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Dating of fallout in lacustrine sediment in southwestern Utah

Alex Clark Tikanen
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Dating of fallout in lacustrine sediment in southwestern Utah

Tikanen, Alex Clark, M.S.
University of Nevada, Las Vegas, 1992
DATING OF FALLOUT IN LACUSTRINE
SEDIMENT IN SOUTHWESTERN
UTAH

by
Alex Clark Tikanen

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Science
in
Chemistry

Department of Chemistry
University of Nevada, Las Vegas
August, 1991
The thesis of Alex Clark Tikanen for the degree of Master of Science in Chemistry is approved.

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Abstract

A reservoir named Sandy Cove is located in an area of southwestern Utah which received the highest fallout from Nevada Test Site nuclear testing during the period 1951-1959. The reservoir, which was built about 1940, was shown by lead-210 (Pb-210) dating to have a constant sedimentation rate and to be relatively undisturbed. A 40 centimeter (cm) core taken from this reservoir contained sediment deposited after 1974 and did not reach back to the Nevada Test Site (NTS) fallout years of 1951 to 1959 or back to the peak worldwide fallout years of 1962-1963. However, the fast sedimentation rate of 2.17 cm/year indicates that this may be the best reservoir for dating NTS fallout in extreme southwestern Utah. The amounts of cesium-137 (Cs-137) and plutonium-239,240 (Pu-239,240) which were found in a 1974-1979 dated Sandy Cove core section were almost identical with the reported activities from a 1974-1979 dated core section taken from Enterprise reservoir in 1979. Enterprise reservoir is located in an area of southwestern Utah which has been shown to have received less fallout from testing at the NTS. Cesium-137 activity decreases from 2.7 to 1.5 picoCuries (pCi) per dry gram of sediment for 1974 to 1979 at Sandy Cove. The Sandy Cove reservoir Cs-137 fallout for 1980-1985 decreases and levels off at 1.0 pCi per dry gram of sediment. A simplified method for the extraction and purification of plutonium from lacustrine sediment was developed.
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Acknowledgements

I wish to thank Dr. Scott Faller and the USEPA-EMSL-LV Radioanalysis Branch for preparing the gamma standard from deep lake sediment, for programming and allowing my use of the Genie VAX system-gamma counters and obtaining in house reports from the Department of Energy's Environmental Measurements Laboratory, New York, N. Y. Much thanks to our diver, Darrin Watts, who held his breath until blue to obtain the core from Sandy Cove reservoir, and to Dr. Vern Hodge, who quickly and precisely answered all of my questions.
Introduction

During the years 1951-1957 sixteen nuclear devices were detonated on 300-700 foot steel towers and produced 90% of the Nevada and Utah population's exposure to radiation directly linked to nuclear weapons testing at the Nevada Test Site (NTS) (1). In contrast, worldwide fallout peaked in 1957-1959 and 1961-1962. Studies of ground contamination by cesium-137 (Cs-137) and plutonium-239,240 (Pu-239,240) in southwestern Utah have been published (2,3). A computer program was written in 1981 to calculate the total human gamma-ray exposure from ground contamination resulting from an above ground nuclear test (1). The exposures to the fission decay and activation products were calculated at a distance of one meter from the ground. The program allowed for the fractioning out of mass chains consisting or partly consisting of refractory elements because they are not deposited as far from ground zero as volatile mass chains. It was noted the program did not take into consideration gamma rays from radioactive gasses or unsettled particulates. Field data acquired after tower based nuclear explosions was released to the Nevada Operations Office of the U.S. Department of Energy in 1981. The computer program calculations were consistent with this data.

By measuring the concentration of Cs-137 and Pu-239,240 in 150 undisturbed lawns in Utah and western Colorado during 1979, an estimation of external gamma-ray exposure was made using the same computer program (2). The
amount of plutonium deposition from the NTS was separable from global plutonium deposition because the Pu-240/Pu-239 ratio is much less for the tower-based events at the NTS than later high-yield nuclear tests with much greater neutron fluxes. This ratio is about 0.18 for global fallout as of 1979 and about 0.032 for fallout originating from NTS. The results of this exposure reconstruction confirm the exposure estimates made from monitoring data obtained after NTS nuclear tests. The results also indicate the exposure received by extreme southwestern Utah's Washington County residents from total NTS fallout was about 1.1 rads (radiation energy absorption units) and that 6 to 10 rads would be needed to produce the excess leukemia deaths reported in that region (2).

