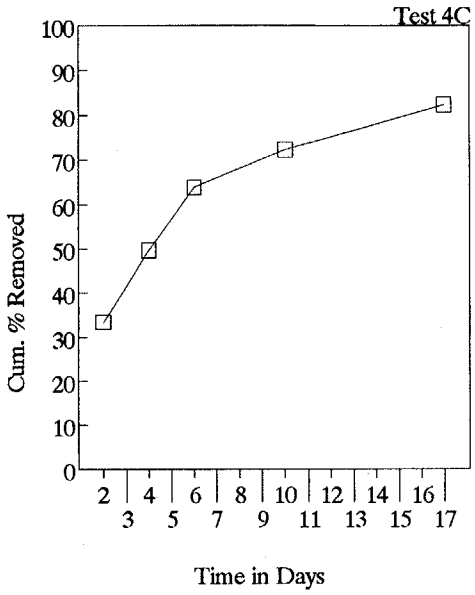
1) Native Soil, 4g
2) Pulp – 100% passing 2mm(2000u)
3) Chelator – .05 M NTA
4) Growth media – TSB
5) Inoccuhum: – None
6) Pulp density – 10% Constant
7) Distilled water makeup
8) 17–day retention
9) 26°C temp.

Test 1: Sterile Soil + NTA + SD–1
Test 2: Sterile Soil + NTA
Test 3: Native soil + NTA + SD–1 +Native Orgs.

Test 4: Native Soil + NTA +Native Orgs.







TEST #4

A		B		C	
Gross	15.993	Gross	15.982	Gross	16.121
Tare	11.911	Tare	11.902	Tare	11.928
Net Wt./g.	4.082	Net Wt./g.	4.08	Net Wt./g.	4.193
TOTAL POSSIBLE/mg.:	0.926	TOTAL POSSIBLE/mg.:	1.026	TOTAL POSSIBLE/mg.:	1.520
TAILS/mg.:	0.083	TAILS/mg.:	0.224	TAILS/mg.	0.268
Cal. Head:	0.926	Cal. Head:	1.026	Cal. Head:	1.520

	DATE	DAY #	A pH	A Vol. (ml) Removed	A U (ppm) In Soln.	A mg In Soln.	A Cum mg In Soln.	A % In Soln.	A Cum. % In Soln.	B Vol. (ml) pH	B Vol. (ml) Removed	B U (ppm) In Soln.	B mg In Soln.	B Cum mg In Soln.	B % Solub	B Cum. % In Soln.	C Vol. (ml) pH	C Vol. (ml) Removed	C U (ppm) In Soln.	C mg In Soln.	C Cum mg In Soln.	C % Solub	C Cum. % In Soln.
	09/30/94	0																					
	10/02/94	2		41	8.60	0.35	0.35	38.0	38.0		42	7.7	0.32	0.32	31.5	31.5		41	12.4	0.51	0.51	33.4	33.4
Native Soil	10/04/94	4		40	7.25	0.29	0.64	31.3	69.4		40	6.9	0.28	0.60	26.9	58.4		40	6.2	0.25	0.76	16.3	49.7
+ NTA	10/06/94	6		40	3.39	0.14	0.78	14.6	84.0		40	3.3	0.13	0.73	13.0	71.4		40	5.4	0.21	0.97	14.1	63.8
+ Natives Orgs.	10/10/94	10		42	1.55	0.07	0.84	7.0	91.0		42	1.7	0.07	0.80	6.8	78.2		42	3.1	0.13	1.10	8.4	72.3
	10/17/94	17		92	0.00		0.84	0.0	91.0		88	0.0		0.80	0.0	78.2		84	1.8	0.15	1.25	10.1	82.4

CALCULATIONS: mg In Soln. = (U(ppm) In Soln. x Vol (ml) removed)/1000
% In Soln. = (mg In Soln./total possible)x 100
Calc. Head = Cum. mg removed + mg in Tails = Total Possible/mg.
*Negative data reported as 0.

REMEDIATED RESIDUALS:

TEST A	TEST B	TEST C	AVG.
20.4 ppm	54.8 ppm	63.9 ppm	46.4 ppm

SUMMARY DATA:

% Solubilization	TEST A	TEST B	TEST C	AVG.
Basis: Calc. Head (Soln + Solid)	91.0 %	78.2 %	82.4 %	83.9 %
Basis: Assay Head (Solids)	. . . . .	. . . . .	. . . . .	87.2%

APPENDIX D: PERCENT EXTRACTION OF TOTAL ACTINIDES BY BIOREDUCTION (TABLE II)

SOIL	TEST	PARAMETER	% TOTAL ACTINIDES EXTRACTED* DAY 2	DAY 4	DAY 6	FINAL
RFP	1 A,B,C	Sterile + NTA + SD-1	62.8	79.2	84.9	**88.8**
RFP	2 A,B,C	Sterile + NTA	43.5	65.5	74.5	**86.0**
RFP	3 A,B,C	Native + NTA + SD-1	47.9	66.9	72.0	**76.7**
RFP	4 A,B,C	Native + NTA	43.8	74.9	83.7	**88.0**
LANL	1 A,B,C	Sterile + NTA + SD-1	61.8	75.8	76.1	**76.1**
LANL	2 A,B,C	Sterile + NTA	50.0	59.0	63.8	**72.5**
LANL	3 A,B,C	Native + NTA + SD-1	55.6	70.9	73.1	**74.7**
LANL	4 A,B,C	**Native + NTA**	**28.9**	58.5	67.7	**71.3**
MOUND	1 A,B,C	Sterile + NTA + SD-1	57.5	85.8	90.6	**92.1**
MOUND	2 A,B,C	Sterile + NTA	29.1	54.7	82.4	**89.3**
MOUND	3 A,B,C	Native + NTA + SD-1	63.1	89.7	93.7	**95.0**
MOUND	4 A,B,C	Native + NTA	49.0	85.0	92.1	**94.1**
HANFORD	1 A,B,C	Sterile + NTA + SD-1	20.7	34.3	56.7	**96.2**
HANFORD	2 A,B,C	Sterile + NTA	13.0	25.7	46.5	**93.8**
HANFORD	3 A,B,C	Native + NTA + SD-1	31.0	51.9	80.2	**96.9**
HANFORD	4 A,B,C	Native + NTA	25.5	48.9	74.7	**95.4**
FERNALD	1 A,B,C	Sterile + NTA + SD-1	51.8	70.4	79.3	**82.4**
FERNALD	2 A,B,C	Sterile + NTA	19.7	39.2	56.5	**95.5**
FERNALD	3 A,B,C	Native + NTA + SD-1	32.8	65.7	79.4	**82.1**
FERNALD	4 A,B,C	Native + NTA	34.3	59.2	73.1	**83.9**

