Personnel Radiation Dosimetry: Amchitka Expedition Phase I and Phase II

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4/25/05

1. General Dosimetry Information and Purpose

Personnel Radiation Dosimetry attempts to capture the radiation exposure of individual persons as opposed to Ambient Monitoring, which measures the level of radioactivity in a particular space or outdoor area. It is customarily used in circumstances where workers might reasonably be exposed to Ionizing Radiation in the course of their work, such as DOE remediation workers, x ray technicians, nuclear power plant employees or researchers using radioactive substances as tracers in biochemical investigations. Personal dosimeters are generally worn on the subject's chest and are thus an approximation of the whole body dose of radiation that the subject receives.

Radiation is both an endpoint of the Amchitka Independent Science Plan and an expedition health concern. A finding that any expedition member was exposed to Ionizing Radiation significantly over background levels will prompt an appropriate medical and safety and health investigation, is an indication that the allowable radiation exposure limit for the expedition was exceeded and a source of radiation was encountered during the expedition. Health physicists at both the Rutgers University (Rutgers Environmental Health Services) and the Vanderbilt University, Department of Radiology and Radiological Sciences were consulted regarding their opinion of the likelihood of public and radiation workers exposure limits being exceeded in the course of the expedition. The conclusion was that any potential exposure would be below the thresholds at which either university would require badging (thermoluminiescent dosimetry badges TLD) or radiation worker training. The allowable exposure limit for a radiation worker is 5000 millirems (mrem) per year. Exposure to this radiation level assumes that the worker has undergone a radiation training program with refresher courses as prescribed by the Nuclear Regulatory Commission (NRC). Since expedition members did not receive this training they were considered to be members of the general public (i.e. not radiation workers) during the expedition and were thus limited to an annual exposure of 100 mrem per year. An Expedition Occupational Exposure Guideline of 10 mrem was chosen. The rationale for the establishment of the Expedition Occupational Exposure Guideline was;

a. 100 mrem is the yearly protection standard for incremental radiation (radiation exposure over background levels, such as from X ray Machines etc.) to members of the public.

b. The risk of development of various cancers from exposure to Ionizing Radiation is thought to be linear, with no threshold exposure level below which there is accompanying cancer risk. It is thus assumed that each incremental increase in radiation exposure, measured in mrem, has an accompanying incremental increase in cancer risk.

c. Radiation exposure should be controlled to "As Low As Reasonably Achievable" (ALARA)

d. The actual Amchitka expedition will take approximately 10% of a year.

e. Therefore, as a guideline an appropriate radiation occupational exposure limit (OEL) for expedition personnel is approximately 10 mrem (i.e., 10% of 100 mrem)

Expedition planners agreed that;

- 10 mrem would be achievable given previous remediation work on Amchitka Island by the Department of Energy (DOE).
- 10 mrem should be more protective than 100 mrem;
- 10 mrem would better reflect ALARA than would 100 mrem, and
- 10 mrem is an equitable proportion of the annual allowable limit.

Therefore an Occupational Exposure Limit Guideline of 10 mrem (cumulative for the expedition) was established. Proper exposure monitoring of ambient radiation levels and personal radiation exposure are both required to determine if this exposure limit could have been or was exceeded and for project exposure and risk management documentation. Ambient radiation exposure levels, taken during both Phase I (on Amchitka Island and during sea operations) and II of the expedition showed no readings on Amchitka Island or in its maritime area over established background levels.

2. Methods

The dosimeters used for the Amchitka Expedition were provided by Landauer Inc. of 2 Science Road, Glenwood, Illinois 60425-1586 (http://www.landauerinc.com/ products.htm). Dosimeter type X9 was chosen because they are particularly well suited for use in harsh environmental conditions. The dosimeters were issued by Landauer on June 1, 2004, at the request of Conrad D. Volz, DrPH, MPH Amchitka Expedition Project Manager and radiation control officer. These dosimeters were shipped to IRM/CRESP where they were retrieved by Dr. Volz and packed with personal, non-radioisotope source gear for travel to Anchorage and Adak, Alaska. These dosimeters were always in the possession of Dr. Volz and included appropriate transit control dosimeters. Dosimeters, to be used during Phase I of the expedition were separated from dosimeters to be used during Phase II, and personal controls, transit controls, blank controls and spiked controls on June 13, 2004, the day the Ocean Explorer steamed for Amchitka Island to commence Phase I activities. The Phase II dosimeters, transit and personal controls and dosimeters to be used as blank and spiked controls were locked in the garage of the Volz Condo Unit in a secure container.