In 1979, a sediment core was retrieved from Enterprise reservoir located 11 kilometers (km) southwest of Enterprise, Utah (3). Figure 1 on page 3 shows the location and estimated cumulative mrad (millirad) doses supposedly received by area residents. The 61 centimeter (cm) core was sectioned into 1 cm slices and analyzed for Pu-239,240, Pu-238, and Cs-137. They dated the core using Cs-137, a method found to be inferior to and sometimes a complete failure compared to the Pb-210 method for dating lacustrine sediments (4). By measuring the amount of Cs-137 in the part of the core corresponding to the years of NTS testing and dividing this value by the total Cs-137 in the core, a ratio for NTS Cs-137 ground deposition was determined for
Fig. 1  CUMULATIVE ESTIMATED DOSE (milliroentgens) IN SOUTHWESTERN UTAH FROM ALL NEVADA TESTS THROUGH 1969

SOURCE:
sodium adjacent to the reservoir. Their results show that 11 plus or minus 6 milliCuries (mCi) of Cs-137/square km fell in the Enterprise area from NTS nuclear tests. Later analysis of soil in the Enterprise area by the Pu-240/Pu-239 method showed that 14 mCi/square km of Cs-137 was due to NTS testing (2).

The Enterprise reservoir was selected because of its age (built in 1940), reported undisturbed character, and location with respect to the NTS. The authors (2) are quoted as saying there are few bodies of water in southwestern Utah which meet these requirements. It was noted by us that Enterprise reservoir was not in the highest fallout area of extreme southwestern Utah (see fig. 1). Another interesting aspect of their research was the high Pu-239/Cs-137 ratio for the NTS testing era (see fig. 2 on page 5) possibly caused by the deposition of plutonium which came from the explosion of several low fission-yield or nonfission devices.

**Purpose of Research**

The purpose of this research was to 1) find a reservoir or body of water which existed before 1950, had not been dredged or disturbed by draining, and was located in the area of highest southwestern Utah fallout. 2) use the Pb-210 dating method (4-8) in conjunction with Cs-137 and Pu-239,240 analysis of a sediment core in order to determine the amount of NTS fallout in the area of the reservoir. The results would serve to verify earlier low risk
Fig. 2  NUCLIDE RATIOS WITH DEPTH IN SEDIMENT

Source (3)
estimates of leukemia mortality to the "down-winders" (2).

The Lead-210 Dating Method

The decay chain of uranium-238 includes radon-222 which escapes into the atmosphere at an average rate of about 42 atoms per minute per square centimeter of land surface (14). Radon-222 then decays through a series of short half-life daughters to lead-210 which is rapidly removed from the atmosphere by rain or snow. Lead-210 which is deposited as lacustrine sediment decays with a half-life of 22.26 years. This permits dating the sediment by measuring the Pb-210 activity. If a constant sedimentation rate is assumed, the sedimentation rate can then be calculated. The activity usually decreases to a constant background level in deeper parts of the core because of radon-222 decay before expulsion into the atmosphere. This constant background level of Pb-210 activity is subtracted out for dating purposes (14). It can be shown that the sedimentation rate can be determined by plotting the depth of sediment against the natural log (ln) of the measured Pb-210 activity regardless of counter efficiency.

Let $s =$ sedimentation rate  \[ \text{Pb}_A^0 = \text{activity at surface} \]

$d =$ depth \[ \text{Pb}_d = \text{activity at depth, } d \]

