THESIS

ELECTRONIC DOSIMETER AND THERMOLUMINESCENT DOSIMETER CORRELATION STUDY AT CATAWBA NUCLEAR STATION

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2014

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ABSTRACT

ELECTRONIC DOSIMETER AND THERMOLUMINESCENT DOSIMETER CORRELATION STUDY AT CATAWBA NUCLEAR STATION

Duke Energy's nuclear fleet is comprised of seven nuclear plants. The dosimetry program at every plant includes a comparison of the dose recorded by the TLDs and EPDs at the end of each quarter. EPD over-response is desirable to a degree because the over-response offers a higher dose estimate; however, too great of an over estimate obscures the actual dose a worker receives. An EPD/TLD correlation study was conducted to quantify and identify factors contributing to excess EPD over-response and offer recommendations to improve the EPD/TLD correlation. The EPD/TLD correlations at Catawba Nuclear Station (CNS) (York, SC) were markedly higher than the EPD/TLD correlations at other Duke Energy nuclear plants. The purpose of this study was to investigate the EPD/TLD correlation experienced at CNS. Assemblies, comprised of a phantom (a one gallon plastic jug filled with water) with a V2/V3 Mirion 2000S EPD, V4 Mirion 2000S EPD and TLD inside of a plastic bag that was zip tied to the phantom, were placed in strategic locations within the CNS auxiliary building. Dose rates in the CNS auxiliary building ranged from approximately 10 μSv/h (1 mrem/h) to 350 μSv/h (35 mrem/h). Assemblies were removed after seven days and the dose from the EPDs and TLDs were determined and recorded. Both the V2/V3 and V4 EPDs over-responded compared to the TLD. The V4 over-response was found to be greater than the V2/V3 over-response. Reducing the V4 EPD bias from 15% to 7% would improve the correlation between EPD and TLD doses while still permitting some over-response, allowing for more meaningful EPD dose estimates.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor at Duke Energy, Graham Johnson, for the opportunity to conduct this investigation and to all of those who collaborated and helped me at Duke Energy. Additionally I would like to thank my advisor, Dr. Thomas Johnson, for all of the help and encouragement throughout my time as a student at Colorado State University.

I would also like to acknowledge the Health Physics class of 2014 for all of their help, revisions, and distractions; these last two years would have been a much duller and rockier road without all of you.

This publication was supported by Grant Number T42OH009229-06 from CDC NIOSH Mountain and Plains Education and Research Center. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC NIOSH and MAP ERC.

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INTRODUCTION

According to the Nuclear Regulatory Commission (NRC) guidelines, adult radiation workers likely to receive a dose in excess of 10 percent of the regulatory limits must have an individual monitoring plan. The external whole body radiation dose limit for radiation workers is 50 mSv (5 rem) per year. A worker expected to receive a dose in excess of 5 mSv (0.5 rems) in one year (10% of the limit) is required to have an individual monitoring plan and would require a personal dosimeter. Individual monitoring is accomplished using personal dosimetry devices, bioassay, and/or survey data. In addition to federal limits set forth by the NRC, administrative limits are also set in the individual monitoring plan. (1)

Personal dosimeters measure the external dose from ionizing radiation to an individual and can be used to ensure the dose received by a radiation worker is below the limits as defined by 10 CFR 20.1201. Except for planned special exposures, the annual limit to a radiation workers is exceeded if any of the following limits in Table 1 are met: total effective dose of 0.05 Sv (5 rems), the sum of the deep dose equivalent and the committed dose equivalent to any organ or tissue (excluding the lenses of the eye) of 0.5 Sv (50 rems), a lens dose equivalent of 0.15 Sv (15 rems), or a shallow dose equivalent of 0.5 Sv (50 rems). (1)

Table 1 Annual dose limit to radiation workers **(1)**

	Dose limit (Sv)
Total Effective Dose	0.05
$\sum$ deep dose and committed dose equivalent	0.5
Lens dose equivalent	0.15
Shallow dose equivalent	0. 5

Personal dosimeters used in the United States to demonstrate compliance with NRC regulations must meet the national standards set out by the American National Standard Institute's (ANSI) (2). Additionally, the ability of the dosimeter to measure a dose at low exposure levels and the confidence associated with the measurements are also important characteristics of a personal dosimeter (3). NVLAP (National Voluntary Laboratory Accreditation Program) provides accreditation to laboratories, such as Duke Energy's (Charlotte, NC) dosimetry laboratories, ensuring that the dosimeters in use are tested, calibrated, and measuring within NVLAP guidelines. (4)

Workers may be required to wear multiple personal dosimeters, specifically primary and secondary dosimeters, in the protected area of nuclear power plants (5). TLDs and EPDs can be used as primary and secondary dosimeters, respectively, in the protected areas of nuclear power plants. The data from personal dosimeters is used to assess the dose equivalent to workers, estimate doses during future operations and maintenance activities, ensure worker dose does not exceed dose limits, and demonstrate compliance with NRC regulations.

The purpose of the Duke Energy EPD/TLD correlation project is to quantify and identify factors contributing to the excess EPD over-response experienced at CNS and offer recommendations to improve the EPD/TLD correlation. Experiments were performed to ascertain the source of discrepancies in dose readouts between V2/V3 and V4 EPDs and TLDs exposed to the same dose and dose rate. Additionally, an investigation into potential inconsistencies in recorded dose caused by the addition of iPAMs (intelligent personal alarm meter) to EPDs was considered.

MATERIALS

In the experimental set up, TLDs and EPDs were used to derive doses and will be discussed here individually, including advantages and disadvantages of each, including the EPD system, individual components such as iPAMs and the two types of EPDs used (V2/V3 and V4). Additionally, prior assessments of EPD discrepancies with dose given are presented and discussed.

Thermoluminescent detectors

TLDs are integrating, passive dosimeters (1). Electrons and holes are created during TLD exposure when ionizing radiation interacts with the inorganic material of a TLD in a manner similar to scintillators. However, unlike in scintillation material, electrons and holes do not recombine promptly; instead, the recombination and subsequential photon release are delayed. Deep traps for holes and electrons in TLD material are desired to increase the delay of the photon release; activators or imperfections in the crystalline lattice of the TLD material lock in the excitation energy. The TLD is a passive device because deep traps in the material allow for buildup of trapped charges, holes and electrons, resulting in no signal produced at the time of exposure. The trapped charges correspond to the amount of energy deposited by the ionizing radiation.

The dose deposited in the TLD material can be determined using a TLD reader after the exposure. The TLD reader gradually heats the TLD chip material, liberating trapped electrons. The liberated electrons travel in the conduction band where they recombine with holes and emit an optical photon. The number of optical photons released is proportional to the dose deposited in the TLD material. The light intensity and sample temperature is used to create a glow curve, an example of a glow curve is provided in Figure 1. The glow curve is used to determine the effective dose to the individual; the total light output is proportional to the number of trapped electrons, which is proportional to the energy absorbed from radiation. (6)

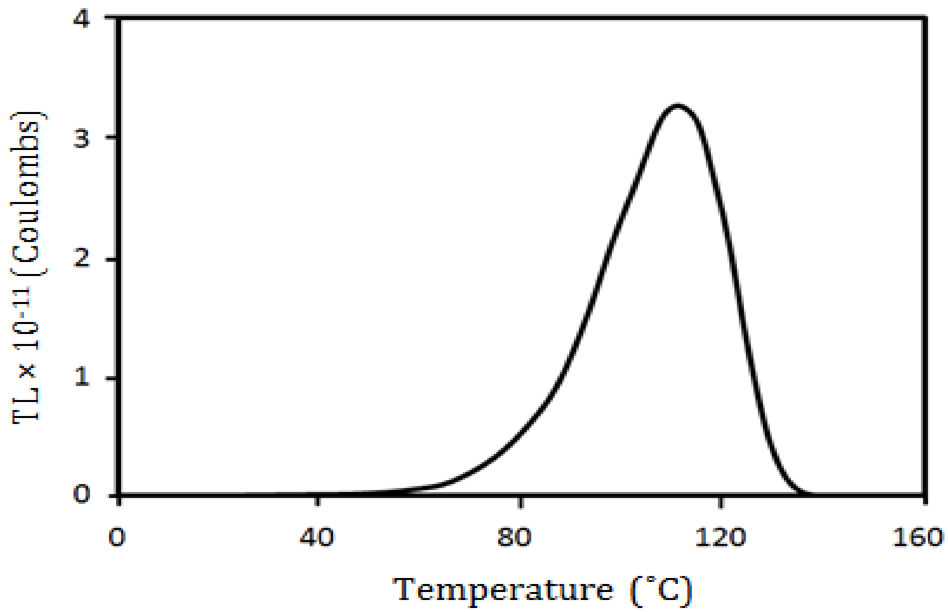

Figure 1 Example of a TLD Glow Curve. **(7)**

Multiple algorithms and corrections are required for an accurate estimation of the dose measured by a TLD. Over time, some electrons and holes recombine, resulting in fading; a diminished photon signal upon readout. Algorithms are used to correct for the optical photons released during the exposure phase (8). Variables that are considered in the fade correction include time passed, the average temperature the TLD was subjected to during the exposure phase, readout mechanism, anneal, and radiation type (9).

Duke Energy uses Harshaw 8814 TLDs (Waltham, MA) at CNS for the determination of the dose of record for individual employees. The 8814 TLD consists of four LiF:Mg,Ti (TLD-100) chips that are mounted on a TLD card between polytetrafluoroethylene sheets on an aluminum substrate. The polytetrafluoroethylene holder covers the TLD chips and provides specific filters for each chip allowing for the estimation of the shallow dose, eye dose, deep dose, and energy discrimination. A description of the TLD chips and filters on the Harshaw 8814 TLD is in Table 2. If neutrons are present, chip 4 is used for the determination of neutron dose and the lens of the eye dose is determined from chip 1. (10)

Table 2 Description of Harshaw 8814 TLDs used by Duke Energy. **(10)**

	Chip #1	Chip #2	Chip #3	Chip #4
TLD	700	700	700	600
Chip Thickness	0.015 in	0.015 in	0.006 in	0.015 in
Absorber thickness	0.091 in	0.040 in	Open Window	0.113 in
Filter	0.004 in Cu	0.162 in PTFE	0.0015 in Mylar	N/A
Use	Low Energy Photon Discrimination	Deep Dose	Shallow Dose	Lens of Eye

TLDs are used for providing the dose of record and demonstrate regulatory compliance; TLDs can demonstrate compliance with ANSI and can satisfy NVLAP procedures. However, TLDs are not desirable in circumstances where radiation workers could receive a dose approaching an administrative or federal dose limit and need immediate dose information. TLDs are a passive dosimeter, and thus do not provide the wearer or radiation workers a “real time” dose or dose rate and have no mechanism for alarming workers when they are approaching a set dose limit or are in a high dose rate area. Rather, the effective dose to the worker can only be determined after exposure using a TLD reader. Due to time and expense of reading TLDs, they are only read monthly, quarterly or, semiannually.

If the worker received an unexpected dose, the dose limit could be exceeded long before the worker’s effective dose is determined by TLD readout. Other concerns for TLDs include increased fading from unexpected temperatures during exposure and loss of stored information upon reading. As previously mentioned, the heating of the TLD material for readout effectively erases all the information stored in the chip; if the reader malfunctions, there are no actions that can be taken to reacquire the lost data. Duke Energy maintains NVLAP accreditation for all TLD reading operations.

Electronic Personal Dosimeters

A secondary dosimeter is desirable in environments where a worker's dose may approach an administrative or federal dose limit or for workers in high dose rate areas. EPDs are an excellent choice for a secondary dosimeter. EPDs have the ability to provide real time estimates for effective dose and dose rate. The most commonly used type of EPD is the silicon diode detector (11).

Silicon diode detectors are arranged in a p-i-n configuration, composed of an n-type material with an excess of donor electrons, intrinsic material, and p-type material that contains acceptor sites for electrons (Figure 2). A reverse bias voltage is applied to create a depletion region between the p and n-type materials, in which there are neither holes nor excess electrons.

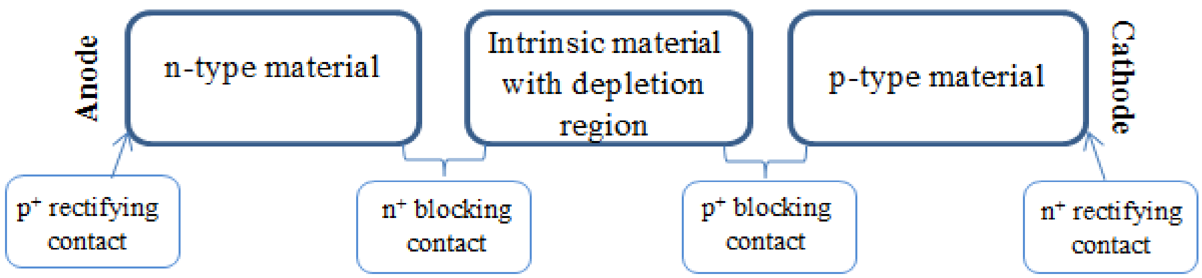

Figure 2 Electron field shape for semiconductor detectors with fully depleted plane. **(11)**

Radiation interacts in the depletion area of the silicon diode detector and creates electron-hole pairs. The number of electron-hole pairs is proportional to the energy deposited by the ionizing radiation. The movement of electrons and holes towards the cathode and anode, respectively, creates a current. The current results in an electrical signal, or pulse, proportional to the energy deposited in the detector. Metallic absorbers, filters, are used to flatten out the energy response of silicon diode detectors, however, the EPD energy response only demonstrates linearity over an explicit energy range. The following is a typical graph of sensitivity for silicon diode detectors (Figure 3). (11)

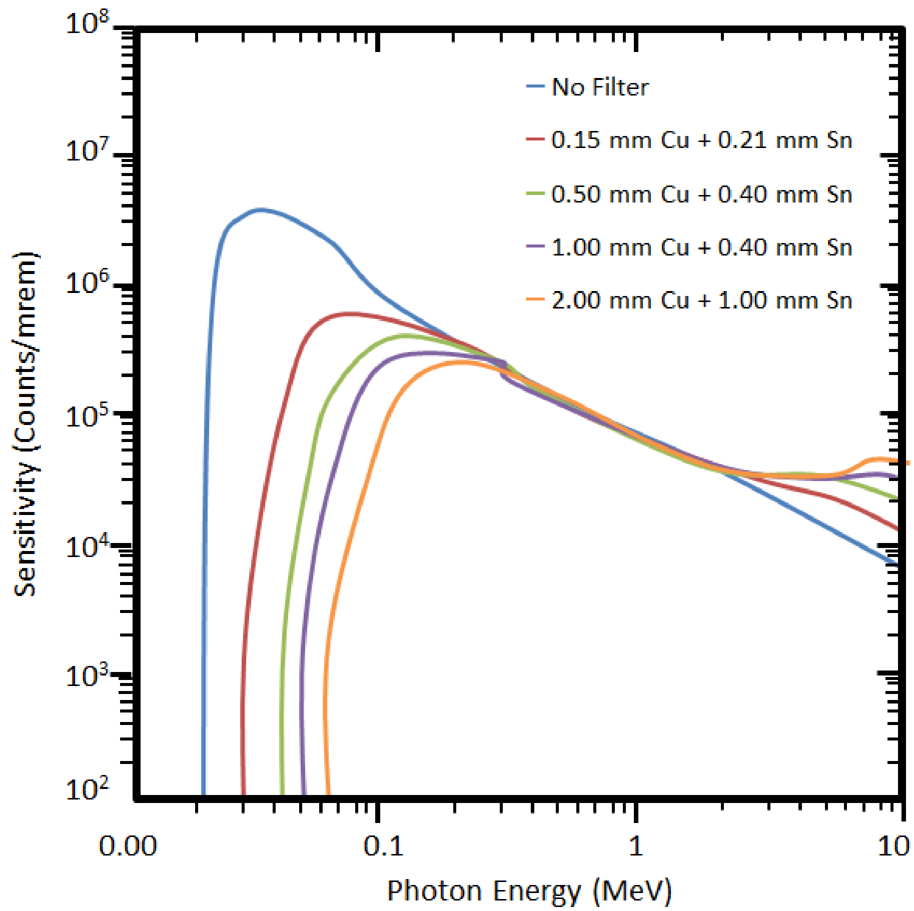

Figure 3 Typical Sensitivity of a Silicon Diode EPD with Photon Energy

The visual display on an EPD provides warnings for high dose and dose rates and allows the workers to monitor their dose throughout a job. Audible and visual alarms can be preset to trigger when a predetermined dose or dose rate is met. The dose data on the EPDs can be recorded immediately after the worker leaves the high dose/radiation zone. The EPD data is important for short-term dose monitoring and dose control; radiation protection personal can use EPD data to plan future exposures for radiation workers and ensure a worker's effective dose will not exceed regulatory limits.