*average of three replicates

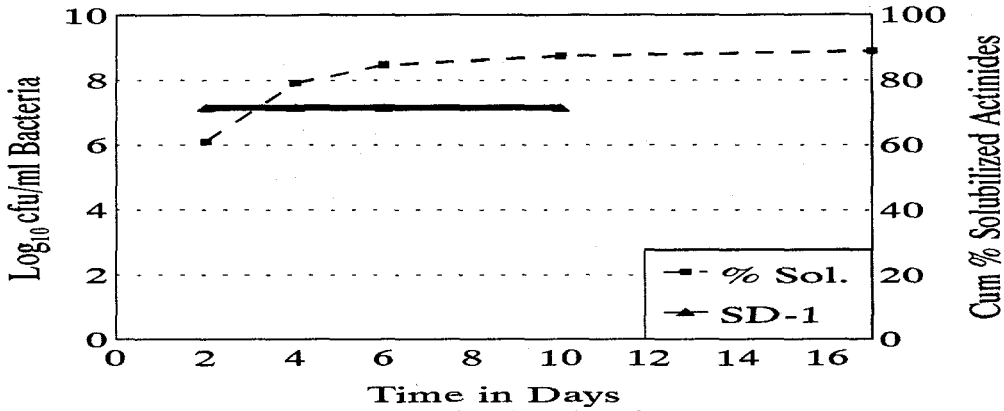
BEST TEST

Appendix E-1

Biological Test Parameters

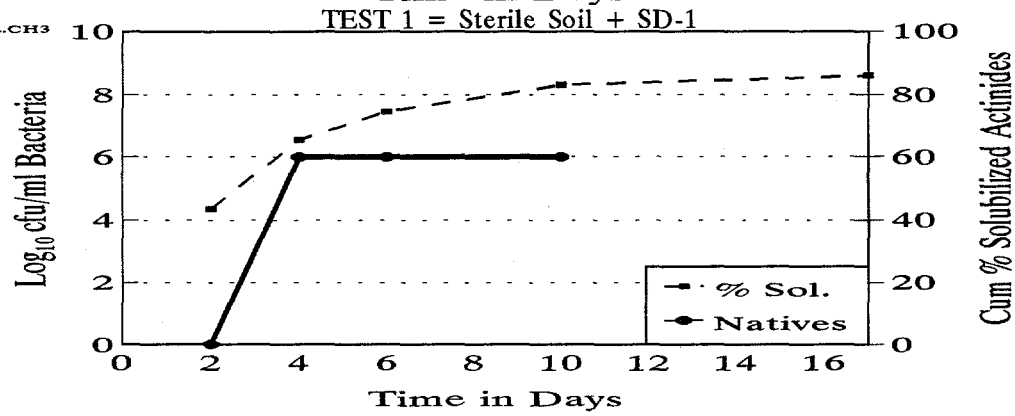
ROCKY FLATS SOIL

Pu-Am



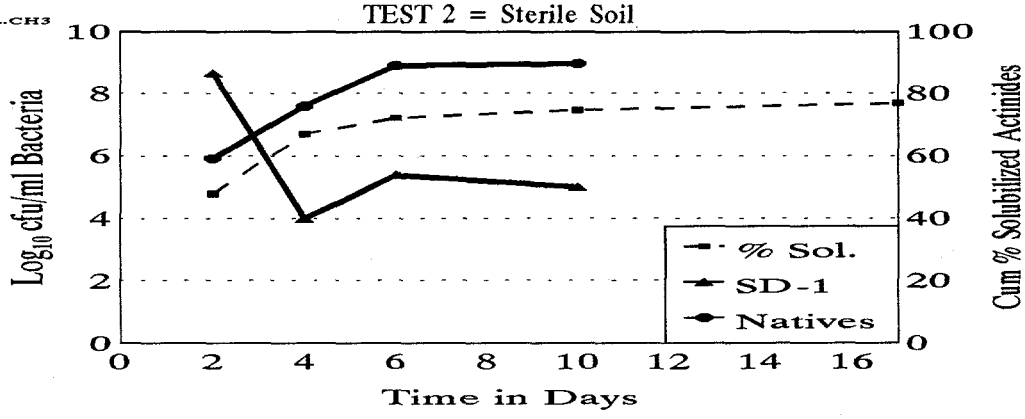
RF-T1CFL.CH3

TEST 1 = Sterile Soil + SD-1



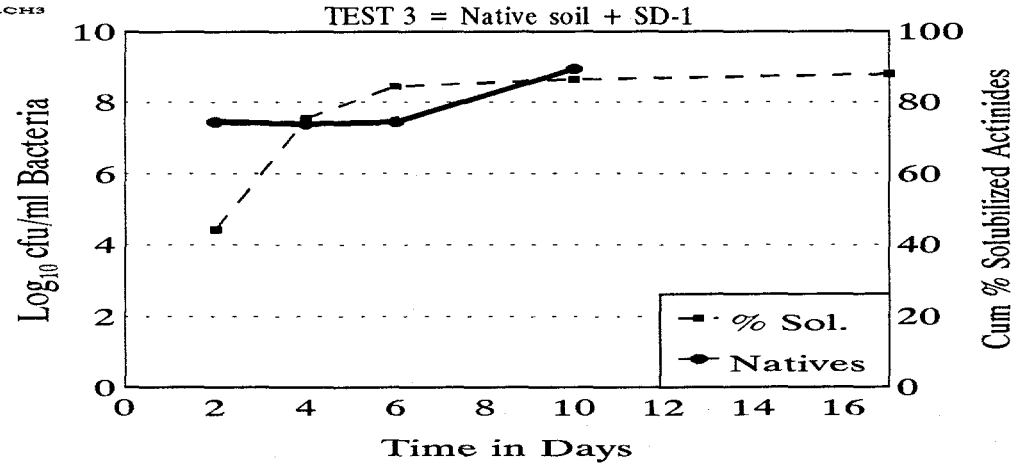
RF-T2CFL.CH3

TEST 2 = Sterile Soil



RF-T3CFL.CH3

TEST 3 = Native soil + SD-1



RF-T4CFL.CH3

TEST 4 = Native Soil

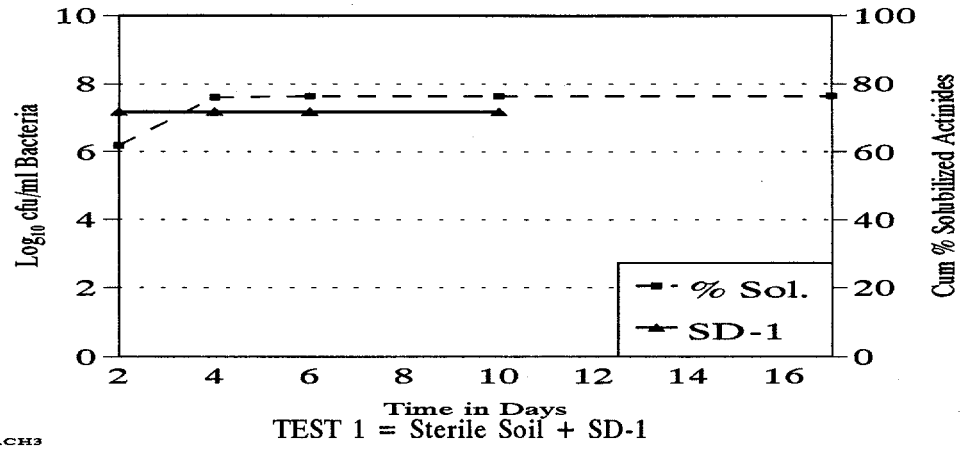
NTA used in all tests.

Appendix E - 2

Biological Test Parameters

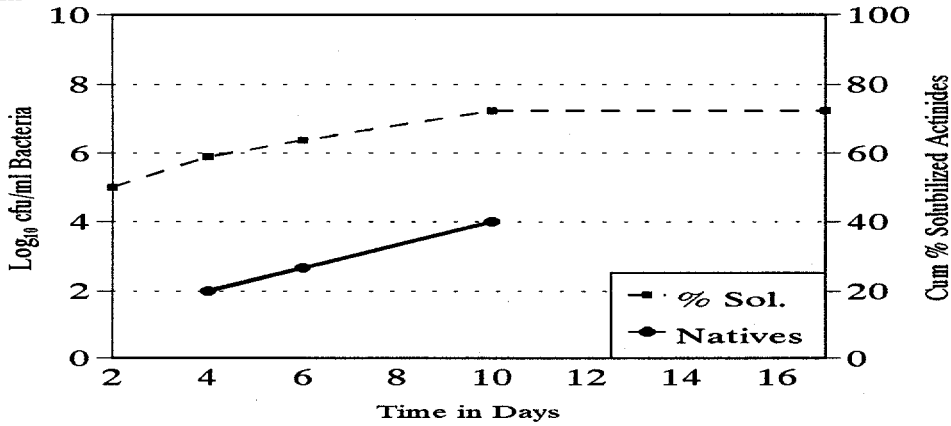
Pu-Am

LANL SOIL



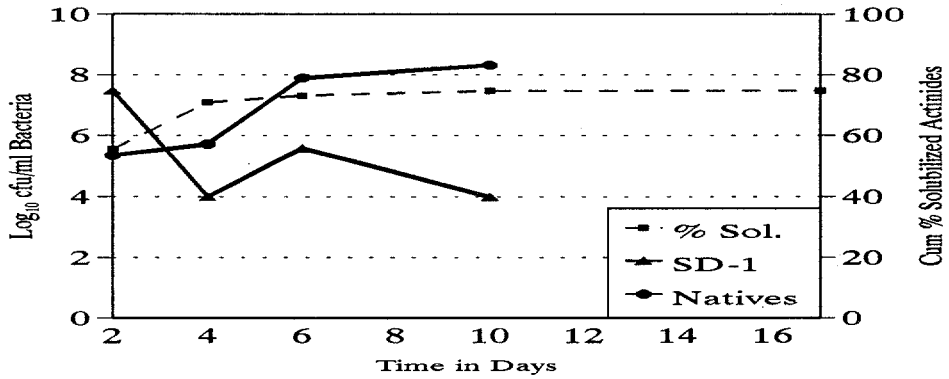
LANL-T1.CH3

TEST 1 = Sterile Soil + SD-1



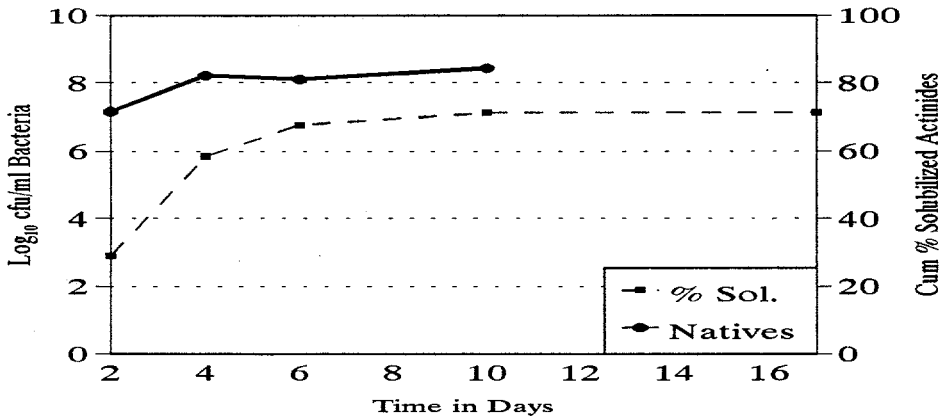
LANL-T2.CH3

TEST 2 = Sterile Soil



LANL-T3.CH3

TEST 3 = Native Soil + SD-1



LANL-T4.CH3

TEST 4 = Native Soil

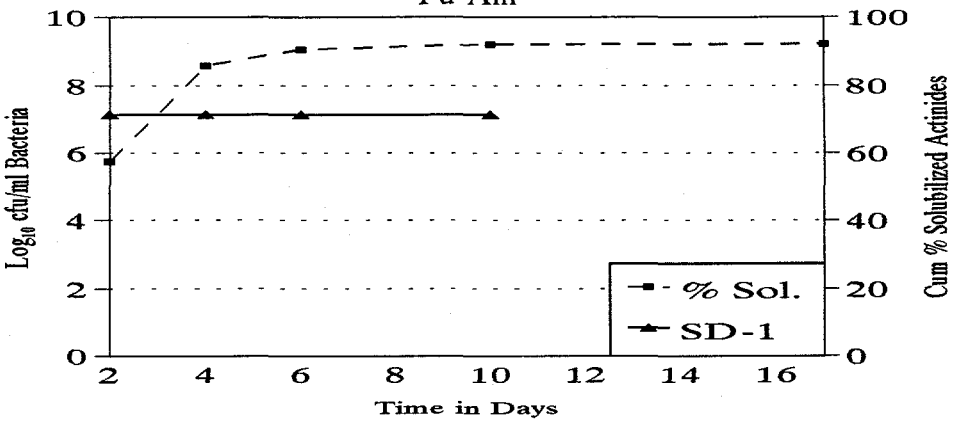
NTA used in all tests.