$\lambda =$ decay constant \[ t =$ time \[ \frac{\text{Pb}_A}{\text{Pb}_d} = e^{-\lambda t} \]

\[ t = \frac{1}{\lambda} \ln \left( \frac{\text{Pb}_A^0}{\text{Pb}_d} \right) \]
This is an equation of a straight line in coordinates of $\ln$ Pb and $d$ whose slope is:

$$m = -\frac{2}{5}$$

so,

$$s = -\frac{2}{m}$$

Instead of measuring the low energy beta particles (0.02 MeV) produced by the decay of Pb-210, it is much simpler to measure the alpha decay of its grand-daughter, polonium-210 (Po-210), which grows in achieving 90% of the Pb-210 activity within 530 days. Neither the transient or secular equilibrium simplifications of the decay laws were adequate to calculate this value. The transient equilibrium equation produced a value of 1436 days and the secular equilibrium equation produced a value of 459 days for the ingrowth of Po-210 to attain 90% of the activity of the pure grand-parent, Pb-210. The number of days required were calculated by numerical trial and error of $t$ in the equation:
\[
\frac{A_2}{A_1} = c_2 Q_0 = \frac{\lambda_2}{\lambda_2 - \lambda_1} \left( e^{-\lambda_1 t} - e^{-\lambda_2 t} \right)
\]

which can be derived from:

\[
\frac{d N_2}{d t} = \lambda_1 N_1 - \lambda_2 N_2 \quad \text{and} \quad N_\ell = \frac{A_\ell}{\lambda_\ell}
\]

assuming no Po-210 originally present and the short-lived bismuth-210 intermediate to be nonexistent.
Locating the Sandy Cove reservoir

During 1990, several trips were made to the St. George area to obtain information on the location of the perfect body of water. The Santa Clara reservoir was found to be nothing but a mud-hole and a core taken from this reservoir was not datable by the Pb-210 method. After conferring with many residents of the area, two reservoirs, Oak reservoir and Sandy Cove reservoir were discovered which fit the requirements. A core of sediment was taken from nearshore in Oak reservoir, which is situated just north of the town of Veyo (see fig. 1) and just outside the highest fallout area. Analysis of sediments in the core showed a discontinuity in the Cs-137 and Pb-210 activities at 6-9 cm from the top of the core (see discussion). It was noticed that there was a layer of sand, most probably from a man-made beach, in the 6-9 cm region of the core. This concluded our attempts at nearshore coring. Sandy Cove, a small hydroelectric reservoir, is next to a gravel road which begins about 5 km south of Veyo on the west side of State Highway 18. A new housing tract area is at this location. The reservoir is about 10 km down the gravel road (see fig. 1). It was built in about 1940 and has never been dredged. Analysis of sediments from the first of two 40 cm cores taken near the deepest part, suggested that there was a uniform sedimentation rate. The results of a study of this core are the topic of this thesis.
Experimental

Chemicals and Equipment

All chemicals were obtained from Fisher Scientific Co. and were either reagent or A.C.S. certified. The anion-exchange resin, Bio-Rad AG 1-X8, was obtained from Bio-Rad Corp. The Pu-242 and Po-208 tracers were obtained from the United States Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas (USEPA-EMSL-LV) Radioanalysis Branch. Alpha counting was done on two Canberra Alpha Spectrometers (Model 7401) connected through a Canberra Model 588 Analog Multiplexer to an Epson Equity Ie computer which was fitted with a Canberra AccuSpec PC Acquisition Interface Board-AccuSpec-A (512 channels). Gamma counting was performed on a Canberra Intrinsic Germanium Gamma Detector interfaced to a Canberra Genie 9900 VAX-Based Multi-User System (4096 channels) courtesy of the US-EPA-EMSL-LV Radioanalysis Branch.

Sample Collection and Sectioning

An 80 cm piece of thin-wall DWV (drain, waste, and vent) 4 inch diameter (inside cross-sectional area of 81.7 square cm) PVC pipe was pushed into the Sandy Cove reservoir sediment at a water depth of about 4 meters. The coring was done approximately half way across the dam and 20 meters away from it. Two sections of pipe were lost at the bottom because of visibility problems caused by finely suspended solids. The objective was to slide the end cap on top of the pipe after insertion into the sediment then
pull it out and quickly cap the bottom end. However, this was too much to handle for our diver. He was able to retrieve 40 cm of sediment by digging his hand into the sediment after insertion of the pipe, covering the bottom end with his hand, and swimming to the surface with the core. The bottom of the core was capped and the core was transported vertically to a deep freezer in the University of Nevada, Las Vegas Hotel Administration Building. It was then cut into twenty 1.75 cm thick sections with a carbide tipped radial arm saw in the rock cutting lab of the UNLV Geoscience building. The core sections were then dried at 110 degrees overnight and weighed. The sediment had an anaerobic smell (smelly) and only a few tiny twigs. Very small empty white snail shells were detected at and below the 36 cm level.