Phase I expedition personnel were issued radiation dosimeters before departure on their trip from Adak Island, at the required Safety and Health Meeting, held on board the Ocean Explorer. At this meeting the importance of wearing the dosimeter at all times, except when asleep at night was stressed. Phase I expedition personnel were photographed wearing their dosimeters. At the time of issuance the name of the individual receiving the numbered dosimeter as well as the organization directly employing the individual was entered. The date and exact time of dosimeter issue was also entered in the Landauer log. Dr. Volz made sporadic checks to insure that dosimeters were being worn by all personnel involved in all aspects of the expedition. All individuals checked were wearing their dosimeters in the correct fashion each time a check was made; individual conversations indicated that each person took seriously the potential hazard of radionuclide exposure. This was made clear from ongoing conversations with Chief Scientists and their technicians as well as Ocean Explorer crew members.

Dr. Volz had the support of the Phase I Ocean Explorer Captain in assuring compliance with all radiation safety procedures outlined in the Safety and Health Plan. Throughout Phase I of the expedition a deploy control was kept in the stateroom of Dr. Volz to measure exposure of a non-personal nature and was intended to capture the background exposure within the hull of the Ocean Explorer.

At the conclusion of Phase I of the expedition, once the Ocean Explorer had docked at Adak Island and before expedition members left the boat; all dosimeters were collected and the exact time and date of collection was noted on the Landauer supplied log. All dosimeters were collected; even those of Ocean Explorer crew members who were expected to participate in Phase II of the expedition. This was done to avoid confounding results that could result from exposure to Ionizing Radiation during their trip to and from Dutch Harbor to drop off Navy Personnel and Equipment. All dosimeters collected after Phase I, including the deploy control were immediately reunited with the remainder of the dosimeters stored in the garage of the Volz Condo, including the transit control, they were stored a separate bag in the same container as the remainder of the dosimeters.

Phase II expedition dosimeters were issued in the exact same manner as Phase I dosimeters. Dosimeters usage was also checked frequently by both, Michael Gochfeld, MD, PhD, Expedition Safety and Health Director and Dr. Volz. Compliance with dosimeter usage seemed universal and the expedition safety and health leaders were supported and assisted in their efforts by Ray Haddon the Ocean Explorer Captain. Phase I expedition members also participating in Phase II were reissued the dosimeter that they wore during Phase I of the expedition, so that their total combined expedition exposure could be determined. A separate Phase II deploy control was mounted in the on-deck aft starboard equipment bin.

Phase II dosimeters were collected on July 20, 2004, while the Ocean Explorer was docked and being unloaded at the Adak, Alaska harbor. All Phase II expedition dosimeters were accounted for. All phase II dosimeters, including the Phase I/II deploy control in the Volz stateroom and a Phase II deploy control in the equipment bin located on the Ocean Explorer’s aft starboard deck, were immediately reunited with the remainder of the dosimeters. All dosimeters were kept on Adak Island by Dr. Volz in his sleeping room.

Personal control dosimeters were issued to all expedition members except Ocean Explorer crew (see field notes) following return to Adak Island. Phase I control dosimeters were issued on June 24, 2004 and Phase II controls were issued on July, 21, 2004. Control dosimeters were received both at the CRESP HQ and at the office of Dr. Volz. The date last exposure of control dosimeters is recorded in Table 1, Dosimeter Spreadsheet. The date of receipt of control dosimeters at both CRESP HQ and at Dr. Volz's office will be maintained with the Landauer logs at Dr. Volz's office. Each expedition member will be asked to describe their geographic movements and approximate in-flight times and provide other information that would add to the ability to interpret control exposures before the results of personal Dosimetry are released to Dr. Volz by CRESP HQ. This data will be incorporated into Table 1.