Appendix E - 3

Biological Test Parameters

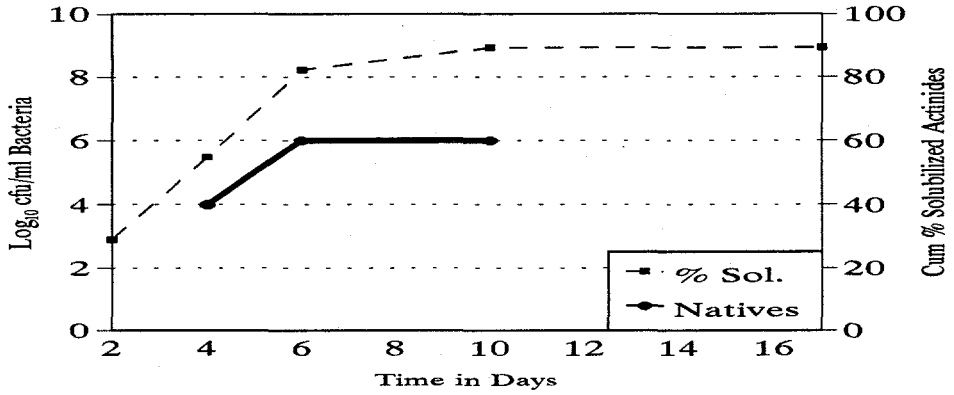
MOUND SOIL

Pu-Am



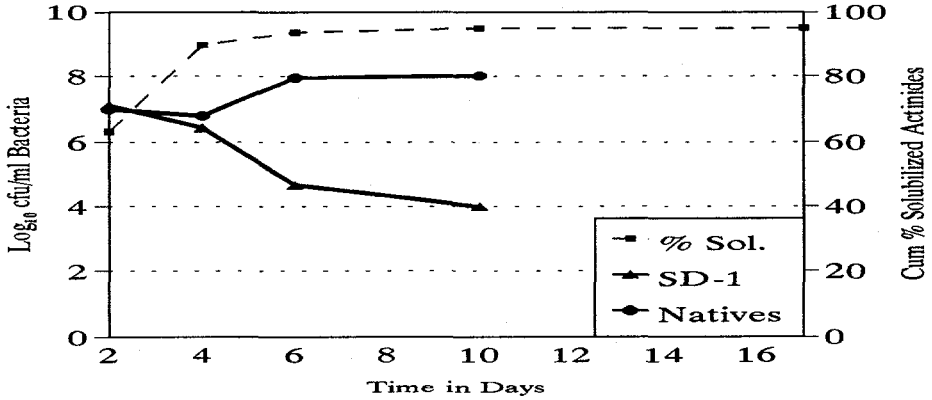
MOUND-T1.CH3

TEST 1 = Sterile Soil + SD-1



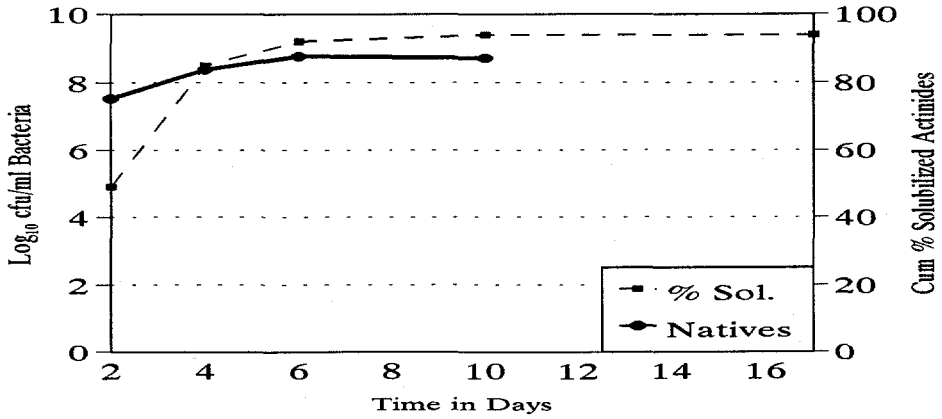
MOUND-T2.CH3

TEST 2 = Sterile Soil



MOUND-T3.CH3

TEST 3 = Native Soil + SD-1



MOUND-T4.CH3

TEST 4 = Native Soil

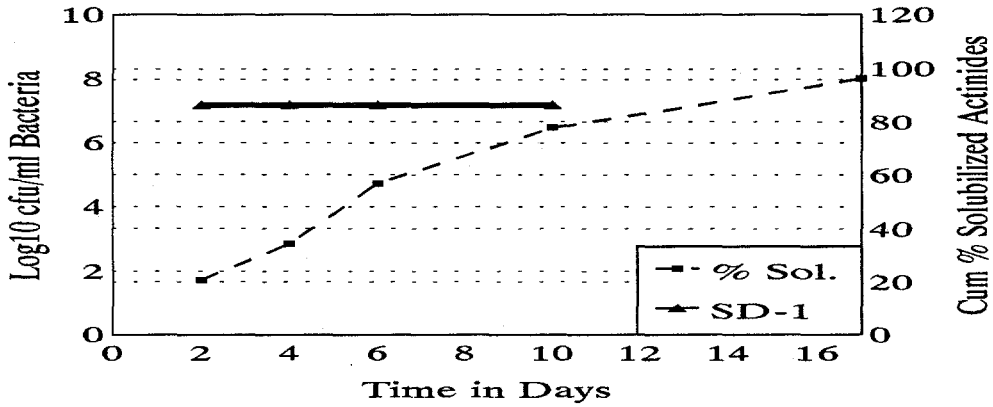
NTA used in all tests.

Appendix E - 4

Biological Test Parameters

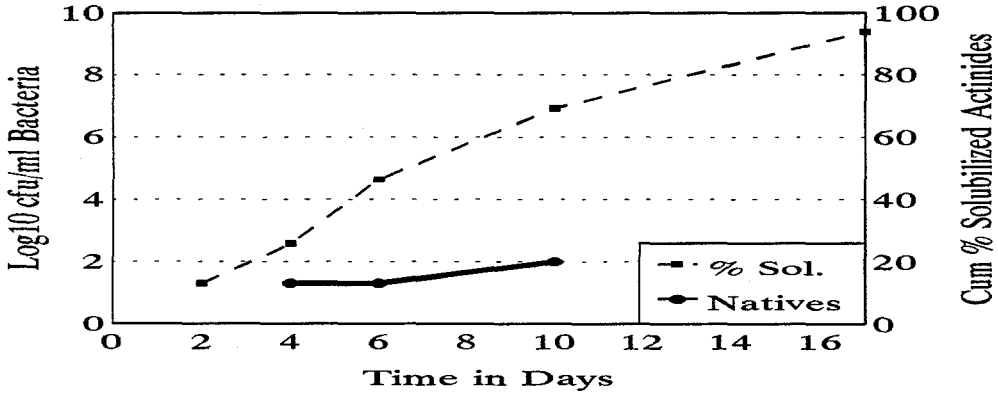
Uranium

HANFORD SOIL



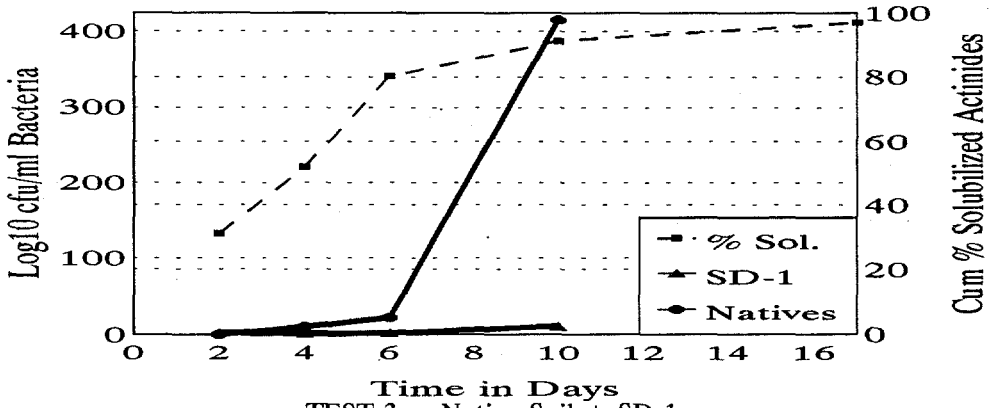
HANF-T1.CH3

TEST 1 = Sterile Soil + SD-1



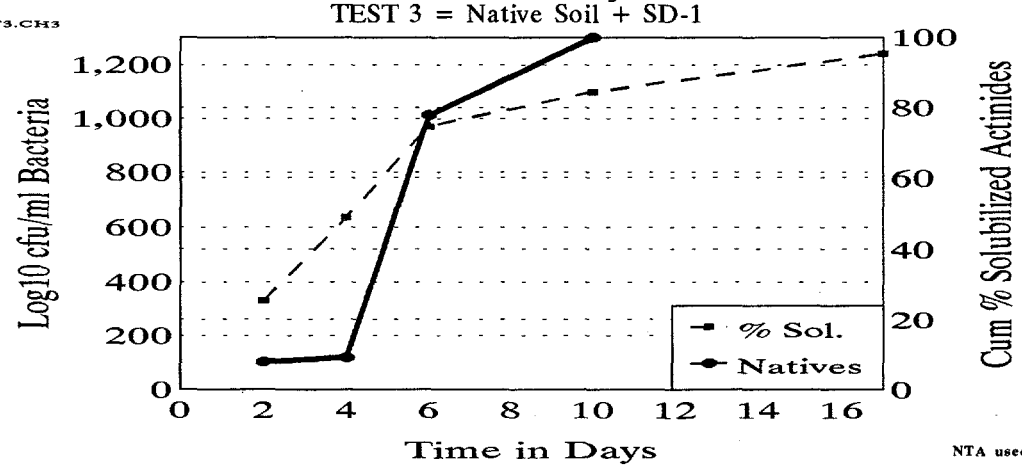
HANF-T2.CH3

TEST 2 = Sterile Soil



HANF-T3.CH3

TEST 3 = Native Soil + SD-1



NTA used in all tests.