**Lead-210 Dating via Polonium-210**

The alpha particle activity of Po-210 can be determined by leaching, autoplating on silver, and counting Po-210 (4,5). Overall chemical yield has been shown to be greater than 90% for a similar leaching procedure (5). The following method was developed to simplify the reported procedure and gave plating efficiencies estimated to be about 90% (see figure 3 on page 12):

Three grams dried sediment, 50 disintegrations per minute (dpm) of Po-208 tracer, 100 mL 16 N nitric acid, and 50 mL 12 N hydrochloric acid were gently refluxed in a 250 mL beaker with a watch glass cover for 12 hours. The acid leach was decanted through glass filter paper with suc-
Po-210 Analysis

SOIL

Po-208 Tracer

continued nitric and hydrochloric acid leach, 24 hours

Filter

Solvent change to 0.5 N HCl

L-Ascorbic acid

Auto-plate onto silver planchet

Alpha count

Figure 3
tion. About 50 mL hot 16 N nitric acid was added to the sediment still in the beaker and the entire contents of the beaker were poured through the same glass filter paper with suction. About 20 mL more hot 16 N nitric acid was poured through the sediment in the Buchner funnel. The acid extract was transferred to a 250 mL beaker and was slowly evaporated to dryness on a hotplate. About 10 mL of 12 N hydrochloric acid was added and the solution was slowly boiled to dryness. The solutions were not left on the hot plate once dry! About 10 mL 0.5 N hydrochloric acid was added and heated for a few minutes to dissolve the residue. The solution was cooled to room temperature and about 500 mg L-ascorbic acid was swirled in. The solution was transferred with 0.5 N hydrochloric acid into a 20 mL plastic scintillation vial to a final volume just below the threads. A silver planchet was placed on top and the scintillation vial cap was screwed on tightly. The vials were wedged together upside down into an empty beaker and placed in a rotary water-bath shaker at high speed at room temperature without the water for about 4 hours. Planchets were then removed, washed with water, dried with acetone, and alpha counted for 1000 minutes. Eight such extractions could be handled at one time.
Cs-137 Analysis

A Cs-137 standard was prepared by mixing a solution of Cs-137 with 100 grams of dried sediment from a deep core section of Oak reservoir which had no detectable fission produced nuclides detectable after gamma counting for 1000 minutes. The standard was prepared by and plastic gamma counting containers (12 cm diameter x 2 cm height) were supplied by Dr. Scott Faller of the USEPA-EMSL-LV Radioanalysis Branch. Sediment from each core section of Sandy Cove reservoir was packed into the same geometry as the standard, weighed, and gamma counted for 6 or 12 hours.

Pu-239,240 Analysis

After Pb-210 dating, the remaining sediment from each core section (from 57 to 104 grams) was spiked with Pu-242 and leached by the method of Wong (9). Initial experiments with Wong's anion-exchange plutonium separation produced about a 30% recovery of Pu-242 tracer on the analysis of dry lake sediment from the Searchlight, Nevada area. Plutonium could not be separated by this method when used on Sandy Cove reservoir sediment. Plutonium adsorbed on the resin column in the tetravalent state was supposed to be reduced by ammonium iodide to the trivalent state which has a very small distribution coefficient in the hydrochloric acid system and is readily eluted. However, no plutonium was eluted when the ammonium iodide in 12 N hydrochloric acid was added to the anion-exchange column for the samples from Sandy Cove. After much experimentation with column eluants, it was found that uranium and plutonium could be
eluted together after separation from other metals which would interfere either with the electroplating (13) or the alpha counting. Because of the high resolution of our new alpha counter, it was not necessary to chemically separate the uranium from Pu-239,240 or Pu-238 for alpha counting. This improvement in the experimental method also eliminated the second anion-exchange column, coprecipitations, or complete dissolution required by other methods (9-12). It has been shown that there is no significant difference between leaching and total dissolution procedures for the extraction of fallout plutonium from soils (9,11).