As a check on laboratory procedures both blanks and spiked controls will be sent to Landauer Inc. A total of 6 blanks and 5 spiked controls will be sent with the complete set of dosimeters. Blanks were never separate from the Landauer issued transit control and therefore can be used to estimate the variation in laboratory results between dosimeters exposed to the same level of radioactivity and can provide a measure of the standard error of the method. The spiked dosimeters were taped directly onto the opened Cesium 137 check source of the Ludlum Ratemeter for periods ranging from 1 minute to 1 hour and 40 minutes. Additionally, 2 (two) dosimeters were exposed as references in Pittsburgh, PA for 7 days. One was issued to a University of Pittsburgh, Center for Public Health Preparedness Coordinator who wore the dosimeter during waking hours, exactly as did expedition personnel. The second dosimeter was mounted on a secretary's desk in front of a bank of windows receiving sunlight throughout the day.

3. Evaluation Design

The evaluation of individual exposure to Ionizing Radiation in situations where workers are potentially exposed to a known source of radiation is very straight forward. The general procedure is to analyze the dosimeters, obtain the total exposure in mrem and adjust this exposure to reflect the time period in which the exposure is received. Statements regarding the proportion of total yearly radiation dosage received by each worker and thus adjustments in their work practices, time spent in high radiation areas (administrative controls), and work or leave assignments can than be made to insure that

each worker receives a radiation dose “As Low as Reasonably Achievable” (ALARA) under the exposure standard applicable to them.
The absolute exposure of expedition personnel to Ionizing Radiation will be evaluated as stated in the previous paragraph. However their work functions and practices and in fact their geographic location relative to nuclear shot cavities, capped debris piles and monitoring wells and between and within work groups varies far more than in traditional work settings. Also the existence of radionuclide leakage and thus exposure and where any leakage and therefore exposure is occurring is unknown. Thus, data relative to expedition group and individual activities is necessary to help interpret and evaluate personal radiation exposure. Data, which will add context to this analysis and have been recorded over the course of both expeditions includes:

- Ambient Radiation Monitoring.
- Safety and Health/ Daily Activity Logs.
- Anti Cross-Contamination Radiation Monitoring.
- Radiation Scanning of Biological, Water and Sediment Samples.
- Geographic Positioning System (GPS) Waypoints, Man Overboard Points and Biological, Water and Sediment Sampling Points.
- Stratos Communications, Volz-Powers, Powers-Volz.
- Expedition Narratives of Volz, Burger and Gochfeld.
- Ocean Explorer Ships Logs
- Navy Oceanographic Sidescan and Multibeam Sonar Course and CTD Drop Records

Since radiation exposure over established background levels is not anticipated for personnel working on this project, any result indicating exposure over the expedition guideline will be investigated as both a Radiation Health issue and a possible expedition endpoint. That is, significant individual or group radiation exposure would indicate an accessible source of radionuclides, which was previously unknown.

Descriptive statistics will be developed for all on-expedition dosimeter results and outliers will be determined. Additionally the sign test will be employed to determine the significance of differences between actual on-expedition dosimeter results and the Expedition Occupational Exposure Guideline of 10 mrem. The null hypothesis (H_o) is that the median of the distribution of the expected exposure value of 10 mrem minus the observed exposure value is 0. This null hypothesis naturally implies that values above and below the median are equally likely. The alternate hypothesis is that is that the median of the expected exposure value minus the observed exposure value is not 0. The level of significance is determined by;

$p \leq 2 * \sum(i=0 \text{ to } k) \{N!/(i!*(N-i)!\}/4$

Where k is the smaller of (n^+) and (n^-) and N=(n^+) + (n^-) and (n^+) and (n^-) are binomially distributed with p=q=1/2

It is also of interest to expedition planners to know if radiation exposure levels for individual expedition members differ between those received on-expedition and those received in a similar time period post expedition. Since both individual on-site and control Dosimetry were performed, the Wilcoxon Matched- Pairs Signed- Ranks Test can be employed to determine if there is a difference between the expedition and control exposure levels. This is a very sensitive test and is used when the underlying distribution is unknown and the number of pairs is too small to use the student t-test.

The test procedure is to rank the differences within each pair (x-y) according to their absolute differences, $|x-y|$. All differences where x=y are ignored. The original signs are than affixed to the rank numbers. All pairs with equal absolute differences are assigned the same rank and are ranked with the mean of the rank numbers that would have been assigned if they would have been different. All positive ranks are summed to (W+) and all negative ranks are summed to (W-).The level of significance is determined by;

p=The Number of all Distributions of Signs/The Ranks that Have A Sum (+Ranks)≤W+ (if W+ <W-)/The Total Number of Possible Distributions of Signs

The null hypothesis (H_o) is that the difference d=(x-y) between members of each pair (x,y) has a median value of 0. Stated another way the difference between the expedition exposure levels and control exposure levels has a median value of 0. The .Alternate Hypothesis is that this difference is not 0. The scale of this test is an ordered metric scale because the differences within pairs must be ranked according to their absolute differences. A Confidence Interval (CI) of the difference between the expedition and control exposure levels will be calculated.