HANF-T4.CH3

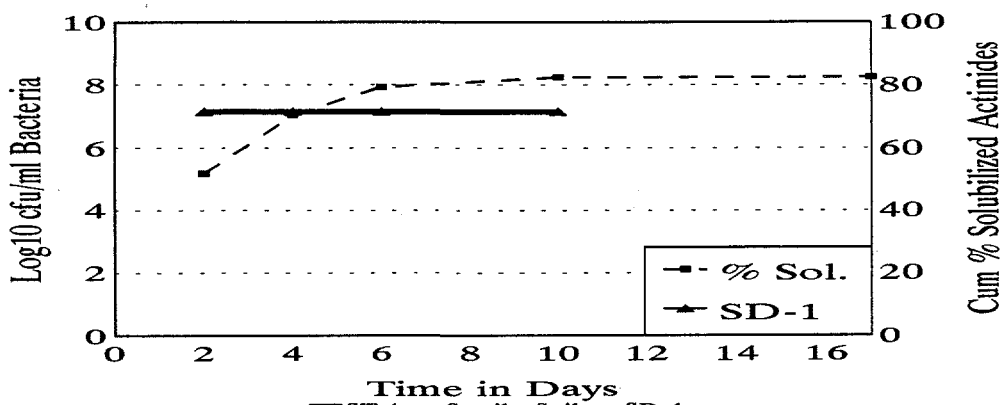
TEST 4 = Native Soil

Appendix E - 5

Biological Test Parameters

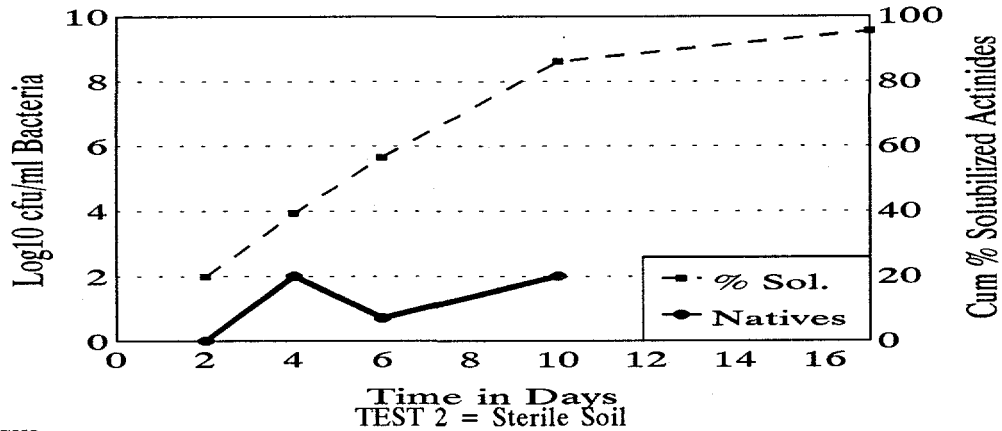
FERNALD SOIL

Uranium



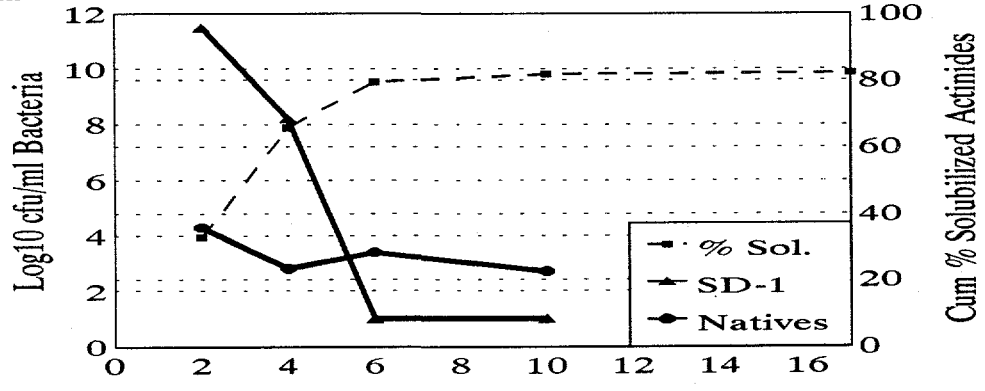
FERN-T1.CH3

TEST 1 = Sterile Soil + SD-1



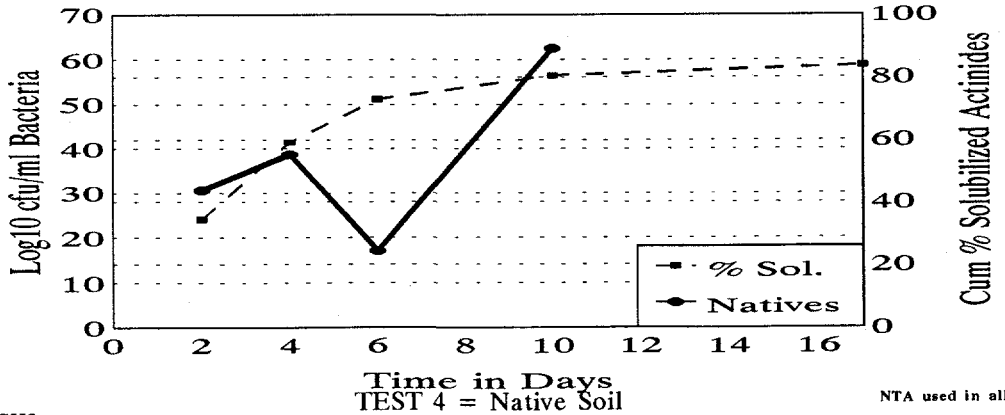
FERN-T2.CH3

TEST 2 = Sterile Soil



FERN-T3.CH3

TEST 3 = Native Soil + SD-1



FERN-T4.CH3

TEST 4 = Native Soil

NTA used in all tests.

Appendix F

Test Results Statistics

ROCKY FLATS SOIL

Extraction Summary

TEST	REPLICATES - DAY 2 A	REPLICATES - DAY 2 B	REPLICATES - DAY 2 C	REPLICATES - DAY 17 A	REPLICATES - DAY 17 B	REPLICATES - DAY 17 C
Test 1: SD-1 + NTA	61.5	55.7	66.4	86.0	90.7	89.8
Test 2: Sterile Soil + NTA	47.5	40.1	43.0	89.3	81.4	87.4
Test 3: SD-1 + Native + NTA	28.1	57.8	57.9	67.1	81.4	81.7
Test 4: Native + NTA	43.1	46.0	42.2	85.2	87.2	91.6

Anova: Single Factor Based on Replicates - Day 2

SUMMARY OF REPLICATES - DAY 2

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	183.6	61.2	28.7
Test 2: Sterile Soil + NTA	3	130.6	43.5	13.9
Test 3: SD-1 + Native + NTA	3	143.8	47.9	295.0
Test 4: Native + NTA	3	131.5	43.8	3.6

ANOVA Based on Replicates - Day 2

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	621.6	3	207.2	2.4	0.1	4.1
Within Groups	683.1	8	85.4			
Total	1304.7	11				

The calculated F-value is less than the critical F-value at the 95% probability level.
Therefore there is not a significant difference between the groups at the 95% probability level.

Anova: Single Factor Based on Replicates - Day 17

SUMMARY OF REPLICATES - DAY 17

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	266.5	88.8	6.2
Test 2: Sterile Soil + NTA	3	258.1	86.0	17.0
Test 3: SD-1 + Native + NTA	3	230.2	76.7	69.6
Test 4: Native + NTA	3	264.0	88.0	10.7

ANOVA Based on Replicates - Day 17

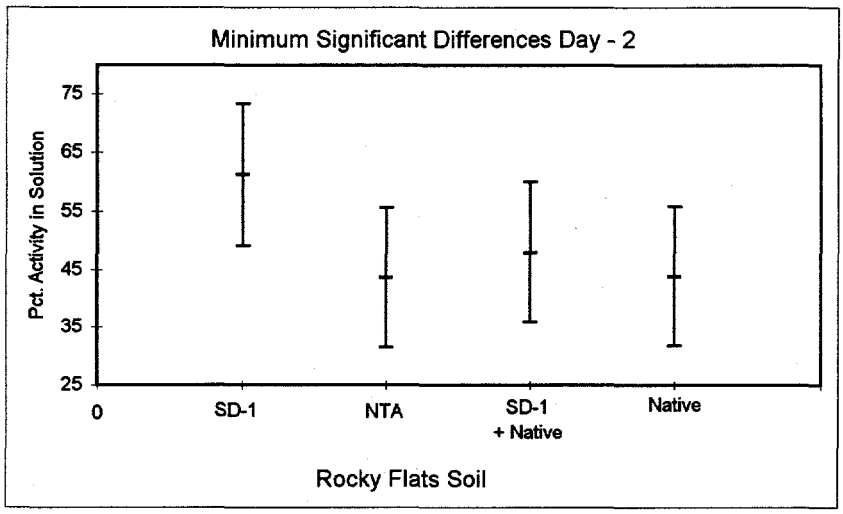
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	279.2	3	93.1	3.6	0.1	4.1
Within Groups	207.1	8	25.9			
Total	486.3	11				

The calculated F-value is less than the critical F-value at the 95% probability level.
Therefore there is not a significant difference between the groups at the 95% probability level.
However, there would be a significant difference at the 90% probability level.
The critical F value at 90% probability = 2.92 which is less than the calculated F.

Appendix F

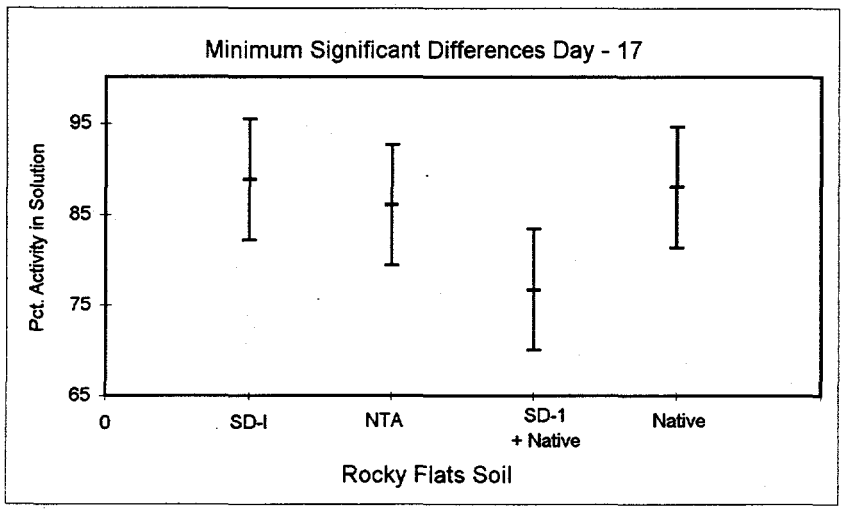
Test Results Statistics

95% comparison intervals for the means of actinide extraction data.
Means whose intervals do not overlap are significantly different.



Comparison of Treatments Day - 2

	SD-1	NTA	SD1+Nat	Native
Mean	61.2	43.5	47.9	43.8
Lower Limit	49.1	31.5	35.9	31.8
Upper Limit	73.3	55.6	60.0	55.9



Comparison of Treatments Day - 17

	SD1	NTA	SD1+Nat	Native
Mean	88.8	86.0	76.7	88.0
Lower Limit	82.2	79.4	70.1	81.3
Upper Limit	95.5	92.7	83.4	94.7

Appendix F

Test Results Statistics

MOUND SOIL

Extraction Summary

TEST	REPLICATES - DAY 2 A	REPLICATES - DAY 2 B	REPLICATES - DAY 2 C	REPLICATES - DAY 17 A	REPLICATES - DAY 17 B	REPLICATES - DAY 17 C
Test 1: SD-1 + NTA	67.3	66.1	39.1	94.5	93.4	88.5
Test 2: Sterile Soil + NTA	28.7	31.9	26.8	89.3	90.0	88.6
Test 3: SD-1 + Native + NTA	65.3	68.2	55.7	94.2	95.6	95.2
Test 4: Native + NTA	52.4	48.8	45.9	96.5	88.2	97.6

Anova: Single Factor Based on Replicates - Day 2

SUMMARY OF REPLICATES - DAY 2

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	172.5	57.5	254.3
Test 2: Sterile Soil + NTA	3	87.4	29.1	6.6
Test 3: SD-1 + Native + NTA	3	189.2	63.1	42.8
Test 4: Native + NTA	3	147.1	49.0	10.6

ANOVA Based on Replicates - Day 2

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1988.8	3	662.9	8.4	0.007	4.1
Within Groups	628.7	8	78.6			
Total	2617.5	11				

The calculated F-value is greater than the critical F-value at the 95% probability level.
Therefore there is a significant difference between the groups at the 95% probability level.

Anova: Single Factor Based on Replicates - Day 17

SUMMARY OF REPLICATES - DAY 17

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	276.4	92.1	10.2
Test 2: Sterile Soil + NTA	3	267.9	89.3	0.5
Test 3: SD-1 + Native + NTA	3	285.0	95.0	0.5
Test 4: Native + NTA	3	282.3	94.1	26.4

ANOVA Based on Replicates - Day 17

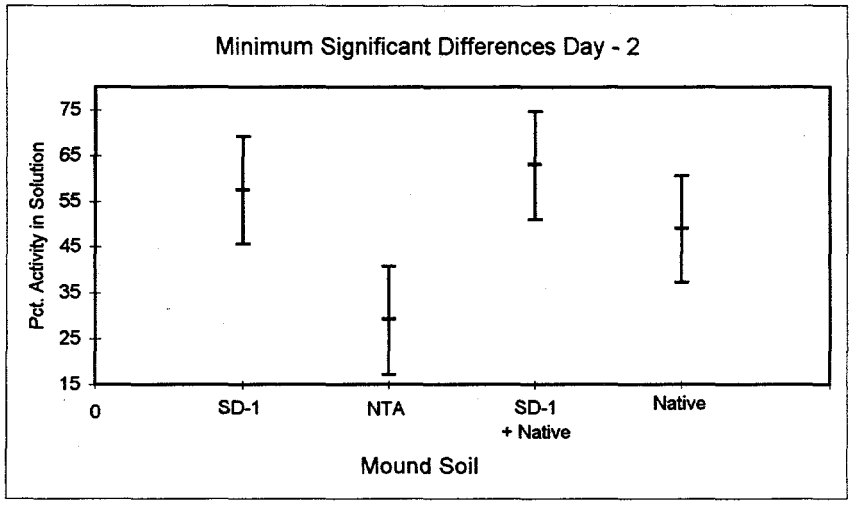
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	57.3	3	19.1	2.0	0.2	4.1
Within Groups	75.2	8	9.4			
Total	132.6	11				

The calculated F-value is less than the critical F-value at the 95% probability level.
Therefore there is not a significant difference between the groups at the 95% probability level.