The new procedure is as follows (see figure 4 on page 16): Fifty to 100 grams dried sediment, 3.85 dpm Pu-242 tracer, 300 mL 16 N nitric acid, 100 mL hydrochloric acid, and a few drops of n-octanol (to control foaming) were added to a 2000 mL beaker. The mixture was left at room temperature for one hour and then gently refluxed for 16 hours under a watch glass. Its volume was estimated and a little more than its estimated volume of 1 N nitric acid added making the nitric acid concentration 6-8 N. It was found when making this dilution that if water is used instead of the 1 N nitric acid, the solution became sometimes cloudy. About 30 mL 30% hydrogen peroxide was added and the solution was slowly boiled down to about one third its initial volume. The preceding step was done for two reasons: 1) hydrogen peroxide helps destroy any organic material but can not be added to concentrated nitric acid,
Plutonium 239,240 Analysis

SOIL

- Pu-242 Tracer
- Concentrated nitric and HCl acids
- Leach 24 hours
- Dilute to 8 N nitric acid
- Hydrogen peroxide, evaporate water
- Filter
- Dilute to 8 N nitric acid
- Make volume about 800 mL
- Sodium nitrite

Anion Exchange

- 150 mL 8 N nitric acid
- 150 mL 12 N HCl
- 10 mL 1.2 N HCl

Eluates discarded

- 5 mL 30% hydrogen peroxide in 250 mL 1.2 N HCl
- Sulfuric acid, evaporate
  
  Electroplate on planchet

Figure 4
and, 2) a very slight trace of hydrogen peroxide seems to stabilize the tetravalent state of plutonium. The resulting acid leach was decanted through glass filter paper in a Buchner funnel with suction followed by two 50 mL rinses of the sediment with hot 16 N nitric acid. The filtrate was transferred to a 2000 mL beaker and was made 6-8 N with 1 N nitric acid and its volume was brought up to 800 mL with 7.2 N nitric acid. Ten grams of solid sodium nitrite was stirred into the acid leach and the resulting solution was heated near boiling for about 30 min under a watch glass. The cooled solution was passed through 25 mL AG 1-X8 anion-exchange resin, pre-conditioned with 7.2 N nitric acid, which was contained in a 1.5x50 cm glass chromatography column fitted with a 1 liter reservoir on top. The column was washed with an additional 150 mL of 7.2 N nitric acid followed by 150 mL 12 N hydrochloric acid. The nitric acid wash removes iron, calcium and other interferences and the concentrated hydrochloric acid wash removes thorium making this method good for thorium analysis. Ten mL of 1.2 N hydrochloric acid was added, the solution was drained to the top of the resin, and all eluates were discarded. Five mL of 30% hydrogen peroxide was mixed with 250 mL 1.2 N hydrochloric acid to elute the plutonium and uranium immediately after the 1.2 N hydrochloric acid. The first 100 mL of eluate contained most of the uranium and the second 150 mL contained mainly plutonium although no quantitative study was made. About 1 mL 18 M sulfuric acid was added to
the 250 mL of eluate and it was slowly evaporated overnight on a hotplate. About 5 mL water was added to the cooled sulfuric acid left in the beaker, it was allowed to cool, and 4 drops of 0.02% sodium salt of thymol blue solution was added. Concentrated aqueous ammonia was added dropwise with swirling until a straw colored endpoint occurred. This solution was rinsed with water into a 20 mL plastic scintillation vial fitted with a stainless steel planchet as described by Talvitie (13). The solution was brought up to 10-15 mL with the rinsings of water. The planchet was electroplated against a platinum wire anode at a little less than 1 ampere for 2 hours. The planchet was rinsed with water, acetone, and alpha counted for 1000 minutes. The yields were between 70 and 80% as indicated by recovery of Pu-242.