Since extensive tabulation must be done to run this test and it cannot be performed on a calculator or programmed in C easily, the Z approximation will be employed as a statistical check. As N>15 then;

Z= (W-0.5- N* (N+1) / 4) / sqrt (N* (N+1)* (2* (2* N+1) / 24), with W the larger of W+ and W-.

3. Field Notes, 9/12/04, Updated 4/25/05

a. In Phase I of the expedition an additional Navy Technician was added to the expedition, without prior knowledge of the Project Manager. As a result, the number of dosimeters, removed from the container and brought to the Ocean Explorer immediately before departure were 1 less than the number of expedition members. The project manager called the Adak Condo caretaker John Highstone to reopen the secured garage containing the project dosimeters but he was not available. The project manager than went to the Adak airport where Mr. Highstone is a cargo handler and he had already left, after approximately 30minutes of searching for him the project manager made a decision that the expedition could not be held up any longer. The project manager issued the remaining dosimeter to the Navy Technician. The decision logic employed was that the technician would be handling Side- Scan and Multibeam sonar as well as the CTD apparatus and could therefore be exposed to Radionuclides while the project manager was mainly shore-based. Additionally, the Project Manager would carry a Ludlum Ratemeter with both the Gamma Scintillation Probe and G-M Pancake Probe both on land and while at sea during the expedition, thus allowing monitoring of ambient levels of radiation in his immediate area.

b. Although adequate numbers of control dosimeters were brought for issue to Ocean Explorer crew, no system of retrieval could be devised to insure return of the dosimeters. Additionally, conversations with both Captains indicated that crew members did not necessarily know their next assignments, which could include fishing or transit near Amchitka Island. As a result no control dosimeters were issued to Ocean Explorer crew members.

4. Results and Statistical Analysis

a. On-Expedition Dosimetry Results

1.) Descriptive Statistics

The expedition net cumulative exposure, in millirems (mrem), for each member of the Amchitka expedition is presented in the All Personnel Data tab of Excel Spreadsheet, DosimeteryAmchNoId_Volz_11_20_04. Individual identifiers have been removed from this data set as these records are confidential medical records, Michael Gochfeld, M.D., PhD, Expedition Health and Safety Director will retain individual identifying information. Net cumulative exposures are calculated by subtracting the exposure of the transit control associated with each members badge from the gross exposure of each badge. The distribution of expedition exposure results is presented in Figure 1, Histogram of Expedition Exposures in mrem. Figure 1 shows that expedition exposure results are fairly tightly grouped around 0 mrem, with the exception of one negative outlier. This may be better appreciated by observing Figure 2, Boxplot of Net Expedition Exposure in mrem. Fifty percent (50%) of the cases fall within the red box, the lower limit depicting the 25th percentile and the upper limit the 75th percentile, and the line within the box represents the median net exposure in mrem. This box is neatly grouped around 0 and the whiskers of the boxplot, representing the largest and smallest values that are not outliers are less than 1.5 times the length of red box, showing a tight grouping of values. There is one extreme outlier, marked with an asterisk. This value is identified in Table 2, Extreme Values and is -7.9 mrem.

It is expected that if expedition personnel were exposed to no ionizing radiation over background that net cumulative exposure, measured in mrem, should be equal to 0 mrem. Table 1 supports the hypothesis that the net cumulative exposure of expedition personnel is 0 mrem. The mean of the expedition exposure is -.4218 mrem and the 95% Confidence Interval for the Mean is – 1.0355 to .1920 mrem, which includes 0 mrem. The median of the net expedition exposure is -.2 mrem. The 25th percentile is -1 and the 75th

percentile is .6, showing a narrow Interquartile range of 1.6 mrem. The maximum net cumulative exposure value is.1920 and the minimum value is -7.90 mrem.