Duke Energy utilizes Mirion Technologies DMC 2000S (San Ramon, CA) EPDs as secondary dosimeters. The DMC 2000S EPDs are solid state, silicon diode type detectors (12). The Mirion EPDs used by Duke Energy have the capability to measure deep dose equivalent and corresponding dose equivalent rate, and shallow dose equivalent and corresponding shallow dose equivalent rate (13). CNS deploys three versions of the DMC 2000S EPDs: V2, V3, and V4. The V2 and V3 EPDs are older models and demonstrate equivalent response to varying energies of radiation (50 keV to 6 MeV) (14). The newer V4 EPD, however, responds differently compared to the V2 and V3 versions to various energies of radiation.

Wireless Remote Monitoring Systems

Specifically for high dose rate areas or for jobs with relatively unknown conditions, a telemetry system may be desired. An electronic dosimeter in conjunction with a transmitter has the capability to relay information via radio signals to a base station. Telemetry systems allow the radiation protection (RP) personnel a more pro-active role in dose management by allowing the RP personnel the ability to ascertain a radiation worker's proximity to areas of high radiation and determine the optimum location and body position for a radiation worker to minimize dose. (15)

When telemetry capabilities are desired at CNS, radiation workers use a Mirion iPAM in addition to their EPDs. The iPAMs are a plastic shell that encases a Mirion 2000S DMC V2, V3, or V4 EPD (5). The iPAMs also offer additional vibrating, audio, and visual alarms and therefore may be advantageous in high noise areas (16). The material of the iPAM that surrounds the EPD has a greater density then air and therefore will attenuate incident radiation differently than if there was no shell encasing the EPD.

Summary of Comparison between TLDs and EPDs

The following table summarizes the comparison between TLDs and EPDs, including advantages and disadvantages of each.

Table 3 Comparison between TLDs (LiF:Mg,Ti) and EPDs (Mirion 2000S)

	TLD	Silicon Diode EPD
Type	Passive Dosimeter	Active Dosimeter
Real Time Measure?	No	Yes
Energy Range	25 keV to 20 MeV (17)	60 keV to 6 MeV (13)
Dose Rate Range	Up to 10^{13} Sv/h (18)	10^{-5} Sv/h to 10 Sv/h (13)
Fading	Yes, 5% per year (5)	No
Measurement Range	10 pGy to 10 Gy (19)	Background to 10 Gy (13)
Linearity	Super linearity above 1 Gy	100 keV to 1000 keV (20)
Dose and Dose Rate Alarms	No	Yes
Particles	Beta, Gamma, and Neutron	Gamma

Observed Differences between V4 and Older Dosimeters

The V4 EPDs are designed to over respond, compared to the V2/ V3 EPDs, to radiation of approximately 65 keV to 150 keV and under respond to radiation with energies less than 65 keV (Figure 4). In this thesis, a comparison between the V3 and V4 will be discussed. The energy response of the EPDs used by Duke Energy is shown in Figure 4.

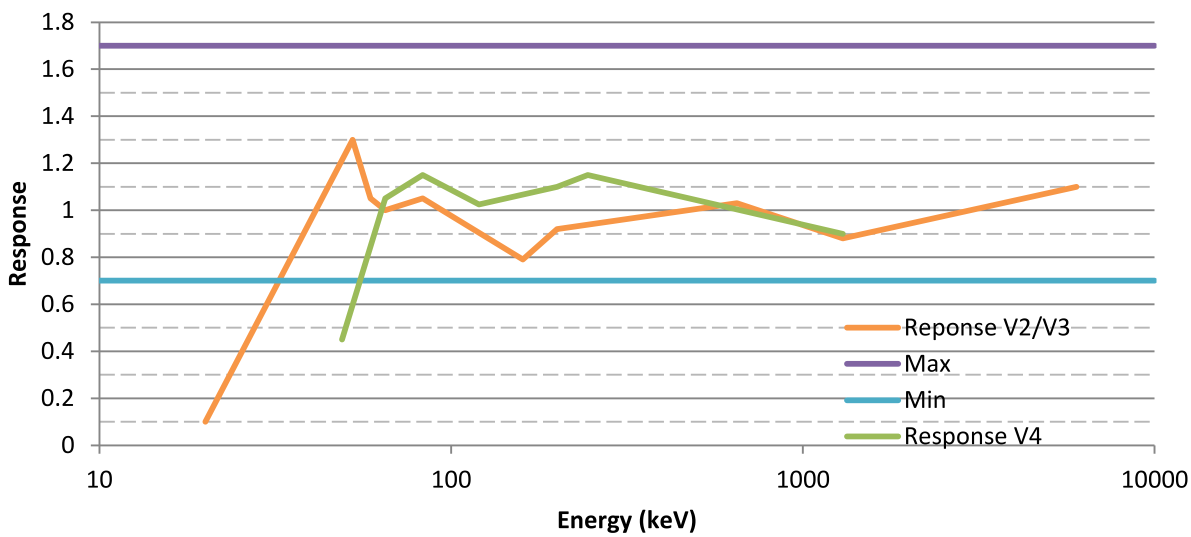

Figure 4 Energy response for the DMC 2000S V2 and V3 EPDs (orange line) and V4 EPDs (green line). **(20)**

The shape of the energy response curve for the V2/ V3, and V4 DMC 200s EPDs exhibits a response as expected for a filtered silicon diode EPD (Figure 3). The older and newer EPD's energy response exhibits an initial linear increase, linear region, slight decrease, and increase at the end of energy range.

Similarly, the energy response between the V2/V3 and V4 EPDs with dose rate was determined and is presented in Figure 5. The linear range of the V2/V3 and V4 DMC 2000S EPDs ranges from dose rates of 1.0×10^{-3} Sv/h (10 rem/h) to 15 Sv/h (1.5×10^{3} rem/h) (Figure 5) (20).

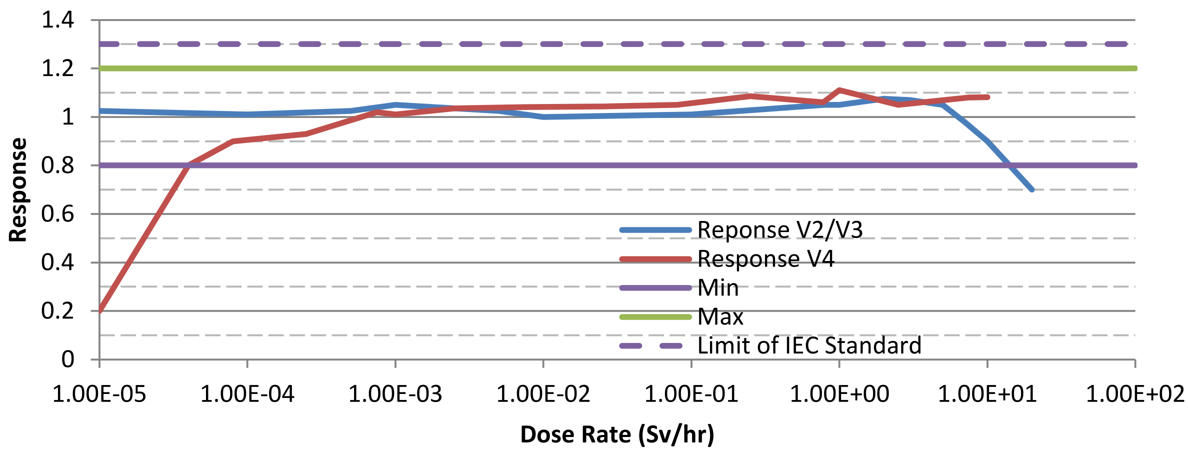

Figure 5 Dose rate linearity of DMC 2000S V2/V3 EPDs (red) and the V4 EPDs (blue). **(20)**

The V2/V3 EPDs maintain dose rate linearity of +/- 20º up to 1 Sv/h (100 rem/h) and +/- 30º from 1 to 10 Sv/h (100 to 1000 rem/h), and the V4 EPDs maintain dose rate linearity up to +/- 10º up to 1 Sv/h (100 rem/h) and less than +/- 20º from 1 to 10 Sv/h (100 to 1000 rem/h). The V4 EPDs have improved linearity in energy response across a larger range for photon energies compared to the V3. (21) The hypothesis is that the difference in EPD response to photons of energies present at CNS will cause the V4 EPDs to read higher than the V2/V3 EPDs, in accordance with the energy response in Figure 4.

METHODS

A DMC 2000S V3 EPD, DCM 2000S V4 EPD and 8814 Harshaw TLD were placed inside a one quart sealable plastic bag. The plastic bags were zip tied to a phantom to create a "pack" (Figure 6). The phantom was created to simulate body tissue and consisted of a one gallon plastic container filled with water. Thirty-two packs were assembled; six of the packs differed in that the V3 and V4 EPDs were placed inside of iPAMs, the remaining twenty-six packs did not utilize iPAMs (APPENDIX A: Pack Components).

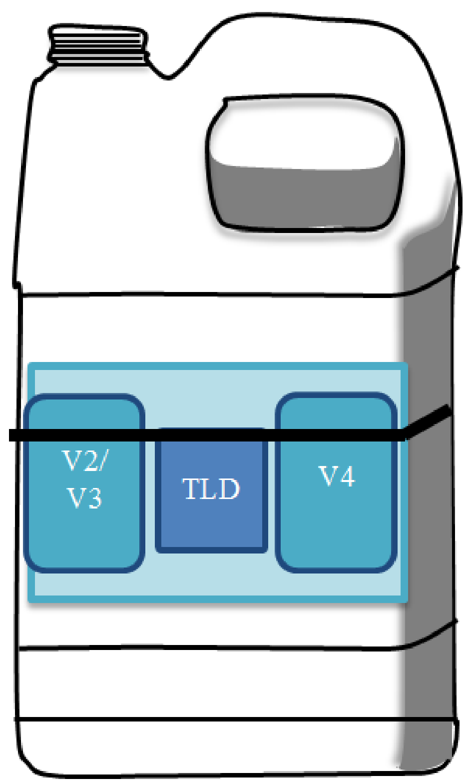

Figure 6 "Assemblies" – phantom with V3 and V4 EPDs and TLD zip tied on. **(22)**

Individual packs were placed in strategic locations within the CNS auxiliary building with dose rates ranging from approximately 0.01 mSv/h to 0.35 mSv/h (1 mrem/h to 35 mrem/h). Locations were identified based on anticipated dose rates and reviewed by Duke Energy ALARA (as low as reasonably achievable) personnel before being selected for this study (APPENDIX B:

Pack Placement). Survey maps of each room were used to assist in identifying locations within the rooms to place packs (APPENDIX C: Room Survey Maps). Thirty-one assemblies were positioned in specific locations for seven days at various heights, based on the ability to secure assemblies. Two packs (packs # 6 and # 37) were removed after one day due to concerns that the TLDs would receive a dose in excess of 50 mSv (5 rem). TLD doses in excess of 50 mSv (5 rem) cannot be easily and accurately read by the TLD reader. The six iPAM packs were positioned adjacent to packs without iPAMs to allow for comparisons of EPDs with and without the addition of iPAMs.

The doses from the EPDs were recorded when the packs were removed. TLDs were taken to Duke Energy's Environmental and Radiological Laboratory (EnRad) to be read. The EPDs were biased by 15% prior to the experiment. TLDs were corrected by a factor of 1.142 to account for fade (in accordance with Duke Energy's procedures).

The dose rate the packs were exposed to was determined using the total dose recorded by the TLDs and the period of time they were exposed. A t-test was used to ascertain if the V2/V3 and V4 EPD responded in a manner that was statistically different. Statistical analysis was performed using Microsoft Excel (Redmond, WA). The difference between V2/V3 EPDs and V4 EPDs was quantified as well as the deviation between the V2/V3 and V4 EPDs and the TLDs (APPENDIX D: Data).

RESULTS

V2/V3 vs. V4 EPDs

A normal quantile plot was used to determine if the V2/V3 and V4 EPD data was normally distributed. The coefficient of determination values, R^2, were 0.955 and 0.959 for the V2/V3 and V4 EPD data, respectively. The R^2 values are close to one, implying normality. On both graphs in Figure 7 there are outlier points, one on the high and one on the low end for the V2/V3 data and one on the low end for the V4 data. These three points correspond to the three packs with the greatest difference between the V2/V3 EPDs and V4 EPDs, suggesting the dosimeters were not in the same radiation field.

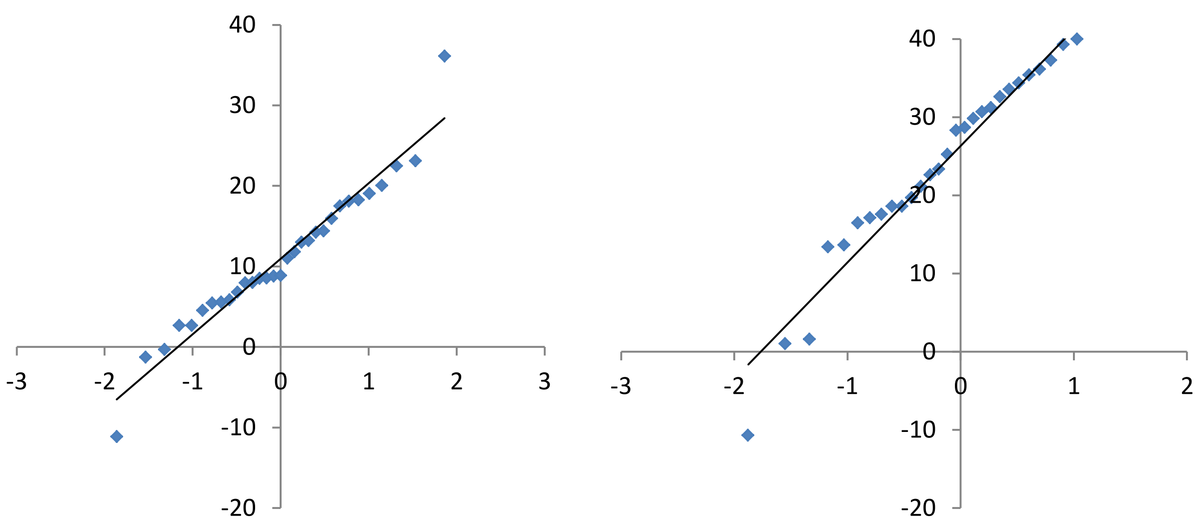

Figure 7 Normal quantile plot for V2/V3 EPD data (left) and V4 data (right)

A t-test using the V2/V3 and V4 EPD dose data determined the difference in the means of the V2/V3 and V4 EPDs is not statistically significant; the p value of 0.78 is less than the t-critical value (2.00) (Table 4). However, the dose recorded by the V4 EPDs was consistently greater than the V3 EPD recorded dose for 28 out of the 32 packs (APPENDIX D: Data). The large range in dose rate ranges, 0.01 mSv/h to 0.35 mSv/h (1 mrem/h to 35 mrem/h), resulted in a large standard deviation for both the EPD mean recorded dose.

Table 4 Two tail t-test results for the comparison of V2/V3 EPDs and V4 EPDs

	V2/V3 vs. V4 EPD t-test
V2/V3 Mean	1510 mrem
V2/V3 Standard Deviation	247 mrem
V4 Mean	1616 mrem
V4 Standard Deviation	261 mrem
Number Observations	32
Degrees Freedom	62
P Value	0.78
t-Critical	2.00

TLDs vs. EPDs

The V2/V3 EPD recorded dose varies from the TLD recorded dose by a factor of 1.11 ± 0.08 when the EPDs are biased by 15% (Figure 8). Reducing the bias to 7% brings the difference the V2/V3 EPD varies from the TLD to unity, 1.02 ± 0.06. The improvement in the V2/V3 EPD and TLD variance is plotted in Figure 9. INPO guidance of plus or minus 25% for EPD/TLD correlations is illustrated using the red lines on the plot below, the green lines in the plot below represent the 99% confidence limit.