Results and Discussion

Unfortunately, we did'nt expect such a high sedimentation rate of 2.2 cm/year at Sandy Cove reservoir and the 40 cm core went only deep enough to look at sediment deposited since 1974, a period of time after the peak worldwide fallout years and after the earlier NTS fallout period. A least squares fit to the ln Po-210 counts per minute vs. depth, shown in fig. 5 on page 19, gave a slope of -0.0143 which indicated the 2.17 cm/year sedimentation rate. However, the data showed the reservoir sediment to be detailed and its high sedimentation rate may give the most vivid picture of the history of fallout in the extreme southwestern Utah.
Figure 5, Sandy Cove reservoir
FIGURE 6, OAK RESERVOIR
Figure 7. Oak Reservoir
Figure 6 on page 20 shows the natural log of the Po-210 activity versus depth for Oak reservoir. The low activity for both Po-210 and Cs-137 (see figure 7 on page 21) at the 6-8 cm depth and visual observation of sand in these core sections possibly indicate the dumping of sand at this shoreline location around 20 years ago. The low sedimentation rate of around 2-3 millimeters per year and the low Cs-137 activity for the Oak reservoir core possibly indicate that the sampling site was underwater for only short time periods during the last 50 years. The Cs-137 activity decreases with depth for the Oak reservoir core, which is more indicative of a non-lacustrine soil sample. In any case, this core was determined inadequate for fallout dating purposes.

Table 1 on page 23 and figure 8 on page 24 show the Cs-137 activity in the core as a function of depth and as a function of the Pb-210 chronology respectively. The raw Cs-137 spectrums are in the Appendix. It was decided to make all measurements using the dry weight as weighing and transferring wet sediment without evaporative losses would have been difficult.

The data from the 1979 Enterprise reservoir core (3) used wet weight in its calculation and therefore the activities per gram are not comparable with our data. They did, however, report activities of Cs-137 and Pu-239,240 in the form of mCi/square km per cm which can be used for direct comparison with our data. The 26-38 cm part of the
<table>
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<th>Depth, cm</th>
<th>Cs-137, pCi/g</th>
<th>%Error*</th>
<th>mCi/sq.km per cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.75</td>
<td>1.12</td>
<td>8.2</td>
<td>**</td>
</tr>
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<td>2-3.75</td>
<td>0.946</td>
<td>4.7</td>
<td>3.4</td>
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<td>6.2</td>
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<td>6-7.75</td>
<td>0.774</td>
<td>6.4</td>
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<td>0.907</td>
<td>5.9</td>
<td>4.0</td>
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<td>10-11.75</td>
<td>0.912</td>
<td>6.7</td>
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<td>5.0</td>
<td>4.9</td>
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<td>38-39.75</td>
<td>2.84</td>
<td>2.7</td>
<td>**</td>
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* one sigma counting error

** core was incompletely filled at top and bottom sections
Figure 8: Sandy Cove reservoir

Year of sedimentation, 19XX

Cs-137, pCi per gram
Sandy Cove core and the 0-8 cm part of the Enterprise core both corresponded to the 1974-1979 time frame. Therefore, the Cs-137 and Pu-239,240 deposition were compared for that time period. Pu-239,240 was estimated from our limited analyses of Sandy Cove sediment (Table 2, page 26) for 1974-1979 to be 2.22 mCi/square km. The value estimated from Enterprise data is 1.81 mCi/square km. The preceding calculation was very rough because of limited data in both cases. The Cs-137 comparison is much better because data for all core sections in that period are available. Sixty-three mCi/square km of Cs-137 was totaled for the 1974-1979 era of the Sandy Cove core in comparison to 75.5 mCi/square km was totaled from the 1974-1979 part of the Enterprise core. Since the Enterprise core was measured and reported in 1979, the activity for the 1974-1979 part of the core would have decayed to 58.6 mCi/square km by 1990 due to the 30 year half-life of Cs-137. The only conclusion we can make from the data is that the combined effect of watershed area and precipitation produced almost identical fallout records in these two reservoirs during the 1974-1979 era, a fallout period not significantly impacted by the NTS and representative of post worldwide atomic weapons tests. The Pu-239,240/Cs-137 activity ratio was about 0.024 in the 1974-1979 part of the Enterprise core. This value would have increased to about 0.031 as of 1990 due to Cs-137 decay. Our value of about 0.032 for the Pu-239,240/Cs-137 activity ratio in deepest part of the Sandy Cove core agrees quite well.
<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>pCi/kg</th>
<th>%Error</th>
<th>mCi/kg km per cm</th>
<th>Pu/Cs</th>
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<td>9.1</td>
<td>0.11</td>
<td>0.028</td>
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<td>11</td>
<td>0.17</td>
<td>0.028</td>
</tr>
<tr>
<td>20-21.75</td>
<td>31.0</td>
<td>11</td>
<td>0.22</td>
<td>0.023</td>
</tr>
<tr>
<td>30-31.75</td>
<td>90.7</td>
<td>6.3</td>
<td>0.37</td>
<td>0.038</td>
</tr>
<tr>
<td>36-37.75</td>
<td>87.4</td>
<td>8.9</td>
<td>0.37</td>
<td>0.032</td>
</tr>
</tbody>
</table>