Table 1, Expedition Dosimetry Descriptive Statistics

	Statistic	Std. Error
Mean	-.4257	.2928
95% Confidence Interval for Mean Lower Limit	-1.0207	
Upper Limit	.1693	
5% Trimmed Mean	-.2437	
Median	-.2000	
Variance	3.000	
Std. Deviation	1.7321	
Minimum	-7.90	
Maximum	1.80	
Range	9.70	
Interquartile Range	1.6000	
Skewness	-2.446	.398
Kurtosis	9.595	.778

Figure 1, Histogram of Expedition Exposures in mrem

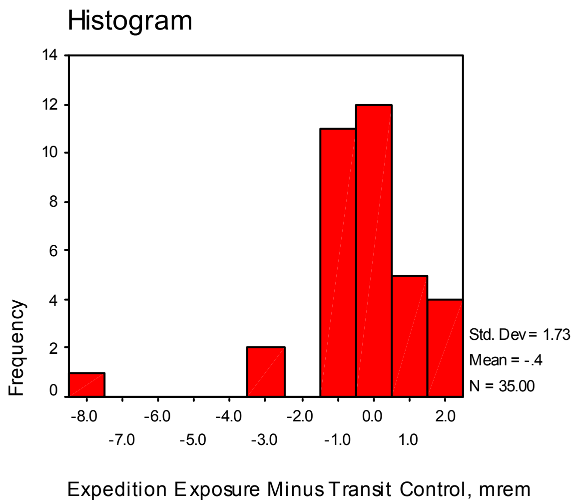
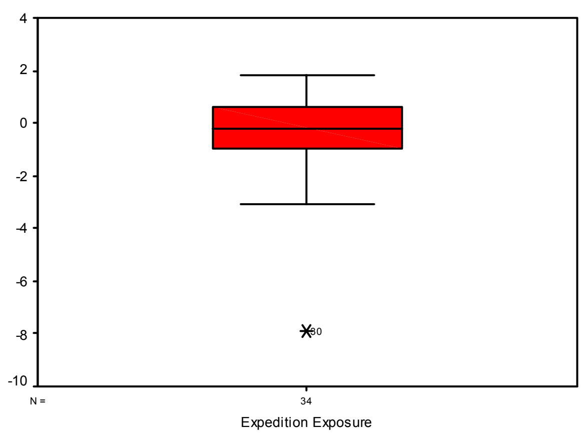


Table 2, Extreme Values

		Number	mrem
Highest	1	5	1.80
	2	16	1.60
	3	23	1.50
	4	18	1.50
	5	17	1.40
Lowest	1	30	-7.90
	2	26	-3.10
	3	28	-2.90
	4	9	-1.50
	5	6	-1.40.

Only partial lists of cases with the value -1.40 are shown in the table of lower extremes.

Figure 2, Box Plot, Expedition Exposure in mrem



2.) Expedition Dosimetry Results, Hypothesis Testing

As previously stated, if expedition personnel were not exposed to ionizing radiation over the course of the expedition in excess of background levels, the median exposure of expedition personnel minus the appropriate transit control should be 0 mrem (Net Expedition Exposure should be 0). The large sample sign test is used to test the null hypothesis that the median of expedition exposures is 0 mrem versus the alternative hypothesis that the median of expedition exposures is not equal to 0 mrem. Alpha is equal to .05. The sign test was chosen to test this hypothesis because the underlying distribution, is not confidently known.

H_o: $M_d = 0$

H_1: $M_d \neq 0$

L = Lower Critical Value = $P_{\alpha/2} = (E(X) - ½) + Z_{\alpha/2} \sqrt{Var(X)}$

U= Upper Critical Value = $P_{1-\alpha/2} = (E(X) + ½) + Z_{1-\alpha/2} \sqrt{Var(X)}$

$L = 11.2 \approx 11$

$U = 23.71 \approx 24$

Decision Rule- Reject H_0 if $X \leq 11$ or ≥ 24

Since the number of pluses equals 14.5 we retain the null hypothesis that the Median Exposure of Expedition Personnel is 0 mrem.

The 95% Confidence Interval of the Median Exposure is given by:

$d^{o}_{L+1} \leq 0 \leq d^{o}_{u}$

The 95% Confidence Interval of the Expedition Median Exposure is:

-.7 mrem ≤ 0 ≤ .2 mrem.