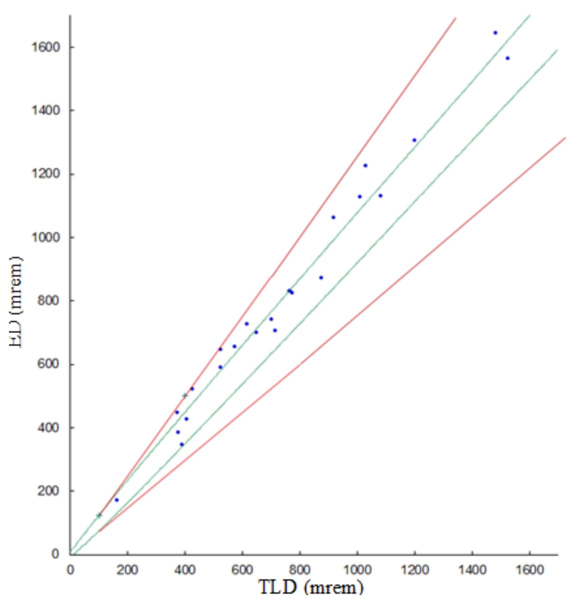

Figure 8 V2/V3 EPD with original 15% positive bias. Red boundary: INPO Guidance: +/- 25% if TLD or EPD >100 mrem. Green boundary: 99% confidence limit for TLD >10 mrem, 2.5s where s = Sqrt (TLD) for TLD < or = 10 mrem, EPD ≥18 mrem.

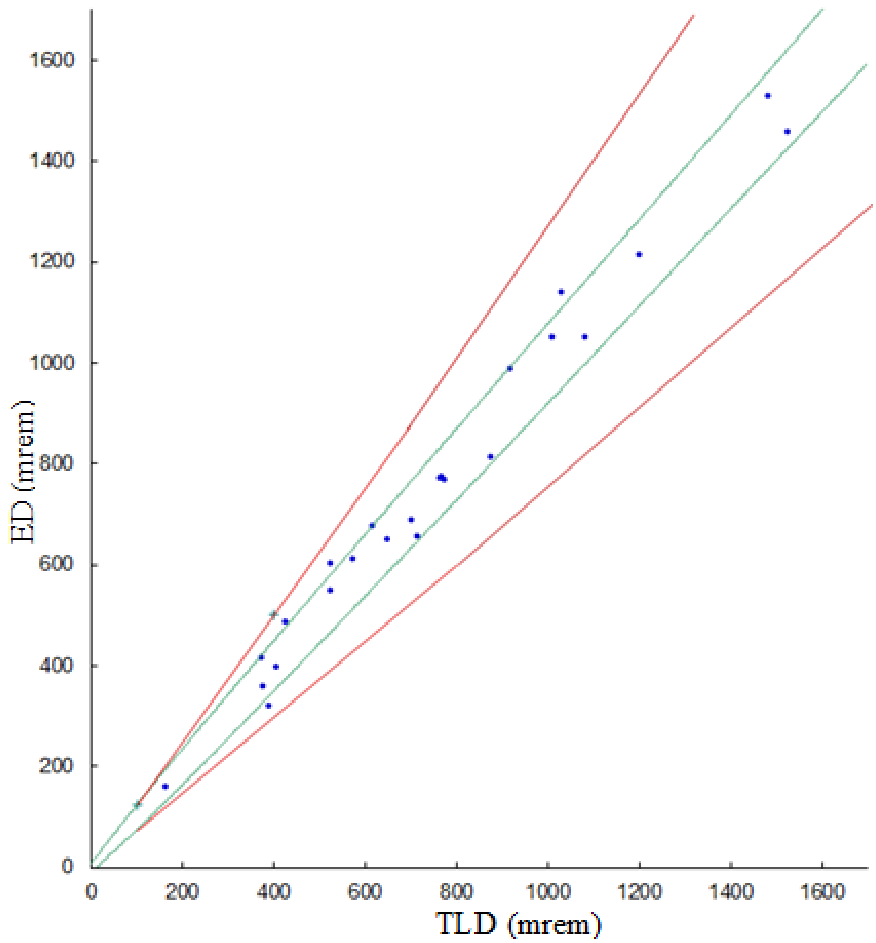

Figure 9 V2/V3 EPD with 7% positive bias. Red boundary: INPO Guidance: +/- 25% if TLD or EPD >100 mrem. Green boundary: 99% confidence limit for TLD >10 mrem, 2.5s where s = Sqrt (TLD) for TLD < or = 10 mrem, EPD ≥18 mrem.

The V4 EPD recorded dose varies from the TLD recorded dose by a factor of 1.27 ± 0.12 when the EPDs are biased by 15% (Figure 10). Reducing the bias to 7% brings the difference the V2/V3 EPD varies from the TLD closer to unity, 1.18 ± 0.11. The improvement in the V4 EPD and TLD variance is plotted in Figure 11.

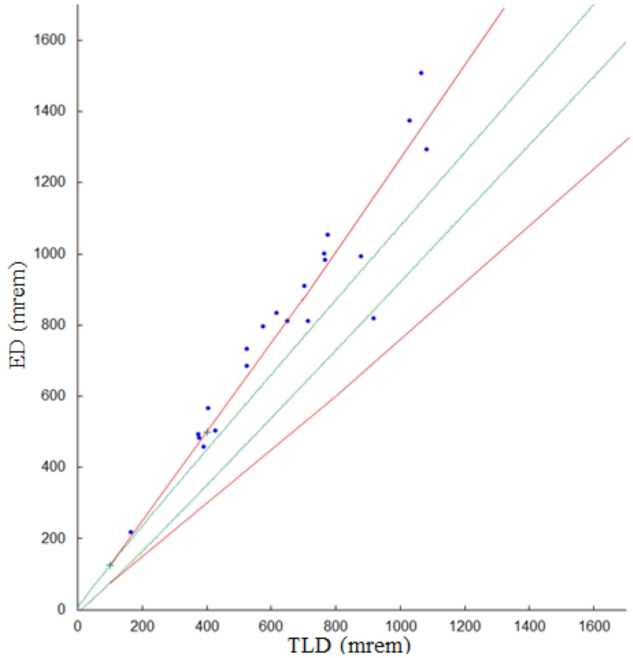

Figure 10 V4 EPD with original 15% positive bias. Red boundary: INPO Guidance: +/- 25% if TLD or EPD >100 mrem. Green boundary: 99% confidence limit for TLD >10 mrem, 2.5s where s = Sqrt (TLD) for TLD < or = 10 mrem, EPD ≥18 mrem.

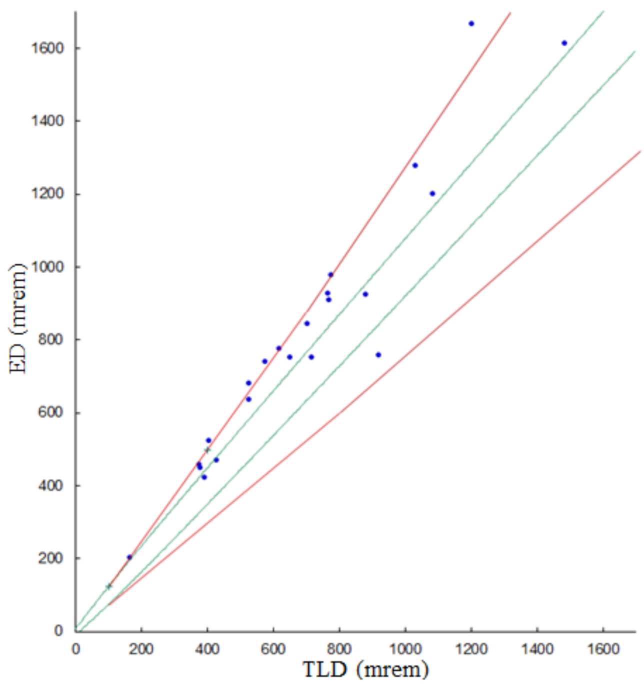

Figure 11 V4 EPD with original 7% positive bias. Red boundary: INPO Guidance: +/- 25% if TLD or EPD >100 mrem. Green boundary: 99% confidence limit for TLD >10 mrem, 2.5s where s = Sqrt (TLD) for TLD < or = 10 mrem, EPD ≥18 mrem.

A comparison between the differences in doses recorded from the EPDs and TLDs is shown in Table 5. The V2/V3 EPDs dose response correlated best with the TLDs rather than the V4 EPD values.

Table 5 Difference of dose recorded from EPDs to TLD dose. All EPD doses are positively biased above TLDs. Maximum difference allowed by INPO is +/- 25%.

	V2/V3		**V4**	
	15% Bias	**7% Bias**	**15% Bias**	**7% Bias**
Avg. Difference from TLD	1.11	1.02	1.27	1.18
Standard Deviation	0.08	0.06	0.12	0.11

iPAMs

Two out of the six sets of iPAM assemblies (assemblies 1 and 2) varied from the adjacent EPD only assemblies (assemblies 16 and 29, respectively) by such a degree to suggest the two packs were not positioned within the same radiation field (APPENDIX D: Data). A t-test performed on the remaining four data sets concluded the data were comparable since the P value, 0.73, was less than the t-critical value of 2.45. The EPDs within the iPAMs read consistently lower than the EPDs without iPAMs (Table 1Table 6).

Table 6 iPAM assembly and EPD only assembly recorded dose and t-test data for 4 iPAM/EPD observations.

		iPAM	EPD Only
TLD Average Dose (mrem)		561 ±138	604 ± 172
V2/V3 EPD Dose (mrem)		606 ± 177	653 ± 192
V4 EPD Dose (mrem)		697 ±173	793 ± 220
t-test degrees freedom	6		
P Value	0.73		
t-Critical	2.45		

DISCUSSION

Duke Energy Personal Dosimetry

Workers in the protected area are required to wear two personal dosimeters, a TLD and an EPD at CNS. The effective dose determined from the TLD is used to report the effective dose to a radiation worker and to comply with NRC regulations (1). A crucial function of the EPD is to estimate the dose recorded by the TLD.

Some amount of EPD over-response to worker exposure is desirable to ensure an overestimate of dose; overestimation of dose insures that the TLD doses read at the end of the quarter are below administrative and regulatory dose limits. Conversely, if the EPD over-response is too large it obscures the estimate of the actual dose a worker receives. A balance is necessary to make certain EPDs offer a reasonable estimate of TLD dose, while providing assurance that doses are below established limits. The Institute of Nuclear Power Operations (INPO) recommends that TLD and EPD recorded doses to be within the 99% confidence limit for TLDs recording doses greater than 0.1 mSv (10 mrem) and an EPD recording doses of greater than 0.18 mSv (18 mrem), and all readings greater than 1 mSv (100 mrem) the TLD and EPD must agree within +/- 25% (23). Duke Energy biases their EPDs by 15%. Once the TLDs are read and the dose recorded by the TLDs is compared to the EPD dose estimate, the collective site dose is expected to be less than estimated, since, the EPDs are known to overestimate effective dose. An overestimation of initial site doses ensures that individual worker doses are below established limits and encourages the ALARA group to continue to make efforts to reduce worker doses.

Although the CNS collective dose decreases upon TLD readout, the decrease in collective dose is greater than experienced at Duke Energy's other legacy nuclear power plants, Oconee Nuclear Station (Seneca, SC) and McGuire Nuclear Station (Huntersville, NC). The doses recorded by the V2/V3 and V4 EPDs differ to a much greater degree at CNS then at other Duke Energy nuclear power plants (Table 7).

Table 7 Average difference in dose recorded by V2/V3 and V4 EPDs at Catawba and McGuire Nuclear Stations. **(20)**

	Catawba		McGuire	
	V2/V3	V4	V2/V3	V4
Number of Transactions	3294	6686	15368	3337
Total Dose (mSv)	80.1	315.14	563.49	141.1
Dose/Trans (mSv/transaction)	0.0243	0.0471	0.0367	0.0423
Total Dose (mrem)	8010	31514	56349	14110
Dose/Trans (mrem/transaction)	2.43	4.71	3.67	4.23

The gamma spectrum from a pipe chase location in CNS is displayed in Figure 6. The Figure 6 gamma spectrum is representative of the typical radiation energies found throughout CNS. The spectral peak at 130 keV in Figure 12 represents the most probable energy of radiations that contribute most to a worker's dose. The average energy of the photons corresponds closely to the greatest difference in the photon response of the V2/V3 and V4 dosimeters. At 130 keV, the number of counts for the V4 is approximately 7400 counts and it is about 6300 counts for V3. The V4 EPD would be expected to read approximately 9% higher than the V2/V3 EPD since the count ratios are 0.54 and 0.45 respectively, therefore, at the relevant energies experienced at CNS, the V4 EPD over responds compared to the V2/V3 EPDs.

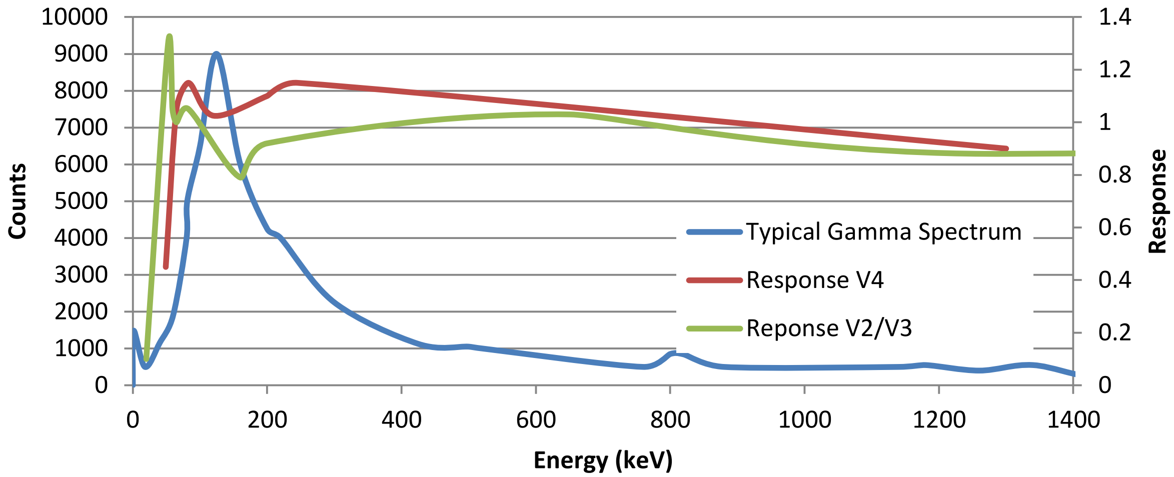

Figure 12 Gamma spectrum at pipe chase in Catawba Nuclear Station with V2/V3 and V4 EPD response overlay. **(20)**

EPDs are calibrated regularly to ensure accurate and linear dose responses (11). Duke energy calibrates EPDs using a cesium-137 source. Cesium-137 decays by beta emission resulting to barium-137m. Barium-137m emits a gamma ray via isomeric transition with an energy of 661.7 keV; the 661.7 keV gamma is used for the calibration of the DMC 2000S EPDs (24). The typical gamma energies observed at CNS are not centered around the peak the EPDs are calibrated at (Figure 12).

CONCLUSIONS

EPD Bias

On average, the doses recorded by V2/V3 and V4 EPDs were greater than the TLD doses. The EPD recorded dose differed from the TLD recorded dose by 9%. Although 86% of the V2/V3 EPD/TLD comparison data are within INPO guidance at 15% EPD bias, the EPD recorded dose would be more representative of the TLD dose using a 7% bias (14). Reducing the EPD bias from 15% to 7% improves the EPD/TLD correlation for both V2/V3 and V4 EPDs and is therefore recommended.

Several nuclear power plants have successfully adjusted the bias on their EPDs to 7%, such as Palo Verde Nuclear Generating Station (23). Changing the bias from 15% to 7% would reduce the excessive EPD over-response while still permitting enough over-response to allow for an overestimate of dose as desired by Duke Energy, yet still remain within INPO guidelines for TLD/EPD correlation. Based on the findings here, a review and reduction of the current EPD bias used at Duke Energy is suggested.

Additionally, calibrating the EPDs using multiple gamma energies, instead of only the single Ba-137m gamma, would provide a calibration that is more representative of the gamma energies radiation workers are exposed to at CNS.

iPAMs

V2/V3 and V4 EPDs inside of iPAMs doses were statistically comparable and consistently under responded compared to EPDs without iPAMs by 7% and 12 %, respectively. The Average EPD iPAM doses were 606 ± 177 mrem and 697 ± 173 mrem for the V2/V3 and V4 EPDs, respectively, and the EPD only doses were 697 ±173 mrem and 793 ± 200 mrem, respectively. The under response appears to be minimal and still provides over-response for the EPDs. Data from only four of the six sets of iPAM placements were utilized. Four data points are insufficient for definitive data analysis and our results should be viewed only as pilot data. More data is needed to quantify the under response caused by the addition of the iPAMs to the EPDs.