* one sigma counting error
It is worth noticing that our gamma ray analysis showed no record of the 1986 reactor burn-up in Chernobyl, U.S.S.R. This event would be recognized by the presence of Cs-134 with a half-life of 2.2 years.

We believe that Sandy Cove's location in the highest NTS fallout area of southwestern Utah warrants a second look to retrieve a core which reaches the bottom of the reservoir, about 1940, a period likely to be highly impacted by weapons testing at the NTS. It has been shown by this project that cores most probably should be taken from the deepest undisturbed part of a reservoir for the best results.

References

1) H. G. Hicks, Health Physics, 42, No. 5, (May), pp.585-600 (1982)
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10) N. A. Talvitie, Analytical Chemistry, 43, No. 13, 1827-1830 (1971)


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14) G. Faure, Principles of Isotope Geology, Wiley & Sons (1977)
Appendix

In the following pages, the raw gamma spectra for sections of the Sandy Cove reservoir are presented. Note that SC1 is the core section 0-1.75 and SC2 is the core section for 2-3.75 cm depth, etc.
Spectrum: MCAD: [USER] SYSTEM1#1
Title: Sample Title: SCI

Counts

Energy (keV)

Start Time: 12-JUN-91 09:31  Sample Time: 12-JUN-91 00:00  FWHM Parameters:
Real Time: 06:00:07.59  Sample ID: SCI  Offset: 1.67E+00
Live Time: 06:00:00.00  Sample Type: SOIL  Slope: 2.63E-03
Spectrum:       MCAO [USER] SYSTEM101
Title:          Sample Title:  SC5

Counts

Energy (keV)

Start Time:  16-JUN-91 09:07  Sample Time:  18-JUN-91 00:00  FWHM Parameters:
Real Time:    06:00:06.06  Sample ID:    SC5  Offset:  1.87E+00
Live Time:    06:00:00.00  Sample Type:  SOIL  Slope:  2.63E-03
Spectrum: MCAO [USER] SYSTEM 1

Title: Sample Title: SC10

Start Time: 13-JUN-91 13:18 Sample Time: 13-JUN-91 00:00 FWHM Parameters:
Real Time: 00:00:08.08 Sample IDs: SC10 Offset: 1.87E+00
Live Time: 00:00:00.00 Sample Type: SOIL Slope: 2.63E-03
Spectrum: MCAO: [USER] SYSTEM191
Title: Sample Title: SC12

Energy (keV)

Start Time: 17-JUN-91 10:19 Sample Time: 17-JUN-91 00:00 FWHM Parameters:
Real Time: 08:00 08:48 Sample ID: SC12 Offset: 1.67E+00
Live Time: 08:00 00:00 Sample Type: SOIL Slope: 2.63E-03
Sample Title: SC15

Start Time: 13-JUN-91 13:17
Real Time: 08:00:02.31
Live Time: 08:00:00.00
Sample Time: 13-JUN-91 00:00
Sample ID: SC15
Sample Type: SOIL
FWHM Parameters:
Offset: 1.39E+00
Slope: 2.34E-02
Spectrum: MCAO. [USER] SYSTEM 10$^+$1
Title:
Sample Title: SC16

Start Time: 19-JUN-91 11:23
Real Time: 00:00:02.41
Live Time: 00:00:00.00
Sample Time: 19-JUN-91 00:00
Sample ID: SC16
Sample Type: SOIL
FWHM Parameters:
Offset: 1.39E+00
Slope: 2.34E-02