Conclusions: We thus retain the null hypothesis that the median net exposure of expedition personnel is 0 mrem and we can say with 95% confidence that the median net exposure of expedition personnel is between -.7mrem and .2

mrem. There were no positive outliers and the highest net expedition exposure was 1.8 mrem.
Net Expedition Exposures in mrem are within limits established a priori by expedition planners and do not exceed exposure standards established for members of the public for any leg of the expedition.

b. Control Results

1.) Descriptive Statistics

Net control exposure in mrem is calculated two ways. First, the gross flight control result was subtracted from gross control results for each individual. Table 3, Net Control Results-Individual Control minus Flight Control, in mrem presents measures of central tendency for these net control results. The mean net control value was -.7261 and the 95% Confidence Interval of the mean has an upper bound of .7149 and a lower bound of -2.1671. It is significant that 0 is in this interval. This flight control flew with D. Volz from Adak to Anchorage to Pittsburgh.

Net control exposure is also calculated by subtracting a gross postal control from individual gross control dosimeter results. This is perhaps the most important net control measure. The postal control was flown from Adak to Anchorage and to Seattle, according to postal officials it was than shipped by truck to Pittsburgh. The entire process took approximately 4 weeks. The postal control was thus not exposed to a transcontinental flight. Table 4, Net Control Results- Individual Control minus Postal Control, in mrem presents measures of central tendency for net control results minus the postal control, all results are in mrem. The mean net control exposure is .065 mrem and the 95% confidence interval of the mean is -1.3811 mrem to 1.5116 mrem. Again, it is important to note that 0 falls within this interval. Table 5, Extreme Values- Net Control Exposure minus Postal Control, in mrem shows that there are 2 values that have z scores, which indicate that they are positive outliers. Dosimeter Subject 6 had a net control exposure of 10.10 mrem, which would lead to a z score of 2.92. If the underlying distribution were normally distributed this score is higher than 99.81% of all possible scores. Also, subject 9 had a control exposure of 5 mrem, giving a z score of 1.43, which is higher than 91.92% of all possible scores. These extreme values are depicted graphically in Figure 3, Histogram of Net Control Exposure minus Postal Control, in mrem.

Table 3, Net Control Results-Individual Control minus
Flight Control, in mrem

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	Statistic	Std. Error
Mean	-.7261	.6948
95% Confidence Interval for Mean Lower Bound	-2.1671	
Upper Bound	.7149	
5% Trimmed Mean	-.9292	
Median	- 1.0	
Variance	11.104	
Std. Deviation	3.3322	
Minimum	-6.60	
Maximum	9.30	
Range	15.90	
Interquartile Range	3.7000	
Skewness	1.022	.481
Kurtosis	2.839	.935

Table 4, Net Control Results-Individual Control minus Postal Control, in mrem

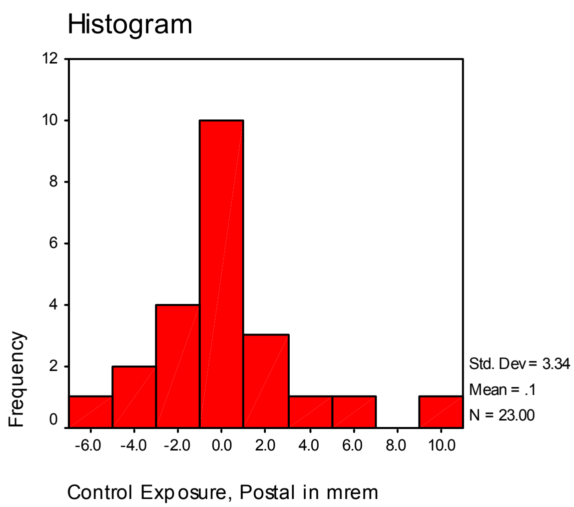
Mean	6.522E-02	.6974
95% Confidence Interval for Mean Lower Bound	-1.3811	
Upper Bound	1.5116	
5% Trimmed Mean	-.1382	
Median	6.522E-02	
Variance	11.187	
Std. Deviation	3.3447	
Minimum	-5.80	
Maximum	10.10	
Range	15.90	
Interquartile Range	3.70	
Skewness	1.002	.481
Kurtosis	2.794	.935

Table 5, Extreme Values- Net Control Exposure minus Postal Control, in mrem

		Case	Value
Highest	1	6	10.10
	2	9	5.00
	3	7	3.20
	4	2	2.80
	5	4	2.00
Lowest	1	8	-5.80
	2	27	-4.60
	3	23	-4.50
	4	13	-2.70
	5	24	-2.00.