Future Investigations

Additional investigations are recommended for the comparison and characterization of V3/V4 EPDs and TLDs. Some improvements should first be made to the experimental design:

- Plan for doses to the EPD/TLD between 200 mrem and 500 mrem – larger doses are not necessary and do not correlate well to doses received by workers
- Isotropic exposures are necessary to ensure the EPDs and TLD are not in different radiation fields. Ensure that the dosimeters are at least one meter or more from the source
- EPDs with and without iPAMs should be placed on the same phantom to ensure the EPD and iPAM-EPD are in same radiation fields
- Evaluate element readings of the TLDs and assess if EPD and TLD are in the same radiation field
- Assess the potential for error in the TLD fade analysis
- Review the corrected element readings and algorithm used to determine the TLD dose
- Specific locations of the 'Packs" should be better documented in future studies so variations in dose can be better ascertained
- More information on the actual photon energy distribution within the plants is needed.

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APPENDIX A: Pack Components

	Location	TLD Serial #	V3 ED Serial #	V4 ED Serial #
IPAMS	1	512877	194808	862527
	2	507341	215459	881554
	3	514272	218985	861460
	4	513155	218977	861937
	5	521273	208529	863519
	6	508257	207528	872967
	7	530897	213222	862997
	8	511698	211987	860864
	9	509305	212509	864051
	10	500714	196172	863614
	11	504165	203845	872373
	12	506812	206494	872175
	13	509698	207329	862270
	15	525018	201000	873301
	16	510730	212836	872087
	17	529336	210610	861291
	18	523543	212894	861346
	19	508553	211090	864423
	21	513322	212173	871269
	22	506319	198777	860960
	23	521563	212522	861285
	28	507303	208509	863203
	29	505434	210090	872032
	30	500004	203321	863656
	31	523485	212451	861658
	32	511263	213951	861372
	33	501733	218722	872028
	34	512825	213002	864082
	36	500850	211764	873602
	37	504293	210040	871555
	38	525483	213170	859993
	39	509758	213785	872098
	40	504343	202777	864028

APPENDIX B: Pack Placement

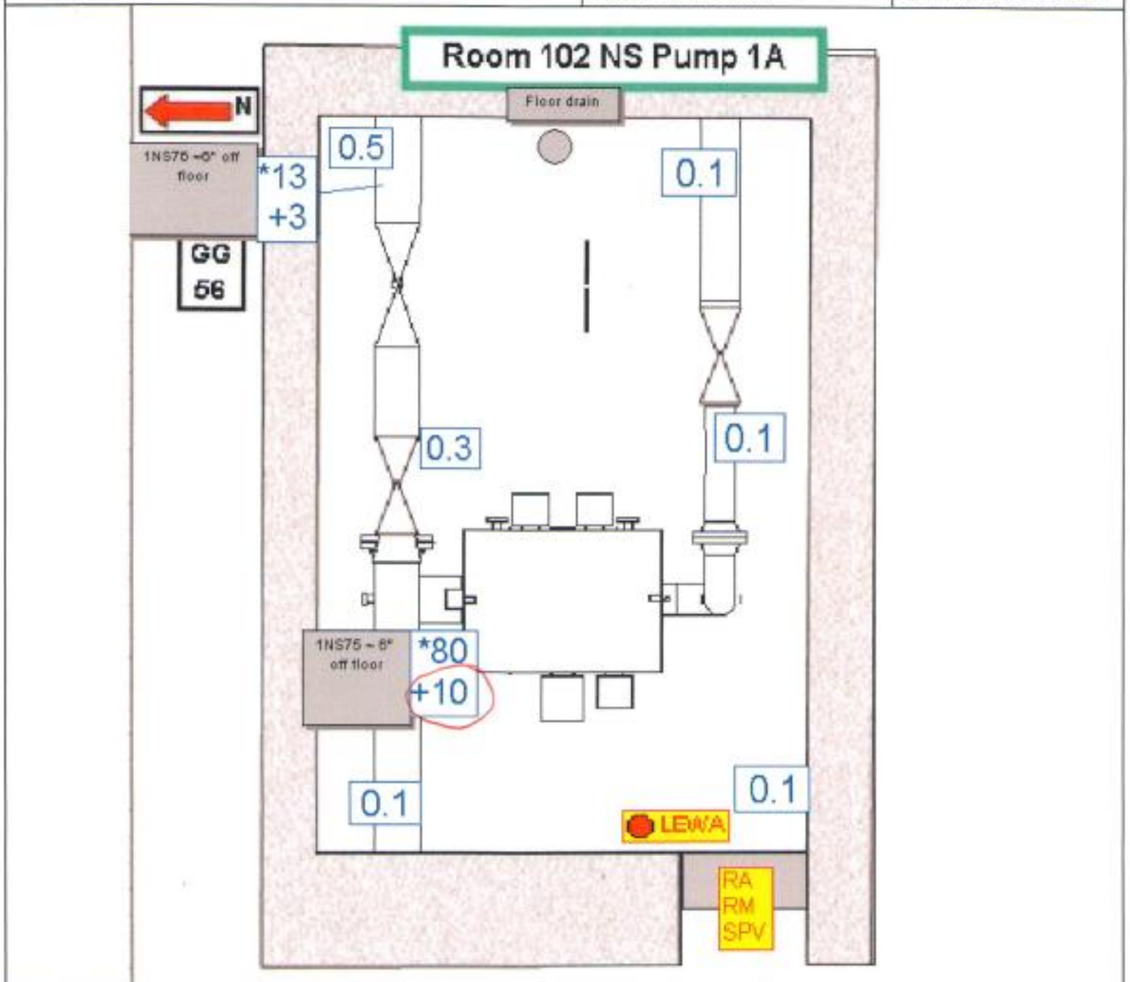
Pack	Elevation (Aux Bldg)	Room	Component	VSDS Dose Rate (mrem/hr)	Approximate Dose Rate (mrem/hr)
1	560'	308	N/A	12 G/A	25
2	577'	419	N/A	13 G/A	25
3	543'	227	N/A	10 G/A	2.5
4	543'	217	N/A	9 G/A	4
5	560'	318	N/A	11 G/A	4.5
6	577'	427	N/A	14 G/A	60
7	543'	238	NM Hx's	12-20 G/A	10
8	577'	403	Hi-Level Waste	N/A	10
9	543'	217 E	Vertical ND Line	7-10 G/A	10
10	560'	309	VCT	7-10 G/A door	20
11	560'	318	NV Line	28 @ 30 cm	10
12	522'	107	1/2 NS-076	11 @ 30 cm	18
13	543'	221	Mixing & Settling Tank	N/A	20
15	522'	104	ND Piping	14 G/A	10
15	543'	215 C	Waste Drain Tank	N/A	8
16	560'	308	N/A	6 G/A	4.5
17	522'	110	ND Piping	13 G/A	5
18	522'	105	ND Piping	12 G/A	12
19	560'	318	N/A	5 G/A	4.5
21	577'	419	NV Line	62 @ 30 cm	8
22	560'	308	NV Line	27 @ 30 cm	25
23	543'	248	NM Hx's	12-20 G/A	10
28	543'	227	Vertical ND Line	7-10 G/A	10
29	577'	419	N/A	7 G/A	25
30	543'	217 W	N/A	3 G/A	4
32	577'	403 B	Filters	N/A	20
33	543'	227	N/A	4 G/A	3.5
34	577'	427	NV Line	63 @ 30 cm	5
36	577'	405	60 Shields	N/A	10
37	577'	427	N/A	8 G/A	60
38	560'	319	VCT	7-10 G/A door	15
39	522'	102	1/2 NS-075	10 @ 30 cm	10
40	522'	109	ND Piping	15 G/A	5

APPENDIX C: Room Survey Maps

Room 102

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\522 Elevation\Room 102	Survey #: M-20130420-7	Date/Time: 4/20/2013 03:01



Postings	β/γ Contamination Results

Lead Surveyor: Lamar Worsham

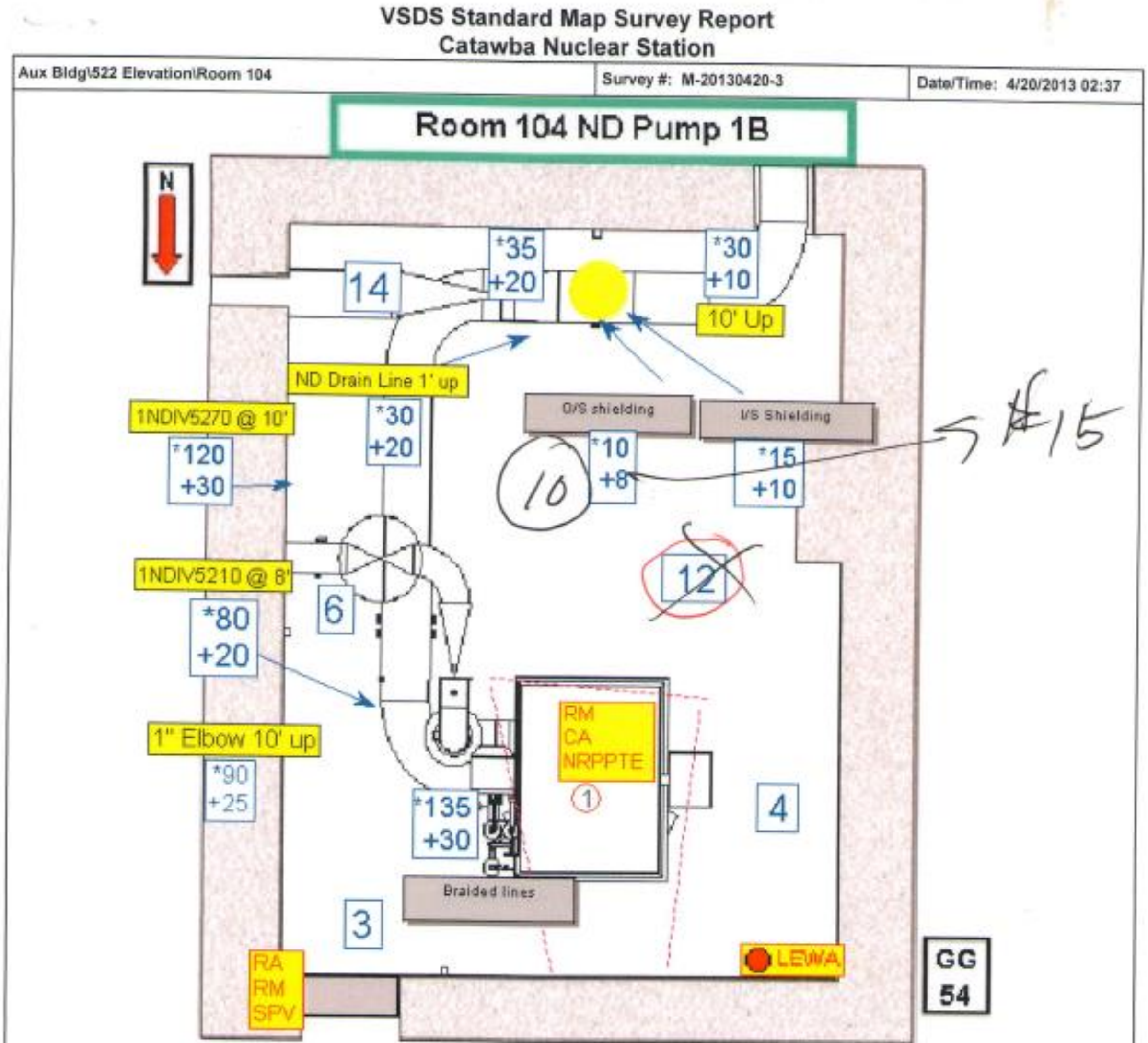
Instrument Serial #'s:

Date	Survey #	Surveyed By

Survey #: M-20130420-7 - Printed On: 6/24/2013 16:13

Image File: Aux Bldg\522 Elevation\Room 102
Page 1 of 1

Room 104



Postings	β/γ Contamination Results	
	1) 3227 DPM/100 cm2	
Lead Surveyor: Lamar Worsham		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Survey #: M-20130420-3 - Printed On: 6/24/2013 15:54

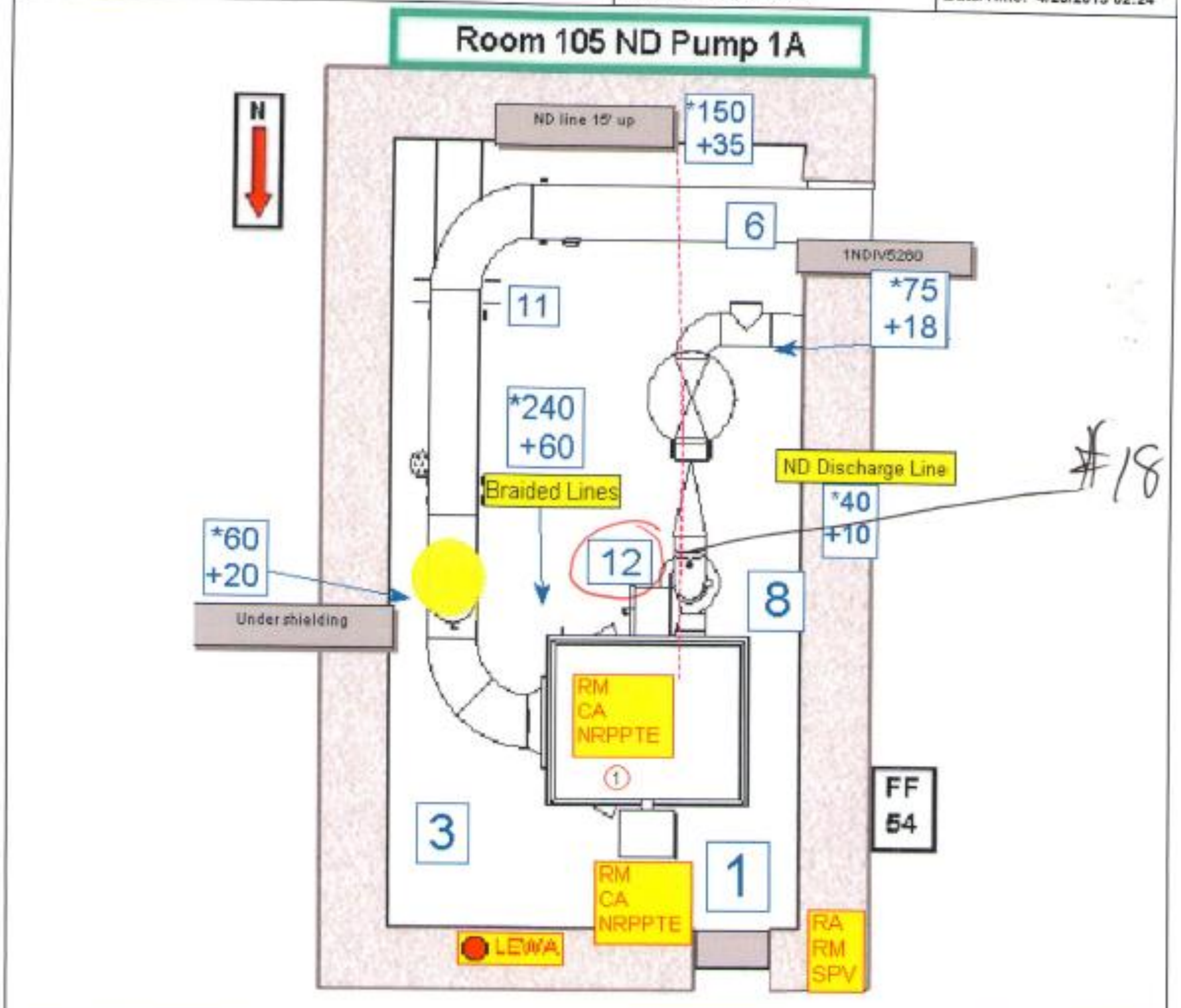
Image File: Aux Bldg\522 Elevation\Room 104

Page 1 of 1

Room 105

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\522 Elevation\Room 105	Survey #: M-20130420-2	Date/Time: 4/20/2013 02:24