Appendix F

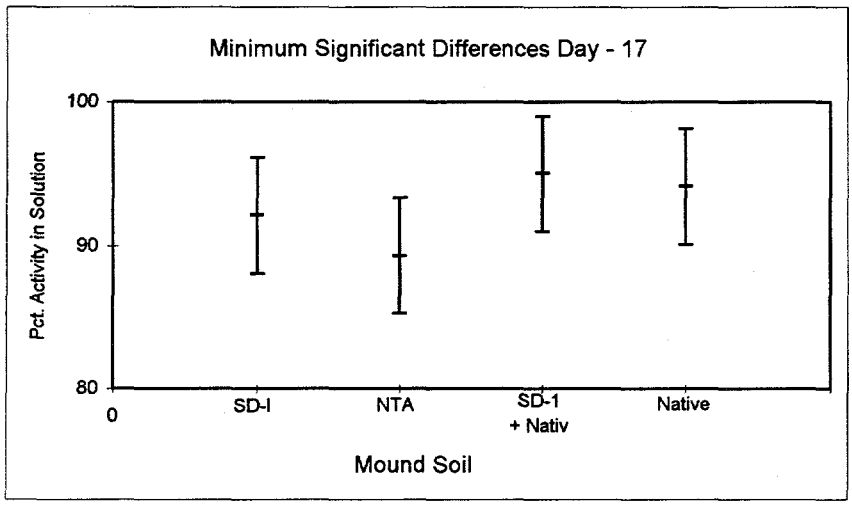
Test Results Statistics

95% comparison intervals for the means of actinide extraction data.
Means whose intervals do not overlap are significantly different.



Comparison of Treatments Day - 2

	SD-1	NTA	SD1+Nat	Native
Mean	57.5	29.1	63.1	49.0
Lower Limit	45.9	17.5	51.5	37.4
Upper Limit	69.1	40.7	74.7	60.6



Comparison of Treatments Day - 17

	SD1	NTA	SD1+Nat	Native
Mean	92.1	89.3	95.0	94.1
Lower Limit	88.1	85.3	91.0	90.1
Upper Limit	96.1	93.3	99.0	98.1

Appendix F

Test Results Statistics

LOS ALAMOS SOIL

Extraction Summary

TEST	REPLICATES - DAY 2 A	REPLICATES - DAY 2 B	REPLICATES - DAY 2 C	REPLICATES - DAY 17 A	REPLICATES - DAY 17 B	REPLICATES - DAY 17 C
Test 1: SD-1 + NTA	68.2	52.7	64.6	84.0	65.8	78.5
Test 2: Sterile Soil + NTA	47.6	54.9	47.4	70.8	76.0	70.7
Test 3: SD-1 + Native + NTA	52.3	55.0	58.3	69.5	74.2	78.8
Test 4: Native + NTA	24.4	29.2	33.1	64.5	70.4	79.1

Anova: Single Factor Based on Replicates - Day 2

SUMMARY OF REPLICATES - DAY 2

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	185.5	61.8	65.8
Test 2: Sterile Soil + NTA	3	149.9	50.0	18.3
Test 3: SD-1 + Native + NTA	3	165.6	55.2	9.0
Test 4: Native + NTA	3	86.7	28.9	19.0

ANOVA Based on Replicates - Day 2

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1824.2	3	608.1	21.7	0.0003	4.1
Within Groups	224.2	8	28.0			
Total	2048.4	11				

The calculated F-value is greater than the critical F-value at the 95% probability level.
Therefore there is a significant difference between the groups at the 95% probability level.

Anova: Single Factor Based on Replicates - Day 17

SUMMARY OF REPLICATES - DAY 17

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	228.3	76.1	87.1
Test 2: Sterile Soil + NTA	3	217.5	72.5	9.2
Test 3: SD-1 + Native + NTA	3	222.5	74.2	21.6
Test 4: Native + NTA	3	214.0	71.3	53.9

ANOVA Based on Replicates - Day17

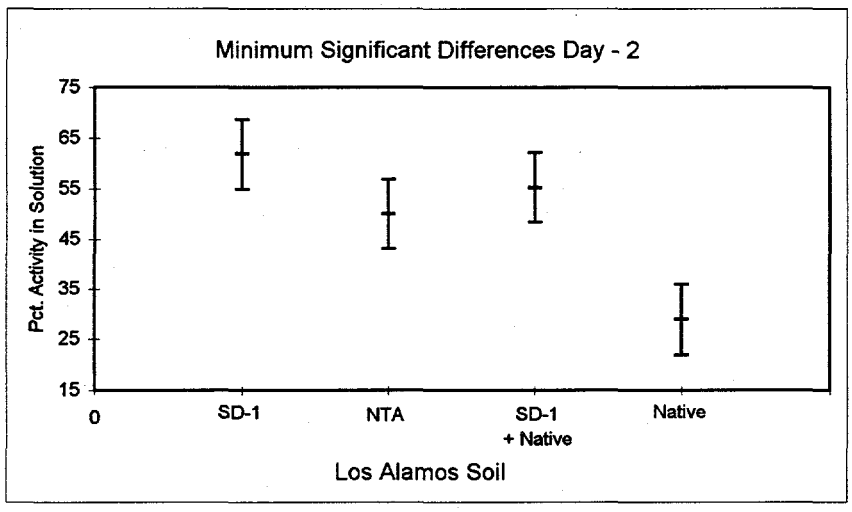
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	38.7	3	12.9	0.3	0.8	4.1
Within Groups	343.8	8	43.0			
Total	382.5	11				

The calculated F-value is less than the critical F-value at the 95% probability level.
Therefore there is not a significant difference between the groups at the 95% probability level.

Appendix F

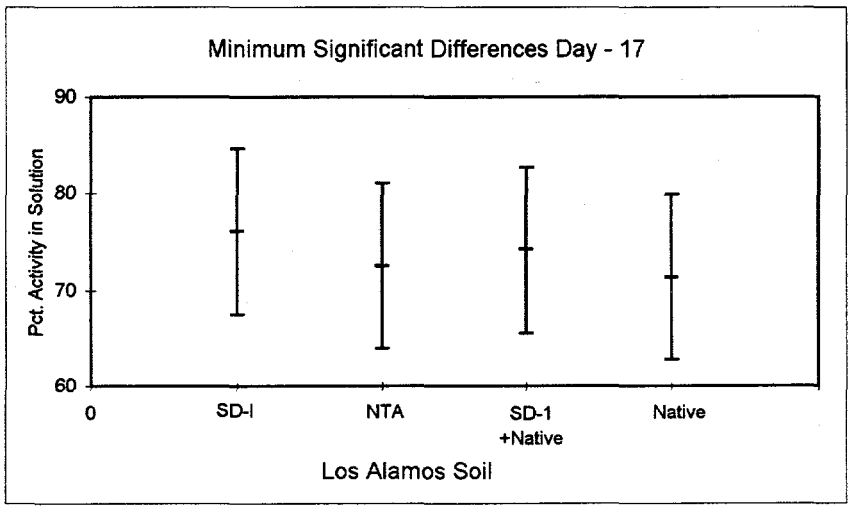
Test Results Statistics

95% comparison intervals for the means of actinide extraction data.
Means whose intervals do not overlap are significantly different.



Comparison of Treatments Day - 2

	SD-1	NTA	SD1+Nat	Native
Mean	61.8	50.0	55.2	28.9
Lower Limit	54.9	43.0	48.3	22.0
Upper Limit	68.8	56.9	62.1	35.8



Comparison of Treatments Day - 17

	SD1	NTA	SD1+Nat	Native
Mean	76.1	72.5	74.2	71.3
Lower Limit	67.5	63.9	65.6	62.8
Upper Limit	84.7	81.1	82.7	79.9

Appendix F

Test Results Statistics

FERNALD SOIL

Extraction Summary

TEST	REPLICATES - DAY 2 A	REPLICATES - DAY 2 B	REPLICATES - DAY 2 C	REPLICATES - DAY 17 A	REPLICATES - DAY 17 B	REPLICATES - DAY 17 C
Test 1: SD-1 + NTA	51.9	53.0	50.5	79.9	83.8	83.6
Test 2: Sterile Soil + NTA	21.0	16.4	21.8	94.5	96.4	95.6
Test 3: SD-1 + Native + NTA	29.6	31.5	37.2	82.6	73.8	90.0
Test 4: Native + NTA	38.0	31.5	33.4	91.0	78.2	82.4

Anova: Single Factor Based on Replicates - Day 2

SUMMARY OF REPLICATES - DAY 2

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	155.4	51.8	1.6
Test 2: Sterile Soil + NTA	3	59.2	19.7	8.5
Test 3: SD-1 + Native + NTA	3	98.3	32.8	15.6
Test 4: Native + NTA	3	102.9	34.3	11.2

ANOVA Based on Replicates - Day 2

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1560.9	3	520.3	56.4	1.0E-5	4.1
Within Groups	73.8	8	9.2			
Total	1634.6	11				

The calculated F-value is greater than the critical F-value at the 95% probability level.
Therefore there is a significant difference between the groups at the 95% probability level.

Anova: Single Factor Based on Replicates - Day 17

SUMMARY OF REPLICATES - DAY 17

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	247.3	82.4	4.8
Test 2: Sterile Soil + NTA	3	286.5	95.5	0.9
Test 3: SD-1 + Native + NTA	3	246.4	82.1	65.8
Test 4: Native + NTA	3	251.6	83.9	42.6

ANOVA Based on Replicates - Day 17

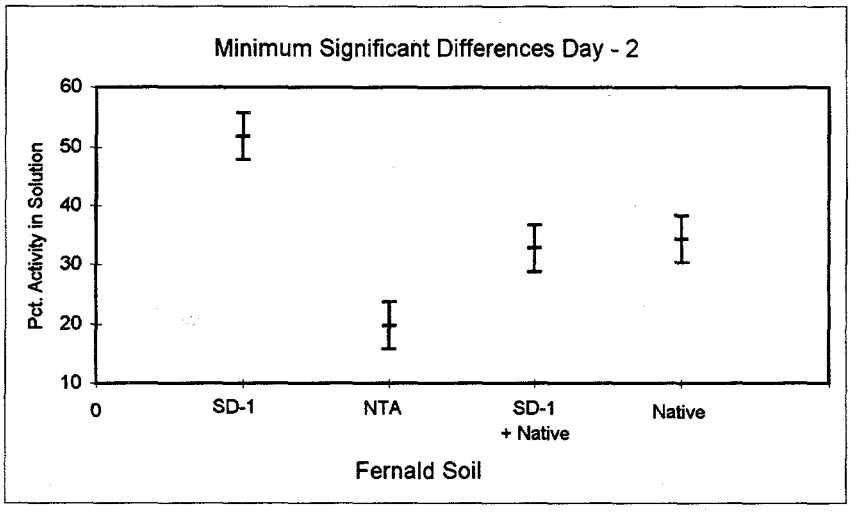
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	367.4	3.0	122.5	4.3	0.04	4.1
Within Groups	228.2	8.0	28.5			
Total	595.6	11.0				

The calculated F-value is greater than the critical F-value at the 95% probability level.
Therefore there is a significant difference between the groups at the 95% probability level.