Only a partial list of cases with the value -2 is shown in the table of lower extremes.

Figure 3, Histogram of Net Control Exposure minus Postal Control, in mrem



2.) Expedition Control Dosimetry Results, Hypothesis Testing

We expected that net control exposure minus the postal control would be greater than 0, given that expedition personnel would be flying home and receiving radiation exposure over background. This hypothesis is tested below. The large sample sign test is used to test the null hypothesis that the median of net control exposure minus the postal control is 0 mrem versus the alternative hypothesis that it is not equal to 0 mrem. Alpha is equal to .05. The sign test was chosen to test this hypothesis because the underlying distribution is not confidently known.

$H_o: M_d = 0$

$H_1: M_d \neq 0$

L = Lower Critical Value = $P_{\alpha/2} = (E(X) - ½) + Z_{\alpha/2} \sqrt{Var (X)}$

U= Upper Critical Value = $P_{1-\alpha/2} = (E(X) + ½) + Z_{1-\alpha/2} \sqrt{Var (X)}$

$L = 5.3 \approx 6$

$U = 16.70 \approx 17$

Decision Rule- Reject H_0 if $X \leq 6$ or ≥ 17

Since the number of pluses equals 11 we retain the null hypothesis that the Median Net Control Exposure of Expedition Personnel is 0 mrem.

The 95% Confidence Interval of the Median Net Control Exposure is given by:

$d^{o}_{L+1} \leq 0 \leq d^{o}_{u}$

The 95% Confidence Interval of the Expedition Median Exposure is:

- 2.0 mrem ≤ 0 ≤ .6 mrem.

Conclusions: We thus retain the null hypothesis that the median net control exposure of expedition personnel is 0 mrem and we can say with 95% confidence that the median net exposure of expedition personnel is from -.2 mrem to 1.7 mrem. There were though positive outliers and the highest net expedition exposure was 10.1 mrem.

3.) Hypothesis Testing, Difference Between Net Expedition Dosimetry Results and Net Control Results

The Wilcoxan Matched Pairs Signed Ranks test was used to test the hypothesis that the median difference between net expedition exposure and net control exposure for each individual is 0 versus the alternative hypothesis that the median difference of pairs is not 0. Table 6, Matched Pairs Wilcoxan Signed Ranks Test Scores-Control Exposure, Postal in mrem - Expedition Exposure, in mrem shows the mean rank and sum of ranks for both negative and positive scores, there was one tie. As expected from this table where the sum of ranks was almost identical for both negative and positive ranks, the two tailed significance of this test was .909. We therefore fail to reject the null hypothesis and assume that the median difference between matched expedition and control case exposures in mrem is 0.

Table 6, Matched Pairs Wilcoxan Signed Ranks Test Scores-Control Exposure, Postal in mrem - Expedition Exposure, in mrem
Ranks

Ranks	N	Mean Rank	Sum of Ranks
Negative Ranks	12	10.83	130.00
Positive Ranks	10	12.30	123.00
Ties	1		
Total	23		

a Control Exposure, Postal in mrem < Expedition Exposure Minus Transit Control, mrem
b Control Exposure, Postal in mrem > Expedition Exposure Minus Transit Control, mrem
c Expedition Exposure Minus Transit Control, mrem = Control Exposure, Postal in mrem

Using the sign test, with a binomial distribution we obtain a two tailed significance approaching .832, adding additional weight to the previous test. The median difference score between matched cases is statistically 0 mrem. The 95% Confidence Level of the median difference is calculated as:

$- 2.1 \text{ mrem} \leq 0 \text{ mrem} \leq 2 \text{ mrem}$.

6. Conclusions

Amchitka Expedition Dosimetry Notification Report

February 4, 2005 (Sent to all expedition personnel)

This report was prepared by Dan Volz, DrPH, Michael Gochfeld, M.D., Ph.D.; Barry Friedlander, M.D. and Michael Stabin, Ph.D., CHP

CRESP Amchitka expedition personnel were considered to be members of the general public regarding their allowable radiation exposure during the expedition. The annual allowable incremental[1] radiation exposure to members of the general public is 100 millirem (mrem). Incremental radiation exposures include those from industrial or other external sources (excluding medical exposures). By contrast to the general public, radiation workers, [defined as those who have undergone a radiation training program with required refresher courses], have an occupational exposure limit of 5000 mrem per year[2].