Postings	β/γ Contamination Results
	1) 1060 DPM/100 cm2

Lead Surveyor: Lamar Worsham

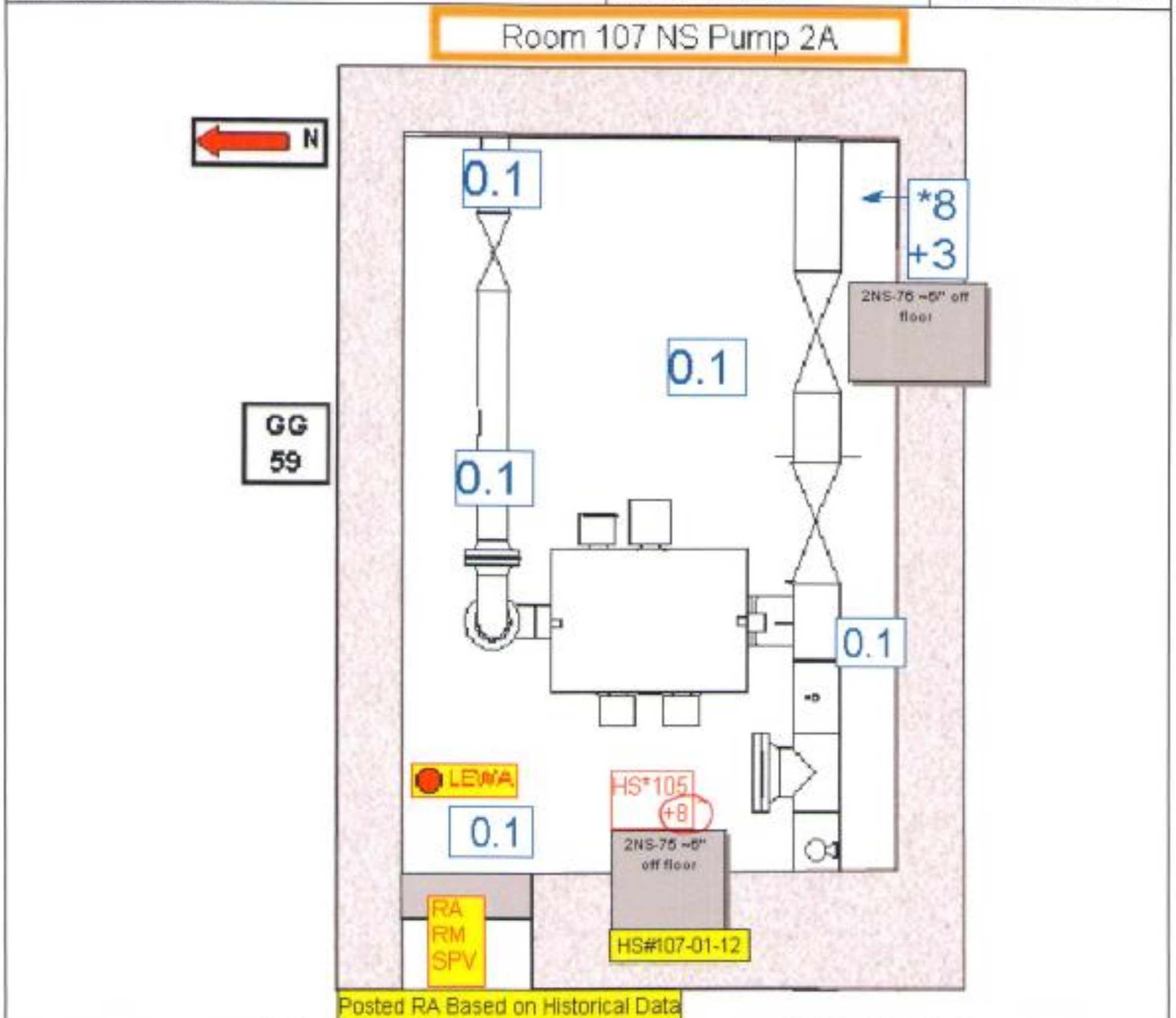
Instrument Serial #'s:

Date	Survey #	Surveyed By

Room 107

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\522 Elevation\Room 107	Survey #: M-20130428-6	Date/Time: 4/28/2013 05:08



Postings	β/γ Contamination Results

Lead Surveyor: Lamar Worsham

Instrument Serial #'s:

Date	Survey #	Surveyed By

Survey #: M-20130428-6 - Printed On: 6/24/2013 16:06

Image File: Aux Bldg\522 Elevation\Room 107

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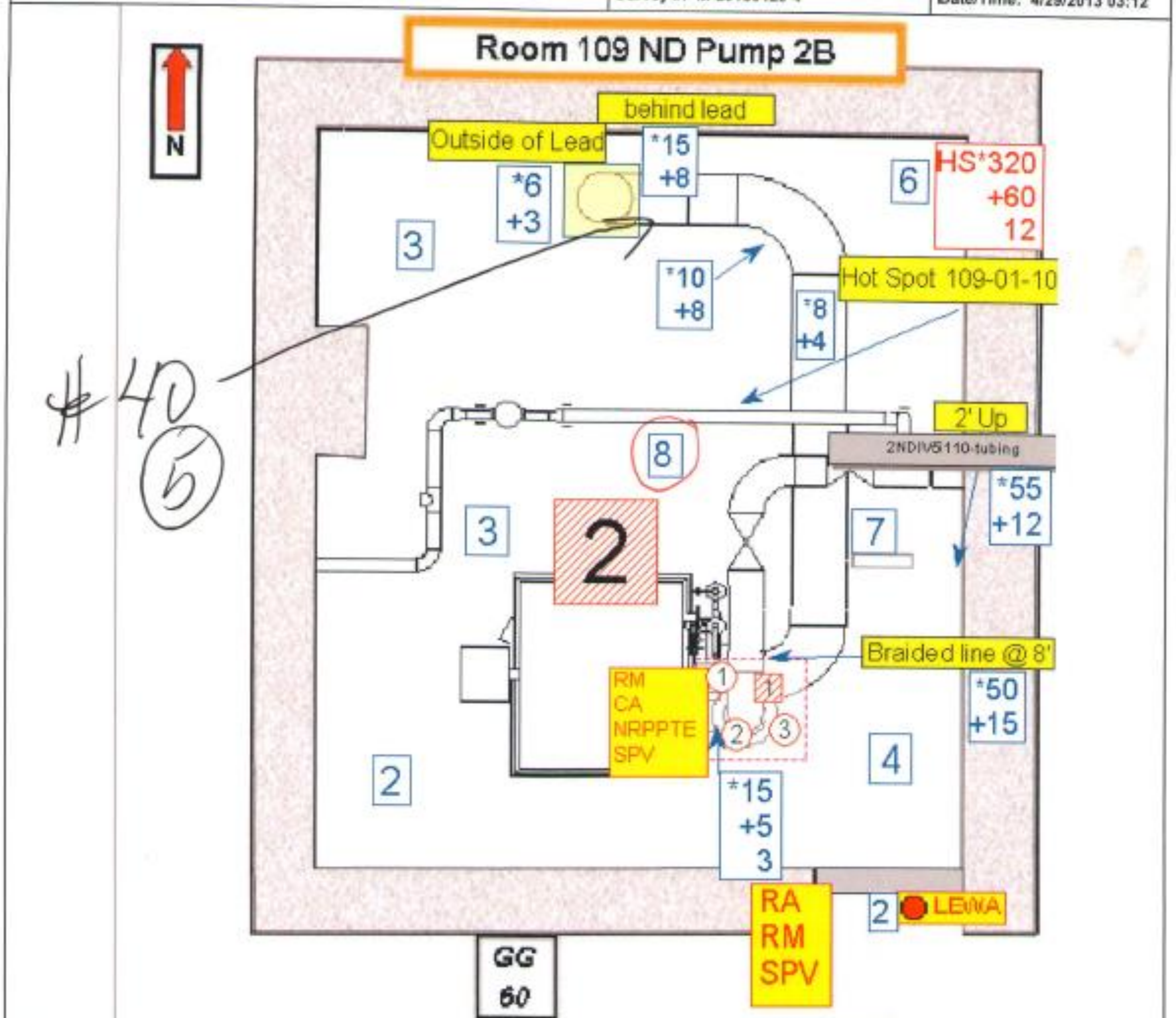
Room 109

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\522 Elevation\Room 109	Survey #: M-20130429-4	Date/Time: 4/29/2013 03:12



Postings	β/γ Contamination Results	
	1) 2) 3)	<1000 DPM/100 cm2 <1000 DPM/100 cm2 <1000 DPM/100 cm2
Lead Surveyor: John A. Brown		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

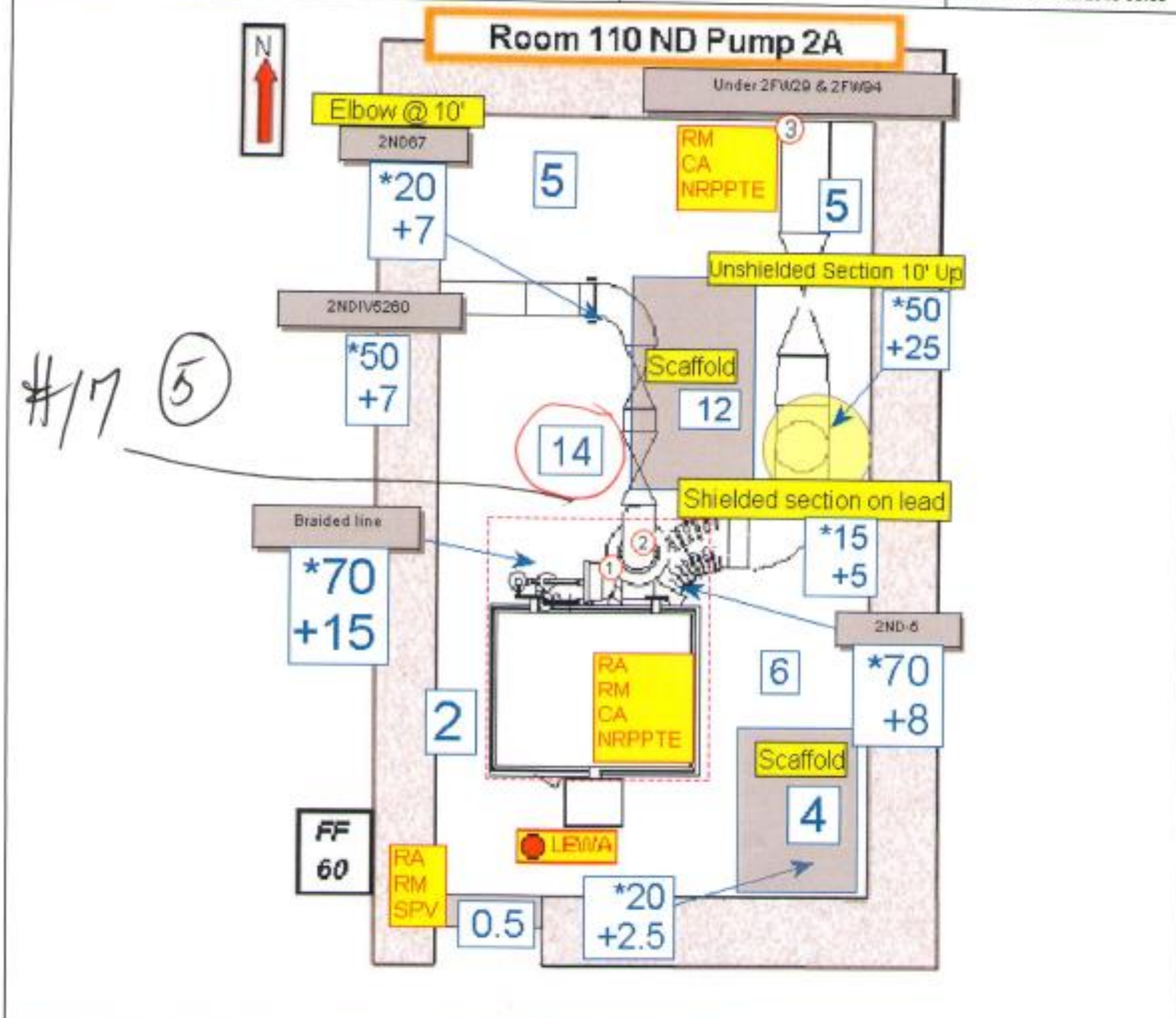
Survey #: M-20130429-4 - Printed On: 6/24/2013 15:59

Image File: Aux Bldg\522 Elevation\Room 109
Page 1 of 1

Room 110

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\522 Elevation\Room 110	Survey #: M-20130429-3	Date/Time: 4/29/2013 03:00



Postings	β/γ Contamination Results
	1) 1869 DPM/100 cm2 2) 4396 DPM/100 cm2 3) <1000 DPM/100 cm2

Lead Surveyor: John A. Brown

Instrument Serial #'s:

Date	Survey #	Surveyed By

Survey #: M-20130429-3 - Printed On: 6/24/2013 15:57

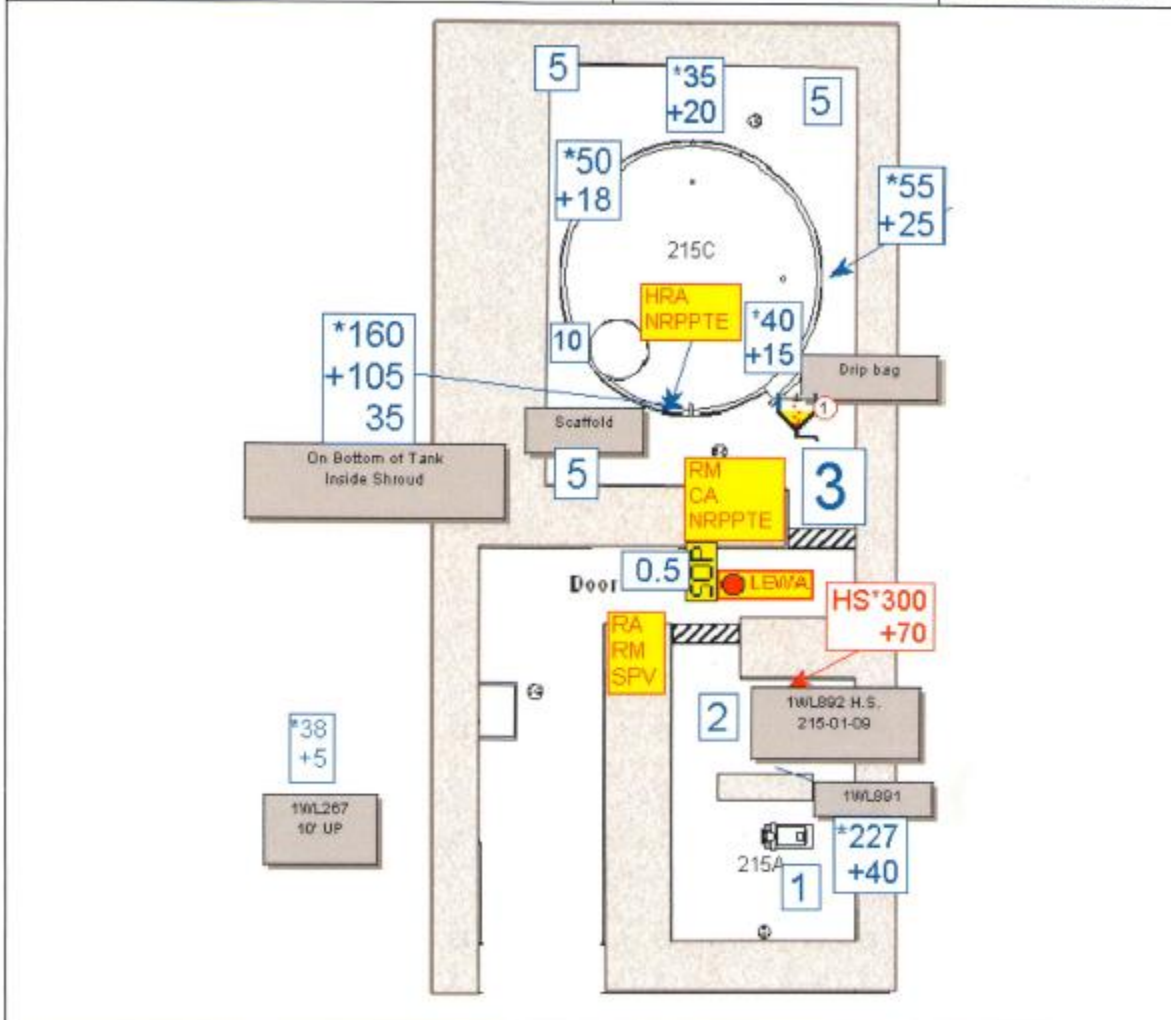
Image File: Aux Bldg\522 Elevation\Room 110