Appendix F

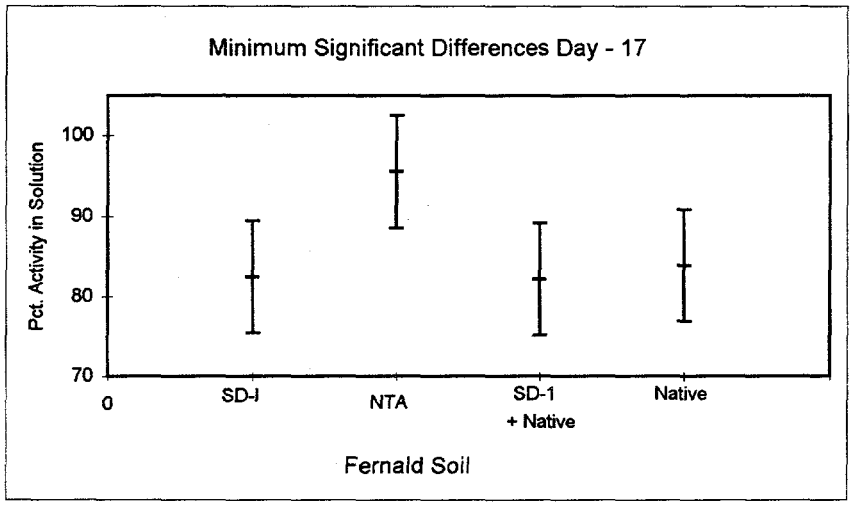
Test Results Statistics

95% comparison intervals for the means of actinide extraction data.
Means whose intervals do not overlap are significantly different.



Comparison of Treatments Day - 2

	SD-1	NTA	SD1+Nat	Native
Mean	51.8	19.7	32.8	34.3
Lower Limit	47.8	15.8	28.8	30.3
Upper Limit	55.8	23.7	36.7	38.3



Comparison of Treatments Day - 17

	SD1	NTA	SD1+Nat	Native
Mean	82.4	95.5	82.1	83.9
Lower Limit	75.5	88.5	75.2	76.9
Upper Limit	89.4	102.5	89.1	90.8

Appendix F

Test Results Statistics

HANFORD SOIL

Extraction Summary

TEST	REPLICATES - DAY 2 A	REPLICATES - DAY 2 B	REPLICATES - DAY 2 C	REPLICATES - DAY 17 A	REPLICATES - DAY 17 B	REPLICATES - DAY 17 C
Test 1: SD-1 + NTA	22.2	20.9	19.1	96.5	95.9	96.2
Test 2: Sterile Soil + NTA	12.5	14.6	11.8	86.3	97.7	97.5
Test 3: SD-1 + Native + NTA	36.4	36.7	20.0	97.2	96.5	97.1
Test 4: Native + NTA	25.8	21.4	29.3	96.1	94.6	95.4

Anova: Single Factor Based on Replicates - Day 2

SUMMARY OF REPLICATES - DAY 2

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	62.2	20.7	2.4
Test 2: Sterile Soil + NTA	3	38.9	13.0	2.1
Test 3: SD-1 + Native + NTA	3	93.1	31.0	91.3
Test 4: Native + NTA	3	76.5	25.5	15.7

ANOVA Based on Replicates - Day 2

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	527.4	3	175.8	6.3	0.02	4.1
Within Groups	223.1	8	27.9			
Total	750.5	11				

The calculated F-value is greater than the critical F-value at the 95% probability level.
Therefore there is a significant difference between the groups at the 95% probability level.

Anova: Single Factor Based on Replicates - Day 17

SUMMARY OF REPLICATES - DAY 17

Groups	*Count*	*Sum*	*Average*	*Variance*
Test 1: SD-1 + NTA	3	288.6	96.2	0.1
Test 2: Sterile Soil + NTA	3	281.5	93.8	42.6
Test 3: SD-1 + Native + NTA	3	290.8	96.9	0.1
Test 4: Native + NTA	3	286.1	95.4	0.6

ANOVA Based on Replicates - Day17

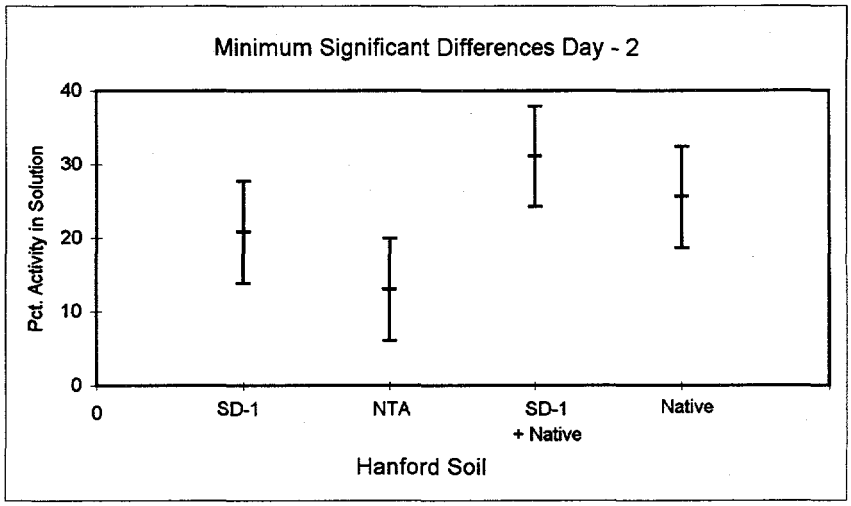
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15.9	3	5.3	0.5	0.7	4.1
Within Groups	86.7	8	10.8			
Total	102.7	11				

The calculated F-value is less than the critical F-value at the 95% probability level.
Therefore there is not a significant difference between the groups at the 95% probability level.

Appendix F

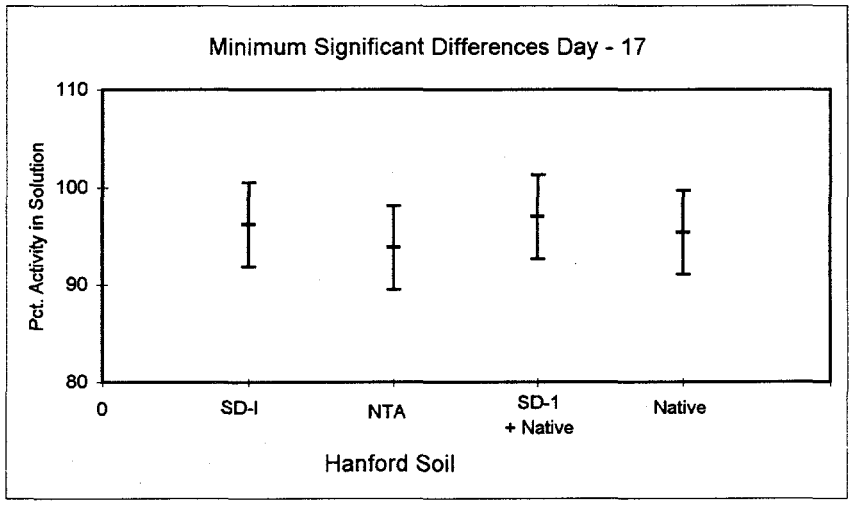
Test Results Statistics

95% comparison intervals for the means of actinide extraction data.
Means whose intervals do not overlap are significantly different.



Comparison of Treatments Day - 2

	SD-1	NTA	SD1+Nat	Native
Mean	20.7	13.0	31.0	25.5
Lower Limit	13.8	6.1	24.1	18.6
Upper Limit	27.6	19.9	37.9	32.4



Comparison of Treatments Day - 17

	SD1	NTA	SD1+Nat	Native
Mean	96.2	93.8	96.9	95.4
Lower Limit	91.9	89.5	92.6	91.1
Upper Limit	100.5	98.1	101.2	99.7

Appendix F

Test Results Statistics

SOLUBLIZATION RATES

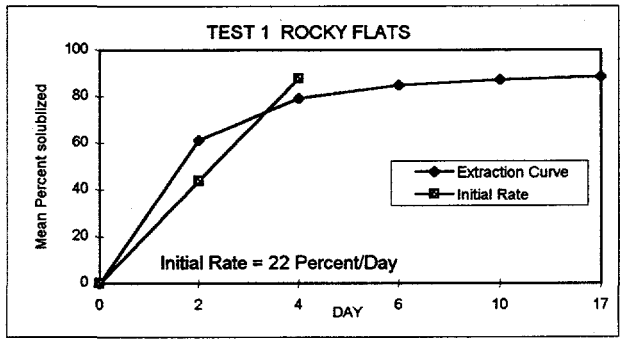
Test 1: SD-1

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	61.5	55.7	66.4	61.2
4	79.0	75.2	83.5	79.2
6	83.3	84.5	87.0	84.9
10	84.7	89.3	88.5	87.5
17	86.0	90.7	89.8	88.8

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	43.9
4	87.9

Initial Rate =22 Percent/Day



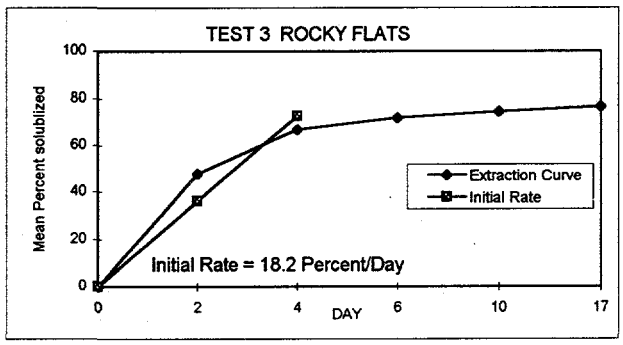
Test 3: SD-1 + NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	28.1	57.8	57.9	47.9
4	52.7	73.9	74.2	66.9
6	60.1	77.9	78.0	72.0
10	63.8	79.8	80.0	74.5
17	67.1	81.4	81.7	76.7