Using the more conservative standard for allowable exposure to the general public, CRESP Amchitka expedition planners established an ***expedition*** radiation occupational exposure limit (expedition radiation guideline) by dividing the yearly incremental exposure of 100 mrem by the days spent on the expedition. Thus the CRESP Amchitka expedition members on Phase I had an expedition radiation guideline level of 3 mrem (as their Phase was 11 days), Phase II personnel had an expedition radiation guideline level of 6.3 mrem (as their Phase was 23 days) and personnel who were on both phases of the expedition had an expedition radiation guideline of 9.3 mrem (34 days on expedition).

The expedition radiation exposure of each individual was determined by subtracting the exposure as measured on a transit control dosimeter[3], kept on Adak Island, from each individual's expedition dosimeter reading. **None of the expedition radiation exposures were statistically distinguishable from the transit control dosimeter reading.**

We would expect that if expedition members received no incremental exposure over background (i.e. the transit control) during the expedition that expedition exposure results should fall randomly around 0 mrem. Expedition exposure statistics support the conclusion that there was no incremental exposure for expedition personnel. The mean expedition exposure was -.43 mrem and the lower and upper limits for the 95% confidence interval of the mean were -1.02 and .17 mrem respectively, an interval which contains 0. A statistical test concluded that the median exposure of expedition personnel was 0 mrem and we can say with 95% confidence that the median exposure of expedition personnel is between -.7 mrem and .2 mrem.

We took an additional control step by asking expedition personnel to monitor their post expedition exposures, wherever they may have gone. Those post-expedition dosimeter exposure levels (controlled, of course, by expedition members) did not differ significantly from expedition exposure levels. The time when the dosimeters operated for this post-expedition measurement was in all cases as long as the in-expedition durations and in many cases was longer.

Please be sure to contact either Dan Volz or Mike Gochfeld or both if you have any questions about the dosimeter monitoring process. If you or one of your expedition members would like their individual dosimeter readings, that person should contact Dan or Mike.

[1] To provide additional explanation, Incremental radiation is radiation over natural background.

Natural background exposure sources include cosmic, cosmogenic, terrestrial and some types of widespread man-made sources such as fallout from nuclear tests and accidents (Chernobyl). For example, cosmic rays are of solar or galactic origin and are generated by the interaction of primary particles with the atmosphere. Cosmogenic radionuclides are generated by the interaction of high energy cosmic rays with stable elements in the atmosphere and the ground. Terrestrial radiation comes from naturally occurring radionuclides found in the earth, several dozen of which have half-lives on the same order of magnitude as the estimated age of the earth. All people are exposed to natural background radiation sources and the NRC estimates the average dose to each person in the U.S.to be about 300 mrem/year. This dose is influenced by a number of factors including a geographic location's geology, latitude, and altitude, and other factors. A person living at sea level near Los Angeles receives about 30 mrem/year of cosmic radiation exposure, while a person living in Leadville, Colorado at 10,000 feet above sea level receives an annual cosmic radiation dose of about 140mrem.

Incremental radiation exposure, by contrast, includes exposure from all other man- made sources including those received occupationally, through the nuclear fuel cycle and via consumer goods, building materials and environmental exposures from Technologically Enhanced Naturally Occurring Radioactive Material (TENROM) such as industrial fly ash, slag and sludge. The largest contributors to most people's yearly radiation exposure from man-made sources are medical procedures. Diagnostic X-rays and nuclear medicine procedures account for an average dose of about 50 mrem/year to the U.S. population.

[2] The Nuclear Regulatory Commission has not seen biological effects to workers exposed to radiation at this level. Generally, biological effects are not expected at doses below about 50,000 mrem.

[3]The transit control was a dosimeter that "accompanied" the expedition dosimeters everywhere except on the expedition. The individual expedition dosimeters were "separated" from the transit control at the point when the Ocean Explorer sailed from Adak sailing for both phases of the expedition. (The control was stored at Adak during the two phases of the expedition) and immediately on return to Adak the individual expedition dosimeters from each phase were gathered and then stored with the transit control. At the end of the expedition, all these expedition dosimeters (individual expedition dosimeters and the transit dosimeter) were kept together until analyzed by Landauer Inc. So the only difference between the individual expedition dosimeters and the transit control is the exposure that the individual expedition dosimeters received during the expedition.