Page 1 of 1

Room 215 A & C

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\215a&c	Survey #: M-20130429-2	Date/Time: 4/29/2013 01:30



Postings	β/γ Contamination Results
	1) 11628 DPM/100 cm2
Lead Surveyor: Donald G. McHose	
Instrument Serial #'s:	

Date	Survey #	Surveyed By

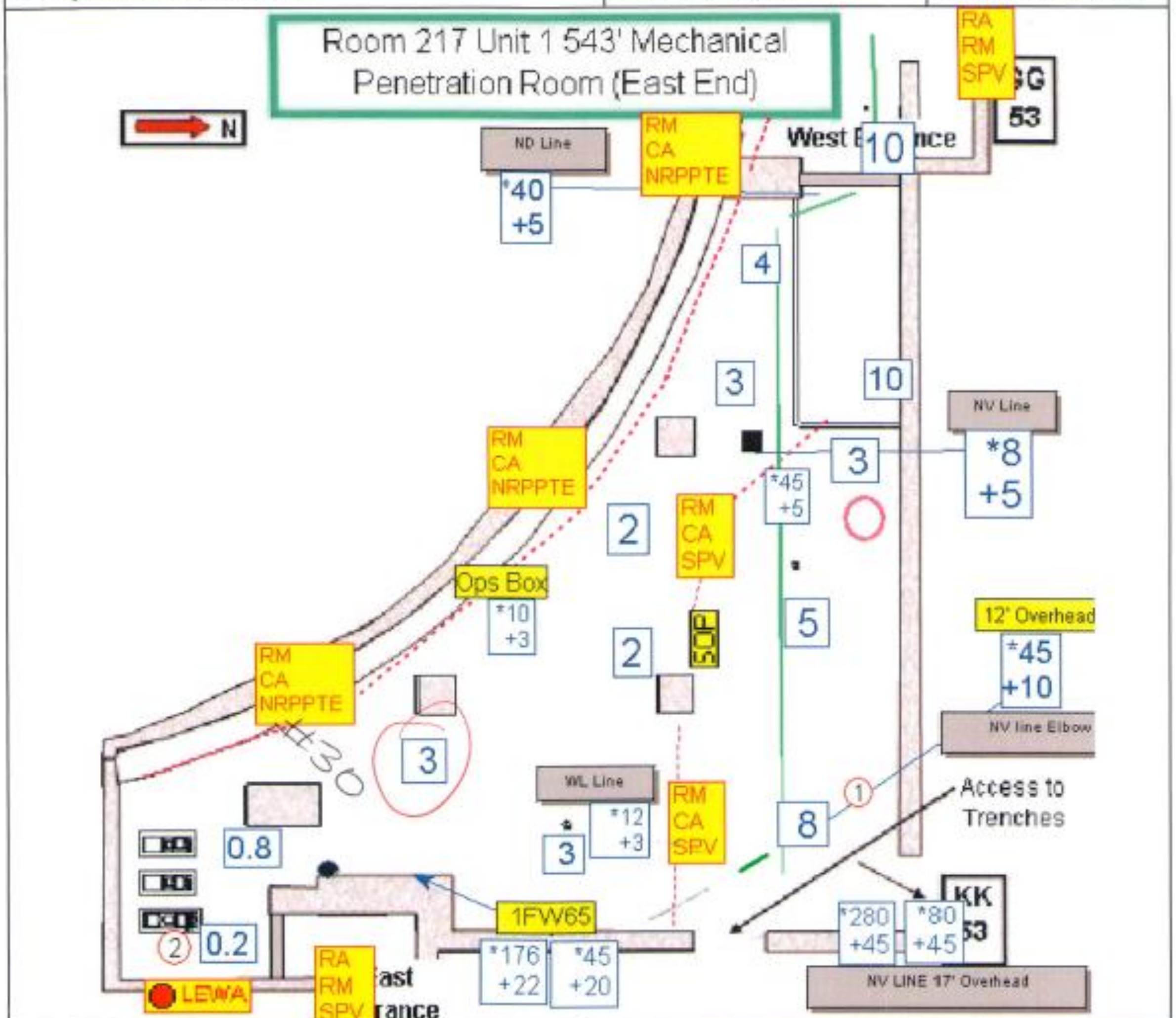
Survey #: M-20130429-2 - Printed On: 6/26/2013 09:48

Image File: Aux Bldg\543 Elevation\215a&c
Page 1 of 1

Room 217 East End

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 217East	Survey #: M-20130526-3	Date/Time: 5/26/2013 04:09



Postings	β/γ Contamination Results
	1) 5576 DPM/100 cm2 2) 1027 DPM/100 cm2

Lead Surveyor: Lamar Worsham

Instrument Serial #'s:

Date	Survey #	Surveyed By

Image File: Aux Bldg\543 Elevation\Room 217East

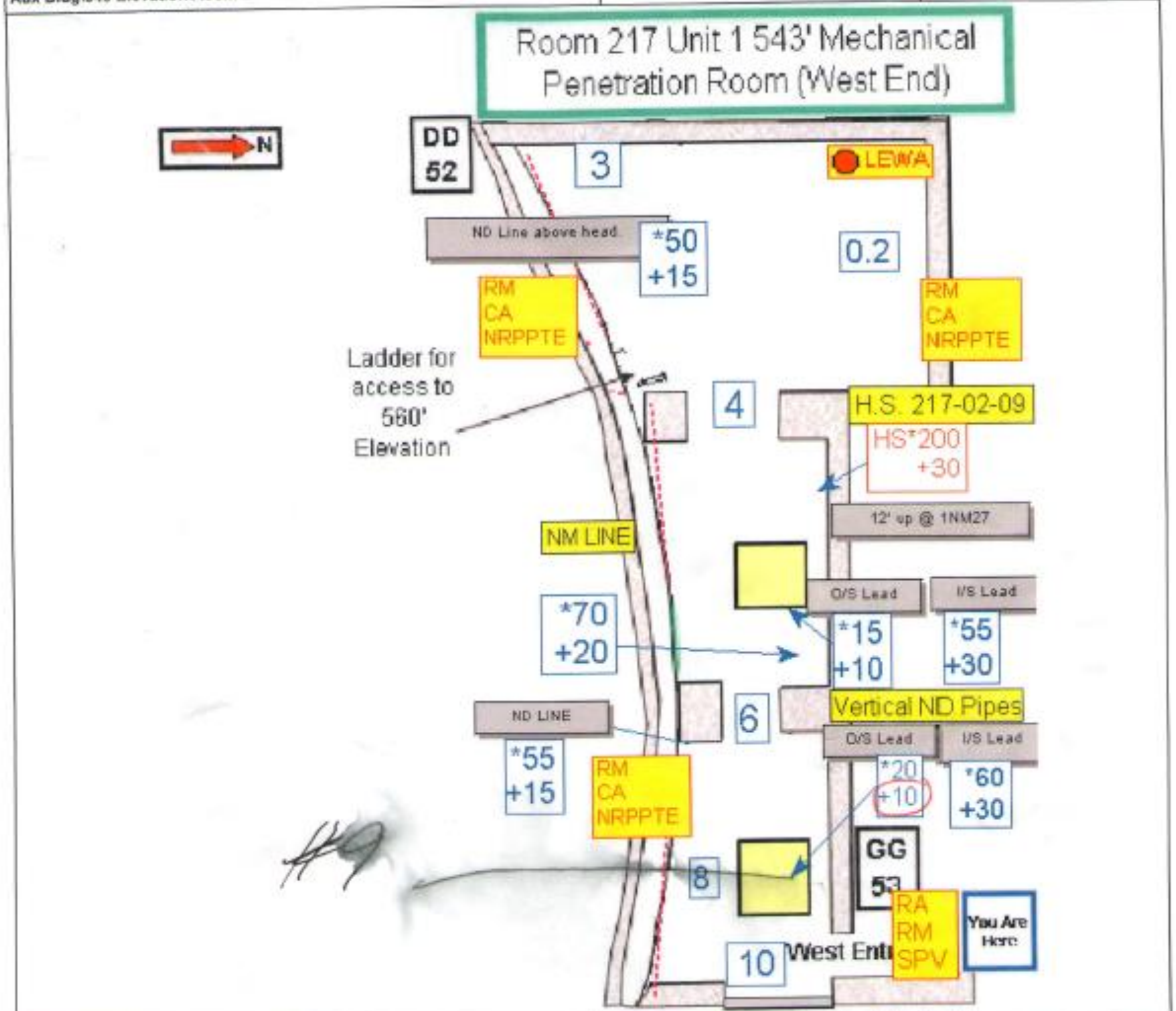
Survey #: M-20130526-3 - Printed On: 6/25/2013 17:09

Page 1 of 1

Room 217 West End

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 217West	Survey #: M-20130526-2	Date/Time: 5/26/2013 04:02



Postings	β/γ Contamination Results

Lead Surveyor: Lamar Worsham

Instrument Serial #'s:

Date	Survey #	Surveyed By

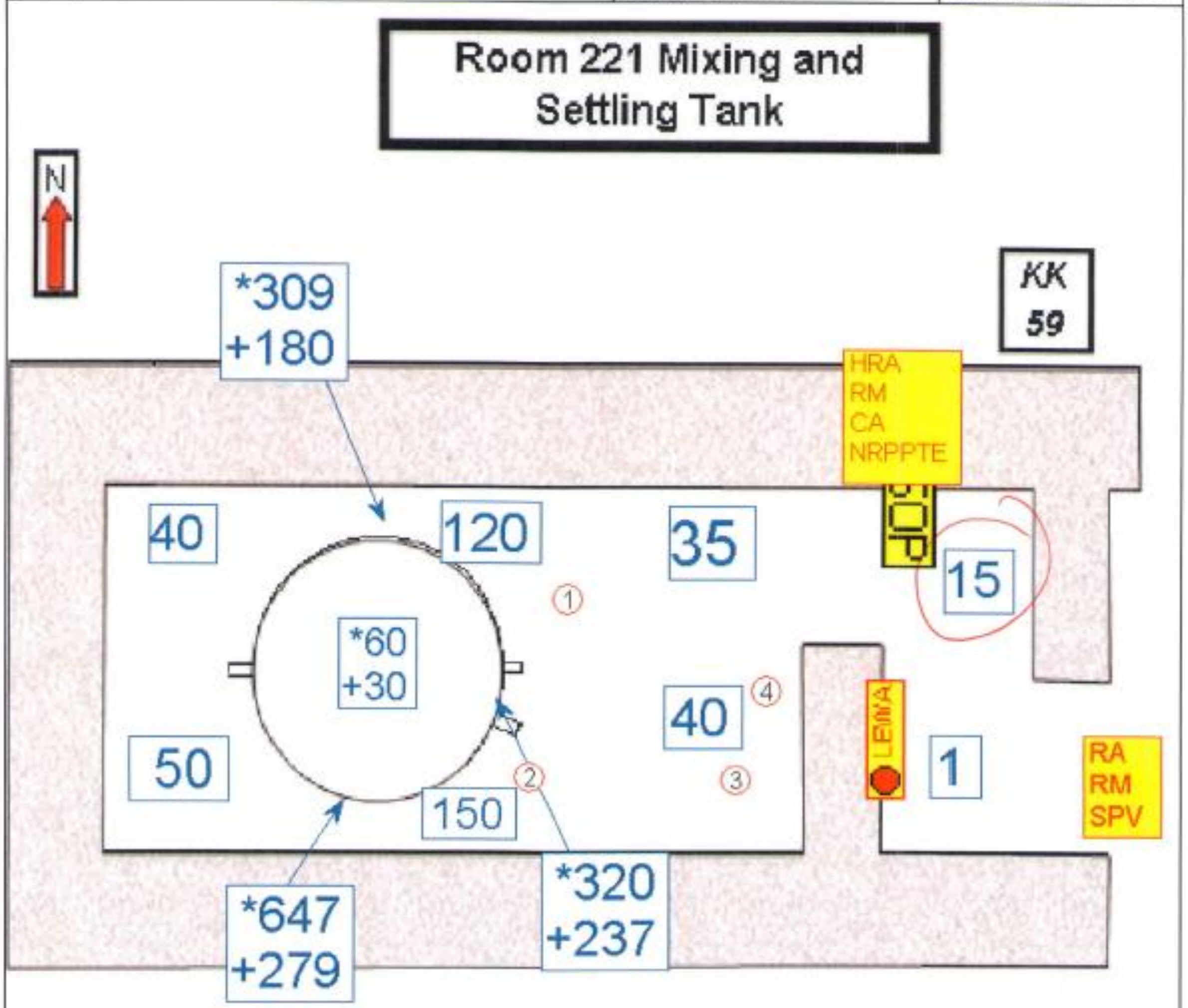
Survey #: M-20130526-2 - Printed On: 6/24/2013 16:46

Image File: Aux Bldg\543 Elevation\Room 217West
Page 1 of 1

Room 221

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 221	Survey #: M-20130504-3	Date/Time: 4/29/2013 02:00



Postings	β/γ Contamination Results	
	1)	1653 DPM/100 cm2
	2)	2581 DPM/100 cm2
	3)	4099 DPM/100 cm2
	4)	4351 DPM/100 cm2
Lead Surveyor: Donald G. McHose		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

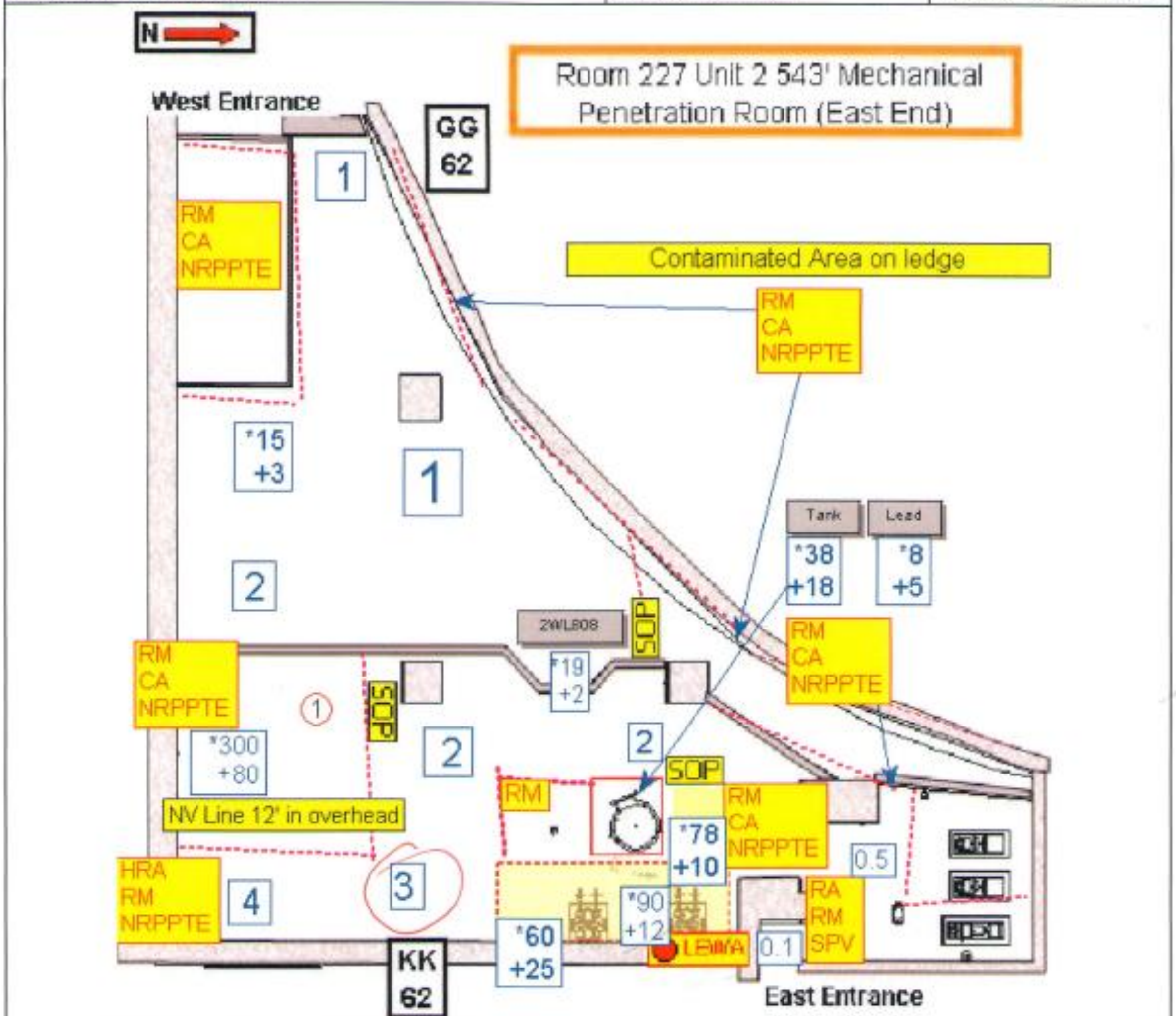
Survey #: M-20130504-3 - Printed On: 6/24/2013 16:56