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	36.4
4	72.7

Initial Rate =18.2 Percent/Day



Appendix F

Test Results Statistics

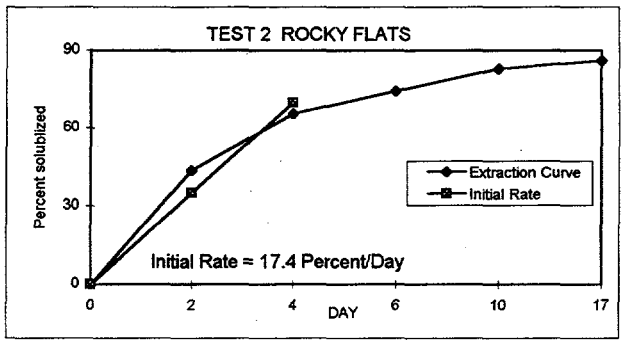
Test 2: NTA

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	47.5	40.1	43.0	43.5
4	69.8	62.6	64.1	65.5
6	79.1	70.6	73.9	74.5
10	86.6	78.3	84.3	83.1
17	89.3	81.5	87.4	86.1

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	34.9
4	69.8

Initial Rate =17.4 Percent/Day



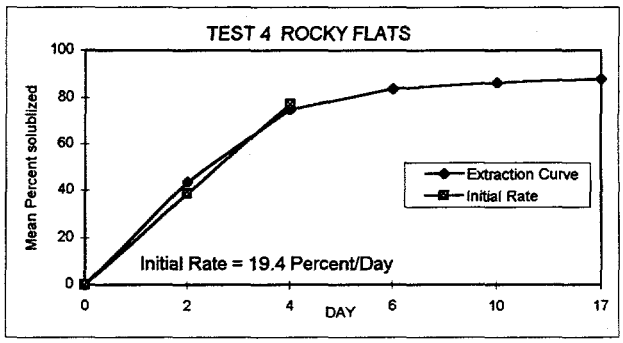
Test 4: NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	43.1	46.0	42.2	43.8
4	72.1	74.8	77.7	74.9
6	80.8	83.4	87.0	83.7
10	83.5	85.6	90.1	86.4
17	85.2	87.2	91.6	88.0

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	38.7
4	77.4

Initial Rate =19.4 Percent/Day



Appendix F

Test Results Statistics

SOLUBLIZATION RATES FROM PERCENTAGES

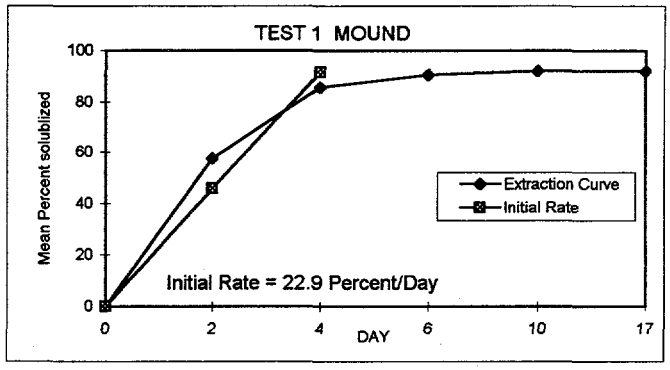
Test 1: SD-1

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	67.3	66.1	39.1	57.5
4	88.3	87.8	81.4	85.8
6	93.0	92.0	86.9	90.6
10	94.5	93.4	88.5	92.1
17	94.5	93.4	88.5	92.1

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	45.8
4	91.7

Initial Rate =22.9 Percent/Day



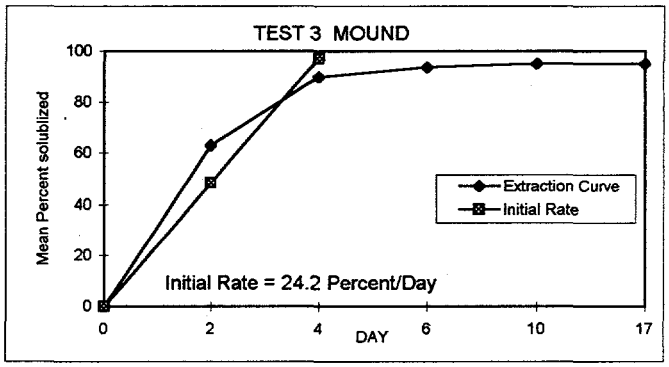
Test 3: SD-1 + NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	65.3	68.2	55.7	63.1
4	89.5	90.6	88.9	89.7
6	93.0	94.6	93.6	93.7
10	94.2	95.6	95.2	95.0
17	94.2	95.6	95.2	95.0

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	48.5
4	97.0

Initial Rate =24.2 Percent/Day



Appendix F

Test Results Statistics

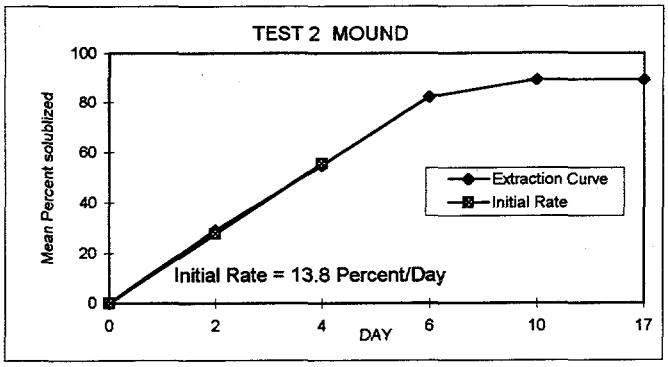
Test 2: NTA

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	28.7	31.9	26.8	29.1
4	67.8	52.7	43.5	54.7
6	84.6	82.5	80.0	82.4
10	89.3	90.0	88.6	89.3
17	89.3	90.0	88.6	89.3

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	27.7
4	55.4

Initial Rate =13.8 Percent/Day



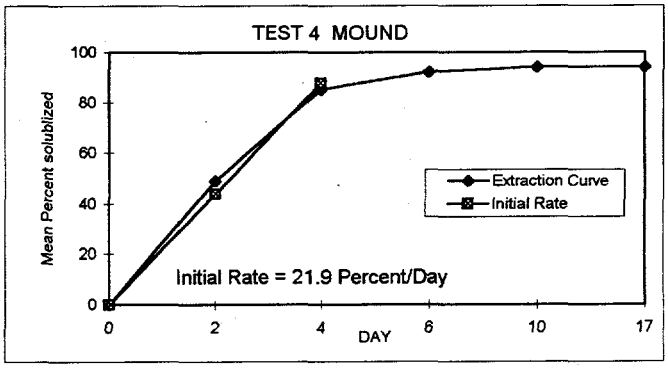
Test 4: NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	52.4	48.8	45.9	49.0
4	85.7	82.5	86.8	85.0
6	94.2	86.7	95.5	92.1
10	96.5	88.2	97.6	94.1
17	96.5	88.2	97.6	94.1

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	43.8
4	87.6

Initial Rate =21.9 Percent/Day



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Test Results Statistics

SOLUBLIZATION RATES FROM PERCENTAGES

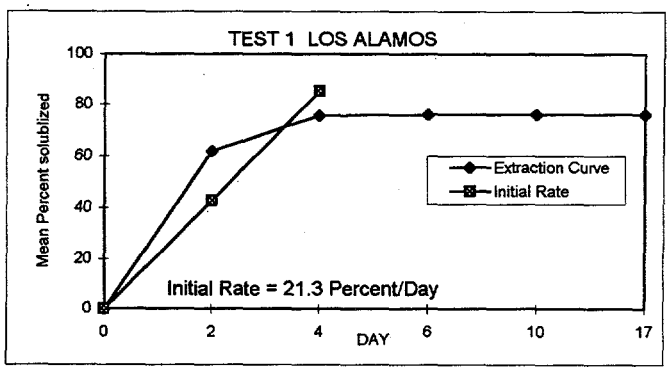
Test 1: SD-1

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	68.2	52.7	64.6	61.8
4	83.5	65.3	78.5	75.8
6	84.0	65.8	78.5	76.1
10	84.0	65.8	78.5	76.1
17	84.0	65.8	78.5	76.1

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	42.7
4	85.3

Initial Rate =21.3 Percent/Day



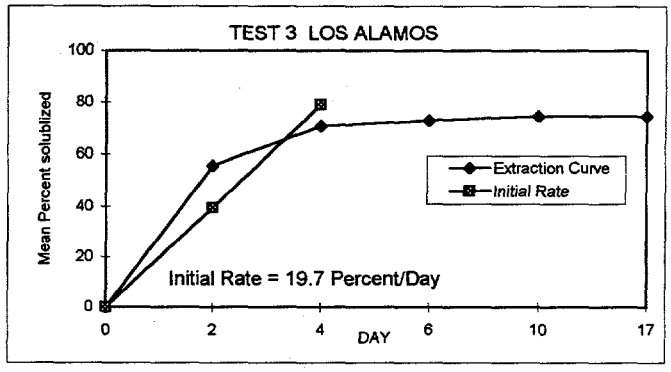
Test 3: SD-1 + NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	52.3	55.0	59.5	55.6
4	65.7	70.8	76.2	70.9
6	68.1	73.0	78.1	73.1
10	69.5	74.2	80.4	74.7
17	69.5	74.2	80.4	74.7

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	39.5
4	79.0

Initial Rate =19.7 Percent/Day



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Test Results Statistics

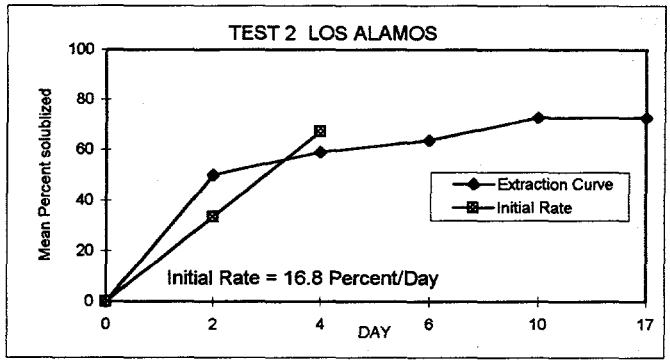
Test 2: NTA

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	47.6	54.9	47.4	50.0
4	56.4	65.7	54.8	59.0
6	68.0	68.5	54.8	63.8
10	70.8	76.0	70.7	72.5
17	70.8	76.0	70.7	72.5

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	33.6
4	67.2

Initial Rate =16.8 Percent/Day



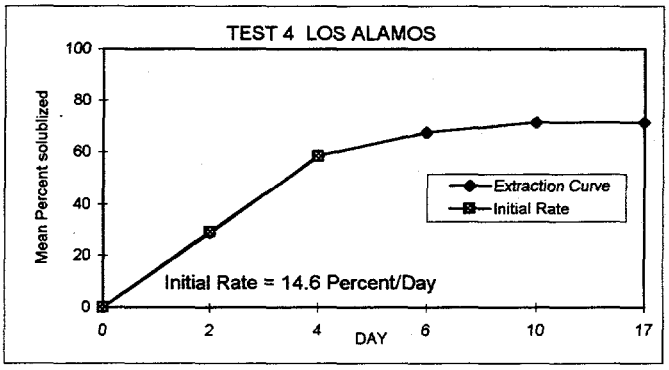
Test 4: NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	24.4	29.2	33.1	28.9
4	52.0	59.5	64.0	58.5
6	60.0	67.7	75.3	67.7
10	64.5	70.4	79.1	71.3
17	64.5	70.4	79.1	71.3

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	29.2
4	58.4

Initial Rate =14.6 Percent/Day



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Test Results Statistics

SOLUBLIZATION RATES FROM PERCENTAGES

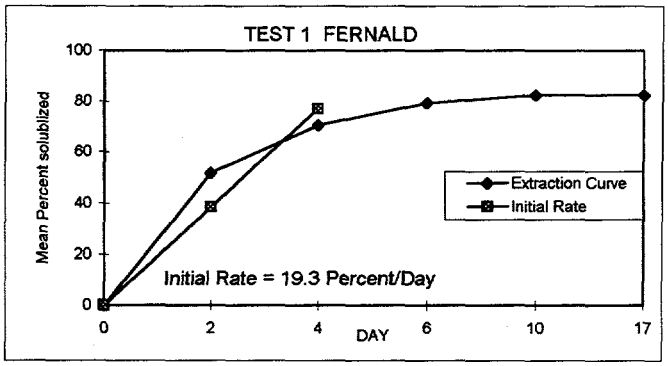
Test 1: SD-1

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	51.9	53.0	50.5	51.8
4	69.0	71.2	71.1	70.4
6	77.5	79.9	80.5	79.3
10	79.9	83.8	83.6	82.4
17	79.9	83.8	83.6	82.4

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	38.5
4	77.1

Initial Rate =19.3 Percent/Day



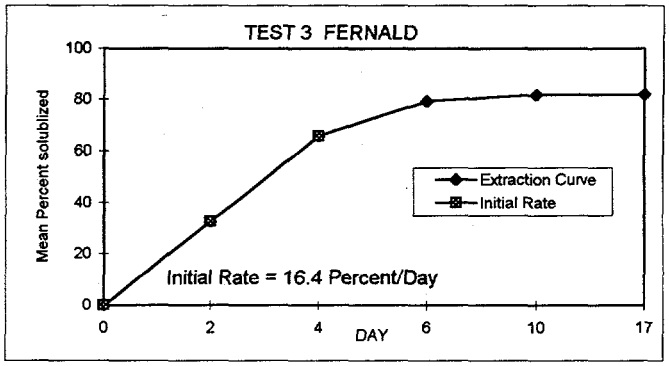
Test 3: SD-1 + NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	29.6	31.5	37.2	32.8
4	64.8	59.6	72.7	65.7
6	79.7	72.7	85.9	79.4
10	82.6	73.8	89.1	81.8
17	82.6	73.8	90.0	82.1

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	32.8
4	65.7

Initial Rate =16.4 Percent/Day



Appendix F

Test Results Statistics

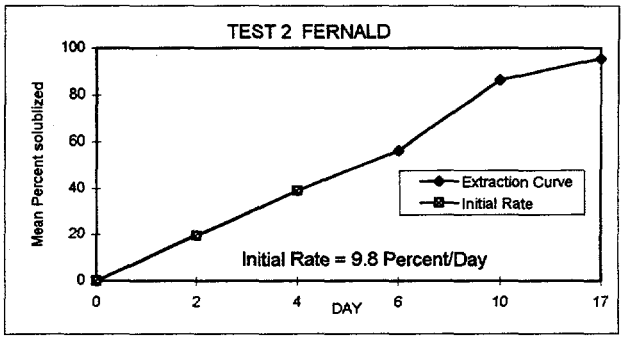
Test 2: NTA

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	21.0	16.4	21.8	19.7
4	35.6	46.9	35.1	39.2
6	45.0	67.9	56.5	56.5
10	84.1	91.8	83.1	86.3
17	94.5	96.4	95.6	95.5

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	19.6
4	39.3

Initial Rate =9.8 Percent/Day



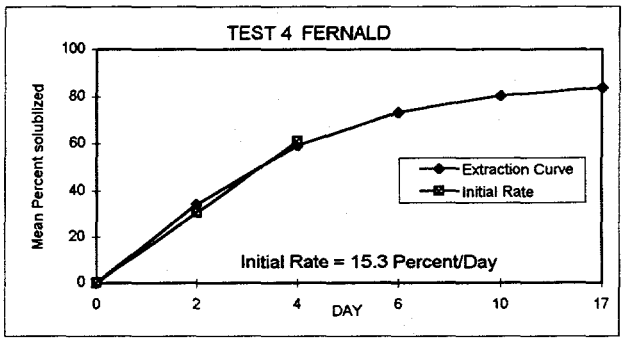
Test 4: NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	38.0	31.5	33.4	34.3
4	69.4	58.4	49.7	59.2
6	84.0	71.4	63.8	73.1
10	91.0	78.2	72.3	80.5
17	91.0	78.2	82.4	83.9

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	30.5
4	61.1

Initial Rate =15.3 Percent/Day



Appendix F

Test Results Statistics

SOLUBLIZATION RATES FROM PERCENTAGES

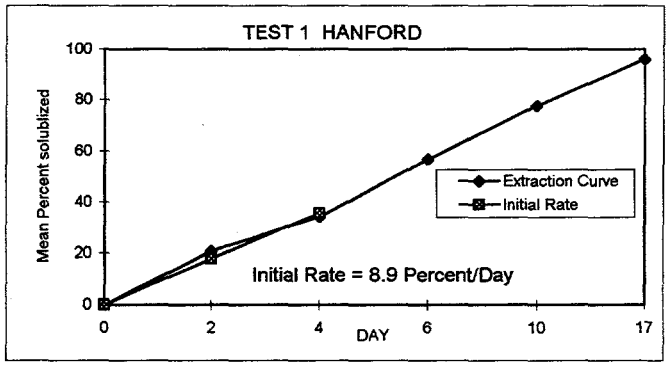
Test 1: SD-1

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	22.2	20.9	19.1	20.7
4	35.0	34.3	33.7	34.3
6	58.5	53.8	57.8	56.7
10	78.3	76.0	78.5	77.6
17	96.5	95.9	96.2	96.2

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	17.9
4	35.8

Initial Rate =8.9 Percent/Day



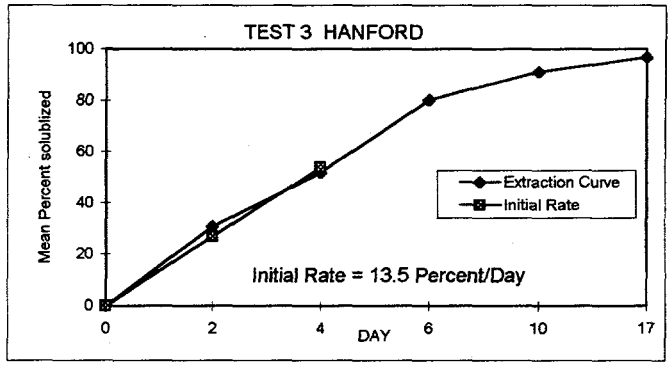
Test 3: SD-1 + NATIVE

	REPLICATES -- Percent Solublized			
DAY	A	B	C	Mean
0	0	0	0	0
2	36.4	36.7	20.0	31.0
4	51.9	53.9	49.8	51.9
6	77.6	78.8	84.2	80.2
10	91.1	90.1	92.4	91.2
17	97.2	96.5	97.1	96.9

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	27.0
4	53.9

Initial Rate =13.5 Percent/Day



APPENDIX G: MATERIALS AND METHODS

Soils tested were from Rocky Flats, Mound, Los Alamos, Fernald, and Hanford. The soils varied in texture, composition and moisture content. They were thoroughly mixed and passed through a 2 mm sieve before testing. Fourteen samples of approximately 4 grams each were drawn from each soil to be tested.

Head assays: Two samples each from Rocky Flats, Mound, and Los Alamos were weighed and sent to the Lockheed Analytical Laboratory (LAL) for alpha spectroscopy analysis. Two samples each from Fernald and Hanford were retained at the Lockheed Environmental Systems & Technologies Co. Soils Treatability Laboratory (STL) for kinetic phosphorimetric analysis (KPA) of their uranium content.

Soil moisture content: Two samples from each soil were weighed, oven dried overnight at 100°C, and reweighed. The means of these weights were used to calculate the percent of moisture present in each soil. Sample weights for all assays were mathematically adjusted to account for the measured moisture content.

Incubation of soils: Twelve samples from each soil were weighed and placed in 50 mL capped centrifuge tubes. Six of these were sterilized in a bench top pressure cooker type autoclave for 45 minutes. All samples were then incubated at room temperature anaerobically on a rotator with growth medium (tryptic soy broth, TSB) containing nitrilotriacetic acid (NTA) with or without added cultures of bioreductive bacteria (SD-1) as follows:

1. Sterile soil + TSB + NTA + SD-1
2. Sterile soil + TSB + NTA
3. Native soil + TSB + NTA + SD-1
4. Native soil + TSB + NTA.

Sampling: Solid/liquid separations were performed by centrifugation after 2, 4, 6, 10, and 17 days of incubation with fresh growth medium replacing the spent solution. The refreshed cultures were returned to the rotator after each sampling. The liquid fractions were assayed by alpha spectroscopy or KPA as appropriate to determine dissolved actinide content. Microbial populations in the liquid fractions were monitored by the plate count method.

Tail assays: After 17 days, the solid fractions were washed three times with distilled water, dried, and sent to LAL or STL to measure the concentration of Pu and Am or U remaining after treatment. Accumulated wash solutions were analyzed for total actinide content.

Appendix F

Test Results Statistics

Test 2: NTA

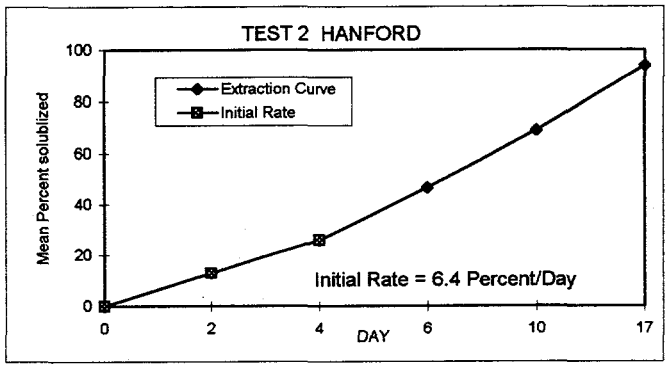
REPLICATES -- Percent Solublized

DAY	A	B	C	Mean
0	0	0	0	0
2	12.5	14.6	11.8	13.0
4	24.8	25.6	26.8	25.7
6	38.4	47.7	53.4	46.5
10	58.1	68.0	80.1	68.7
17	86.3	97.7	97.5	93.8

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	12.9
4	25.8

Initial Rate =6.4 Percent/Day



Test 4: NATIVE

REPLICATES -- Percent Solublized

DAY	A	B	C	Mean
0	0	0	0	0
2	25.8	21.4	29.3	25.5
4	56.0	47.1	43.5	48.9
6	77.5	72.9	73.7	74.7
10	86.7	83.3	83.8	84.6
17	96.1	94.6	95.4	95.4

RESIDUAL OUTPUT

DAY	*Predicted Y*
0	0
2	24.6
4	49.3

Initial Rate =12.3 Percent/Day