Image File: Aux Bldg\543 Elevation\Room 221
Page 1 of 1

Room 227 East End

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 227East	Survey #: M-20130531-4	Date/Time: 5/31/2013 19:36



Postings	β/γ Contamination Results	
	1) 2,500 DPM/100 cm2	
Lead Surveyor: John A. Brown		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Image File: Aux Bldg\543 Elevation\Room 227East

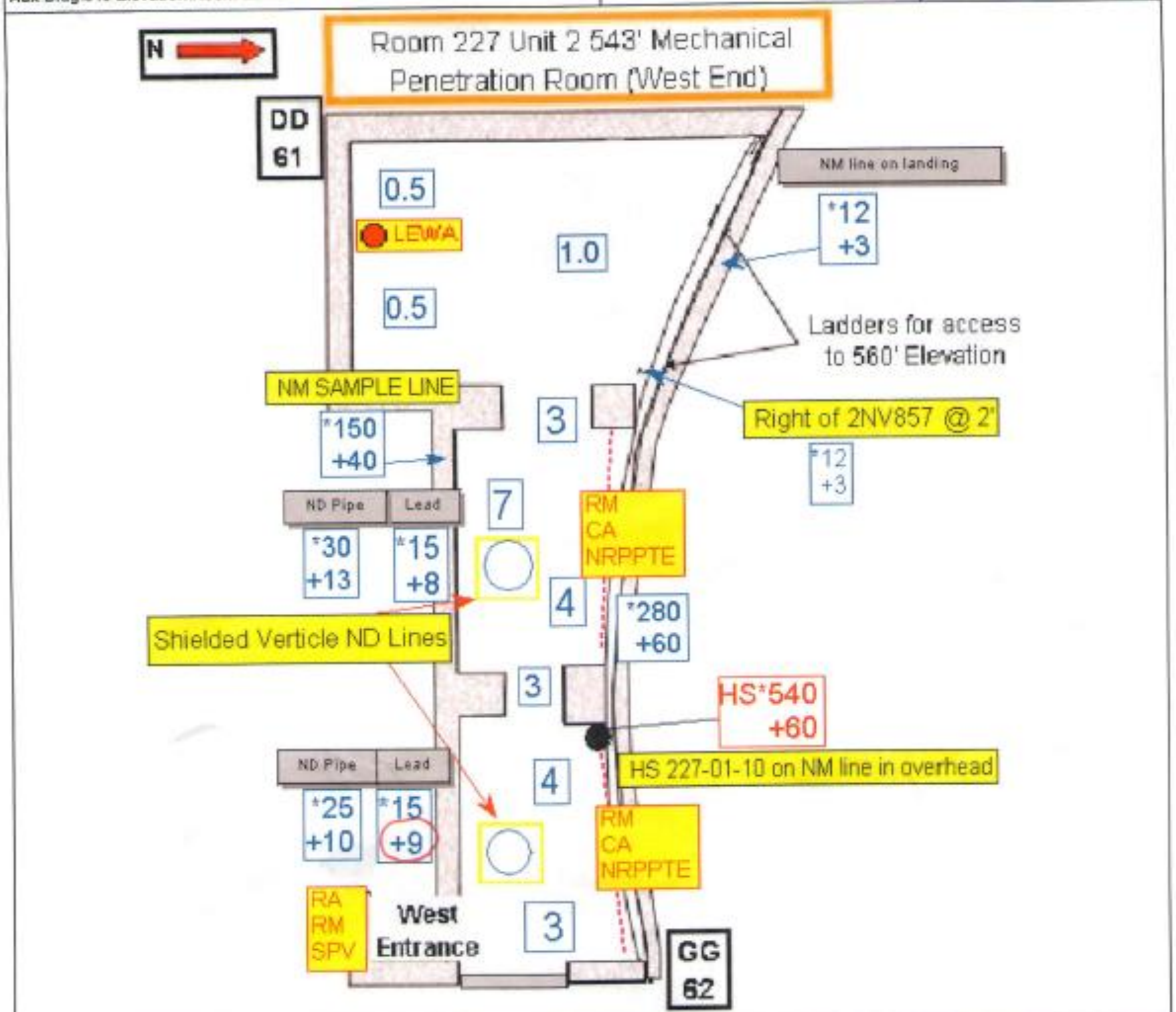
Survey #: M-20130531-4 - Printed On: 6/25/2013 17:12

Page 1 of 1

Room 227 West End

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 227West	Survey #: M-20130531-9	Date/Time: 5/31/2013 23:42



Postings	β/γ Contamination Results	
Lead Surveyor: John A. Brown		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

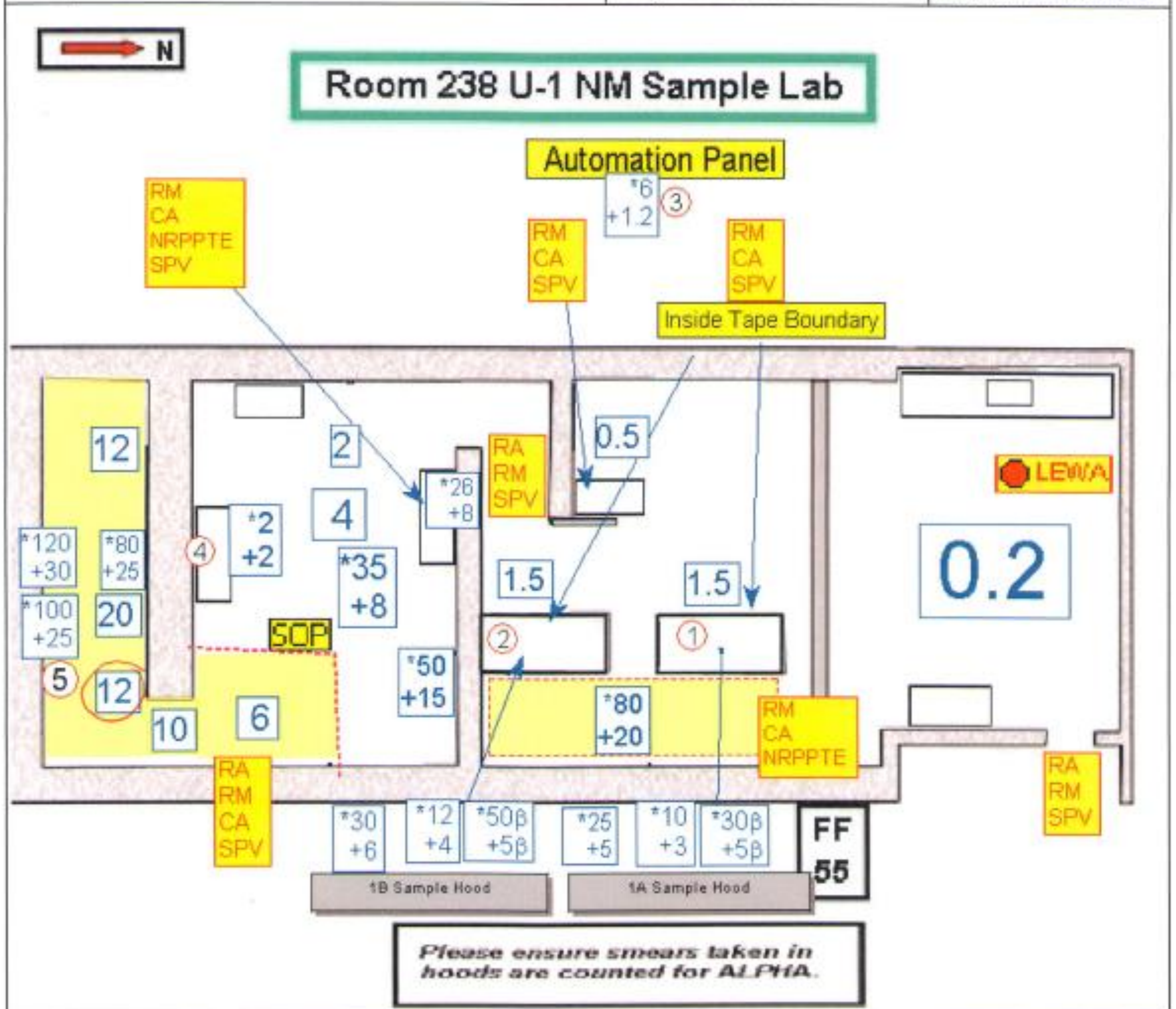
Image File: Aux Bldg\543 Elevation\Room 227West
Page 1 of 1

Survey #: M-20130531-9 - Printed On: 6/24/2013 16:45

Room 238

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 238	Survey #: M-20130413-1	Date/Time: 4/13/2013 09:15



Postings	β/γ Contamination Results
	1) 68,620 DPM/100 cm2
	2) 156,860 DPM/100 cm2
	3) 1,200 DPM/100 cm2
	4) 6,379 DPM/100 cm2
Lead Surveyor: Ronald D. Pearson	5) 1,200 DPM/100 cm2
Instrument Serial #'s:	

Date	Survey #	Surveyed By

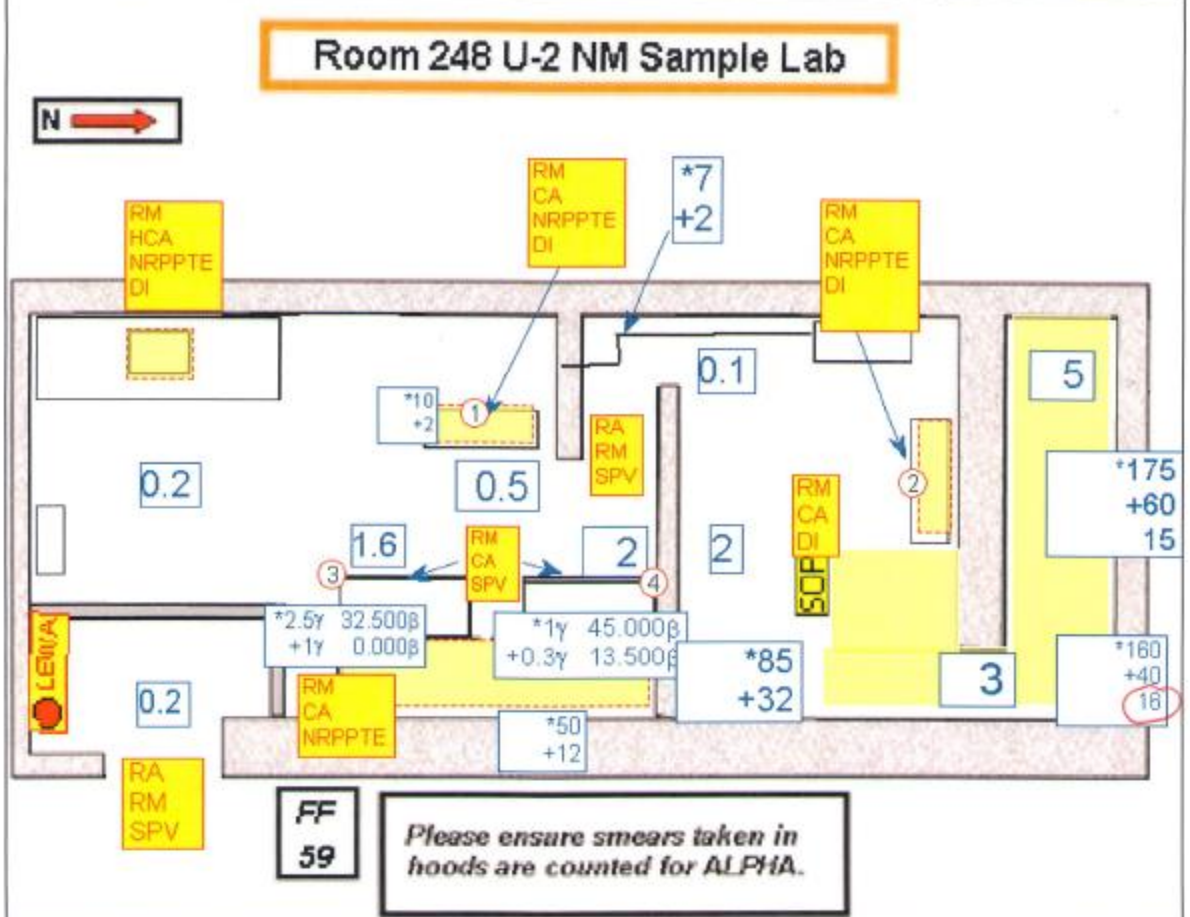
Survey #: M-20130413-1 - Printed On: 6/24/2013 16:33

Image File: Aux Bldg\543 Elevation\Room 238
Page 1 of 1

Room 248

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\543 Elevation\Room 248	Survey #: M-20130406-2	Date/Time: 4/6/2013 09:06



Postings	β/γ Contamination Results
	1) 1200 DPM/100 cm2
	2) 1000 DPM/100 cm2
	3) 20000 DPM/100 cm2
	4) 85000 DPM/100 cm2

Lead Surveyor: Jasper L. Armstrong

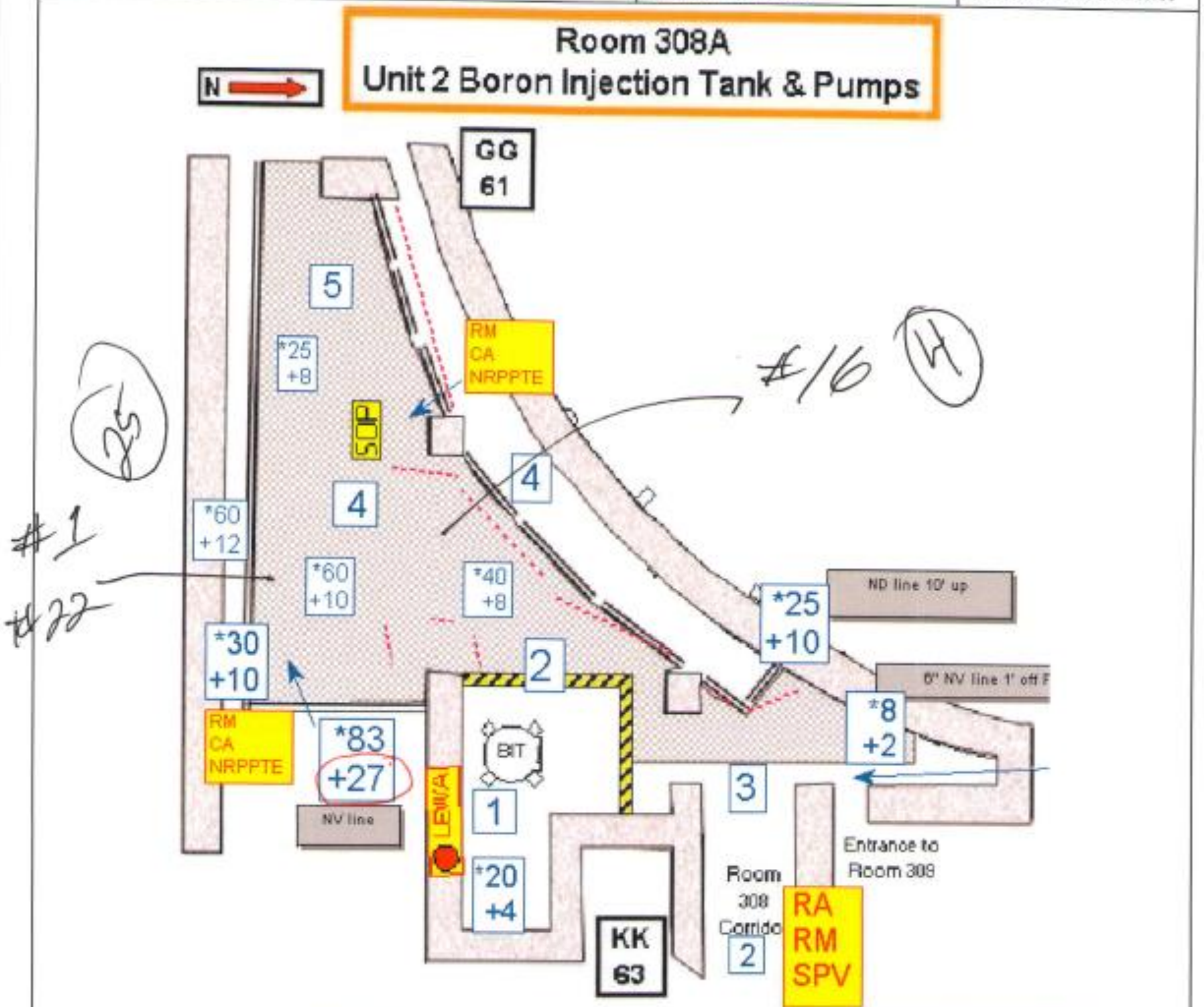
Instrument Serial #'s: 00139

Date	Survey #	Surveyed By

Room 308A

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\560 Elevation\Room 308A	Survey #: M-021313-9	Date/Time: 2/13/2013 03:00



Postings	β/γ Contamination Results
Lead Surveyor: Ronald D. Pearson	
Instrument Serial #'s:	

Date	Survey #	Surveyed By

Survey #: M-021313-9 - Printed On: 6/24/2013 15:40

Image File: Aux Bldg\560 Elevation\Room 308A
Page 1 of 1

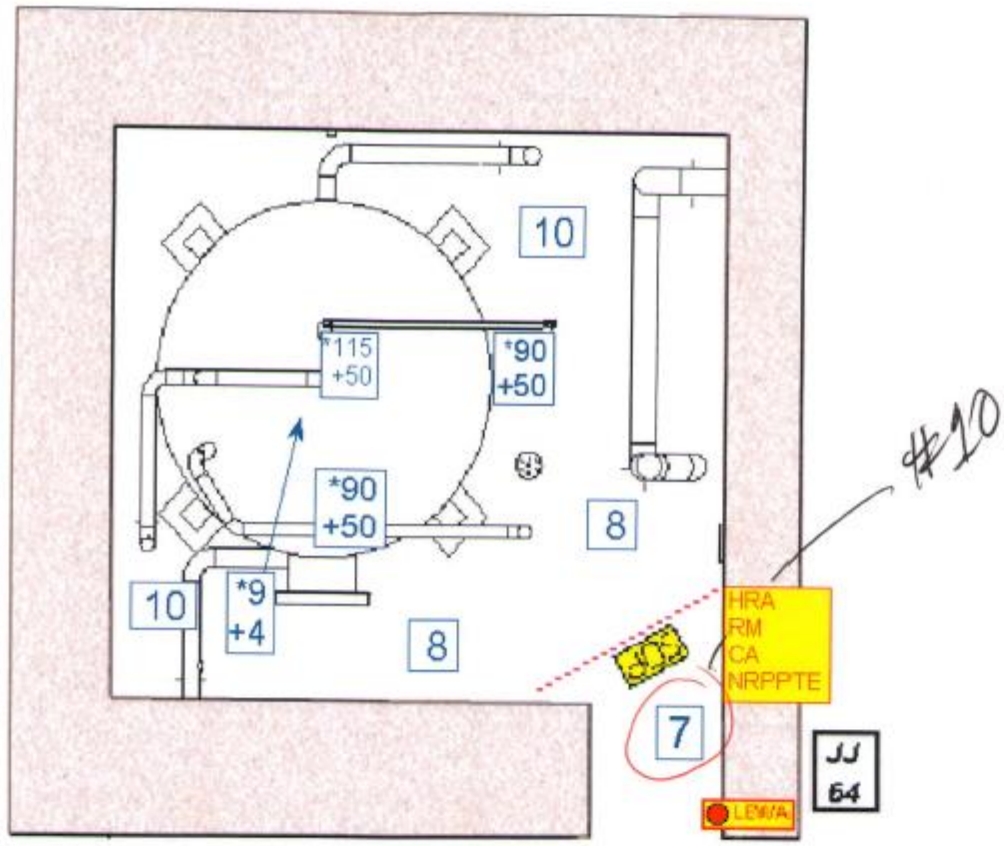
Room 309

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\560 Elevation\Room 309	Survey #: M-20130531-5	Date/Time: 5/31/2013 19:38

N

Room 309 U-2 Volume Control Tank



Postings	β/γ Contamination Results
Lead Surveyor: John A. Brown	
Instrument Serial #'s:	

Date	Survey #	Surveyed By

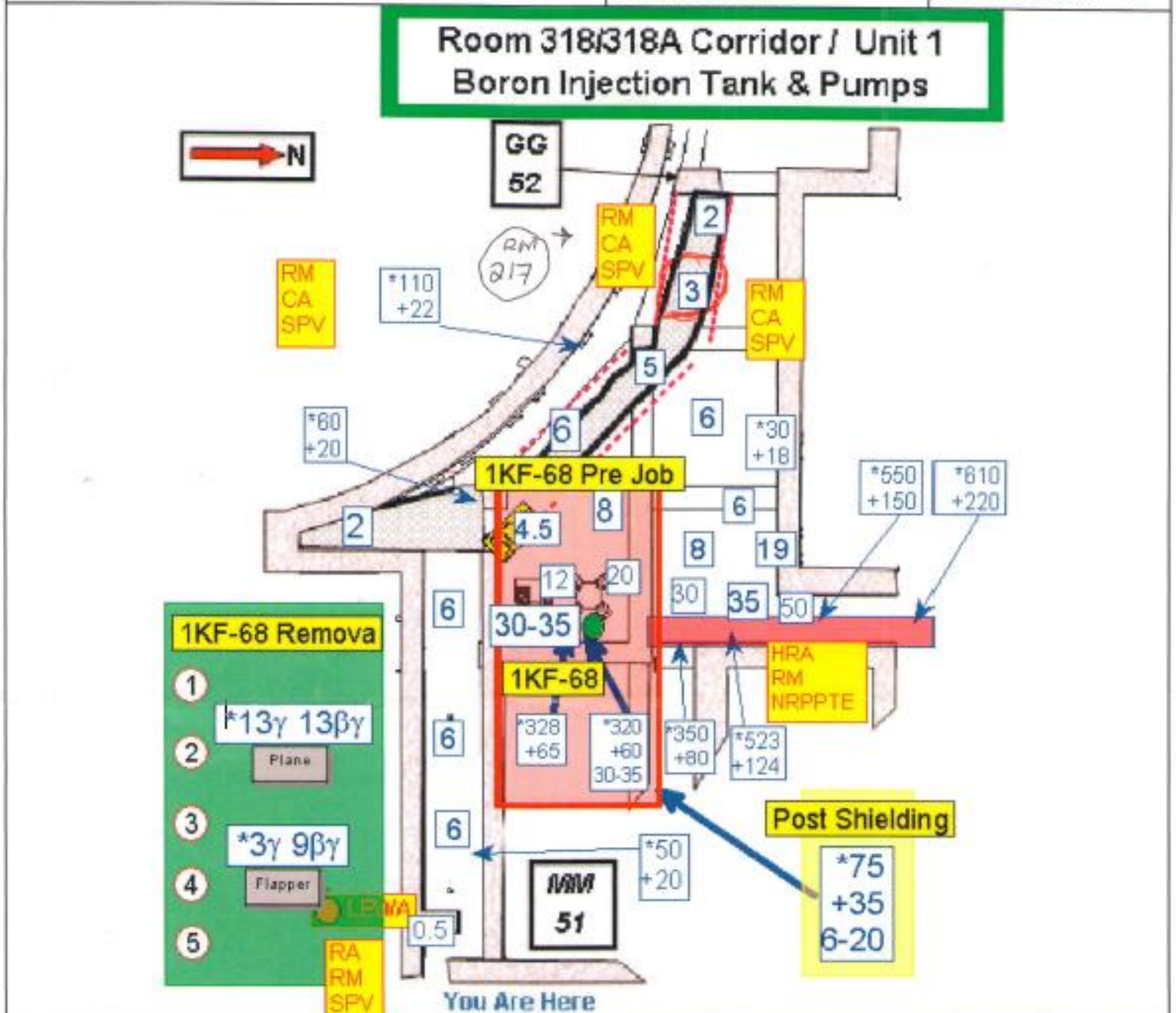
Survey #: M-20130531-5 - Printed On: 6/25/2013 16:36

Image File: Aux Bldg\560 Elevation\Room 309
Page 1 of 1

Room 318/318A

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\560 Elevation\Room 318&318A	Survey #: M-20130619-3	Date/Time: 6/19/2013 11:47



Postings	β/γ Contamination Results
	1) 78,000 DPM/100 cm2
	2) 3,000 DPM/100 cm2
	3) 33,000 DPM/100 cm2
	4) 7,000 DPM/100 cm2
Lead Surveyor: Scott Shytle	5) 2,000 DPM/100 cm2
Instrument Serial #'s:	

Date	Survey #	Surveyed By

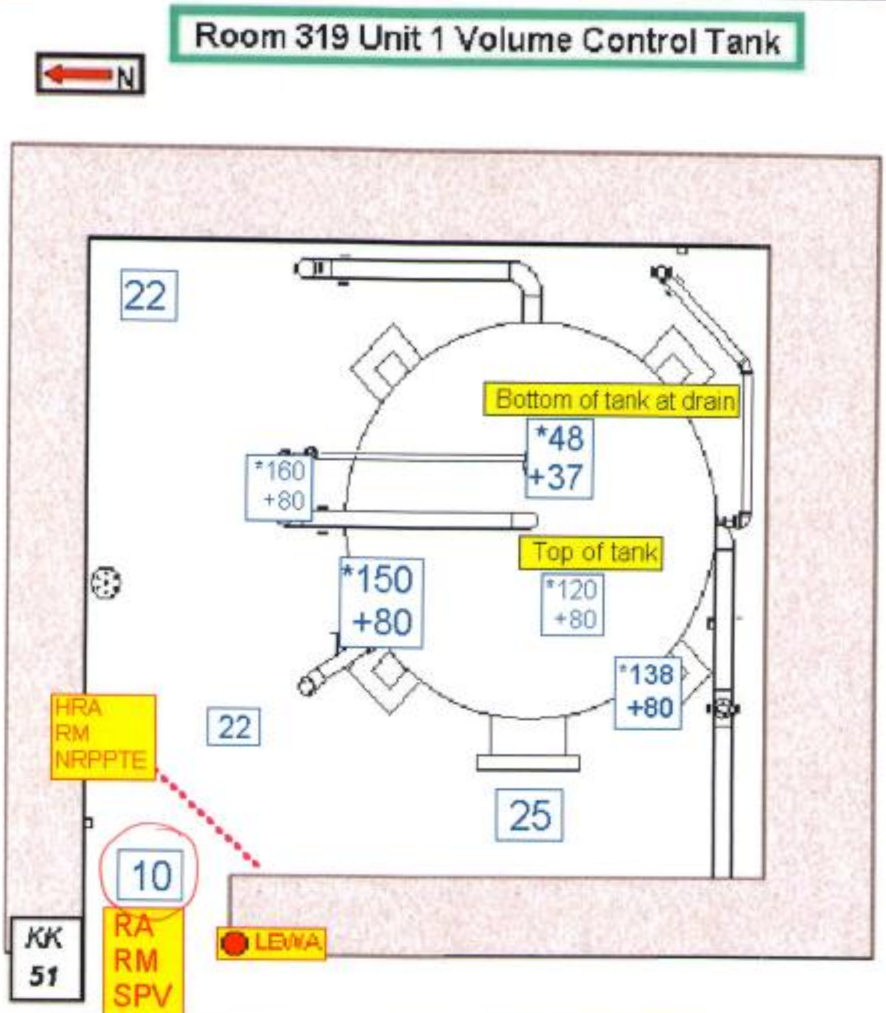
Survey #: M-20130619-3 - Printed On: 6/25/2013 16:49

Image File: Aux Bldg\560 Elevation\Room 318&318A
Page 1 of 1

Room 319

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\560 Elevation\Room 319	Survey #: M-20130531-6	Date/Time: 5/31/2013 19:39



Postings	β/γ Contamination Results	
Lead Surveyor: John A. Brown		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Survey #: M-20130531-6 - Printed On: 6/25/2013 16:34

Image File: Aux Bldg\560 Elevation\Room 319
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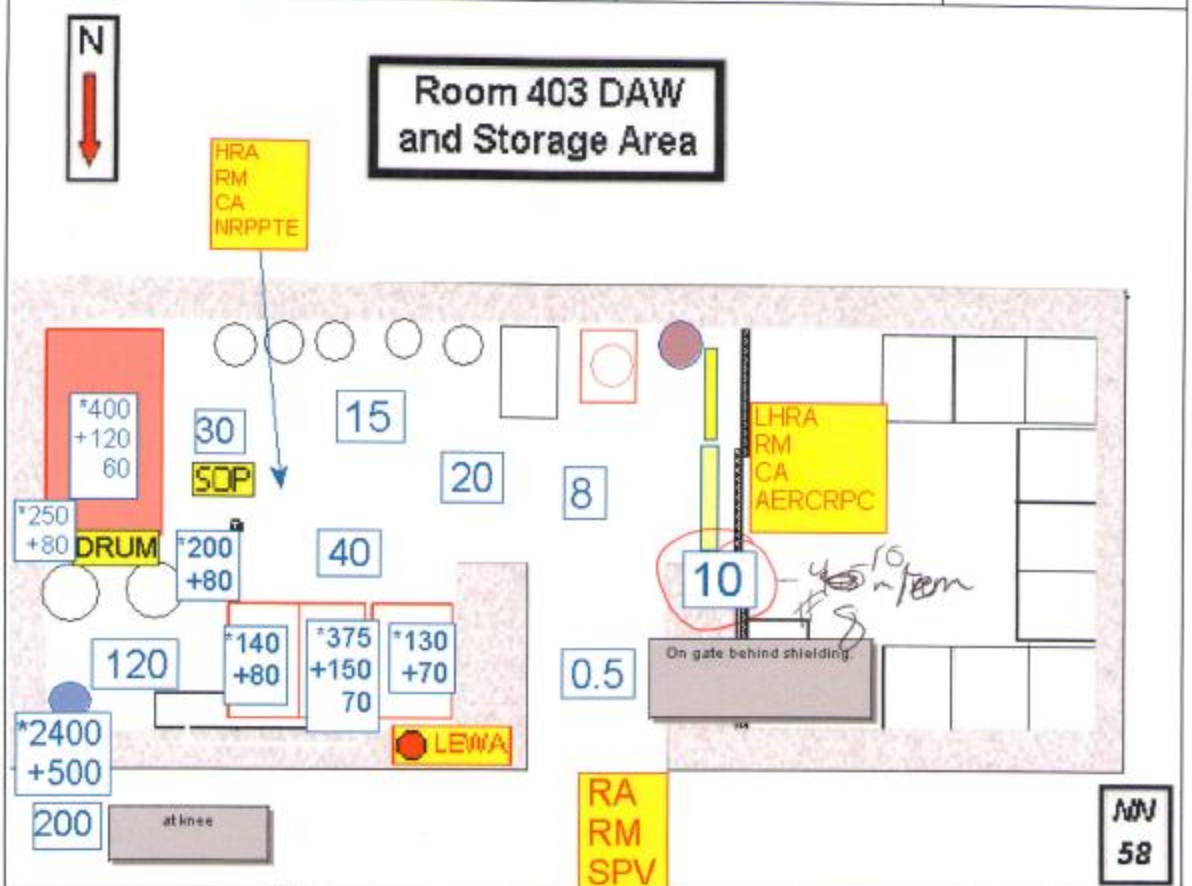
Room 403 (1)

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 403	Survey #: M-112912-15	Date/Time: 11/29/2012 11:05



Postings	β/γ Contamination Results

Lead Surveyor: Kenneth F. Davis

Instrument Serial #'s:

Date	Survey #	Surveyed By

Survey #: M-112912-15 - Printed On: 6/24/2013 16:58

Image File: Aux Bldg\577 Elevation\Room 403

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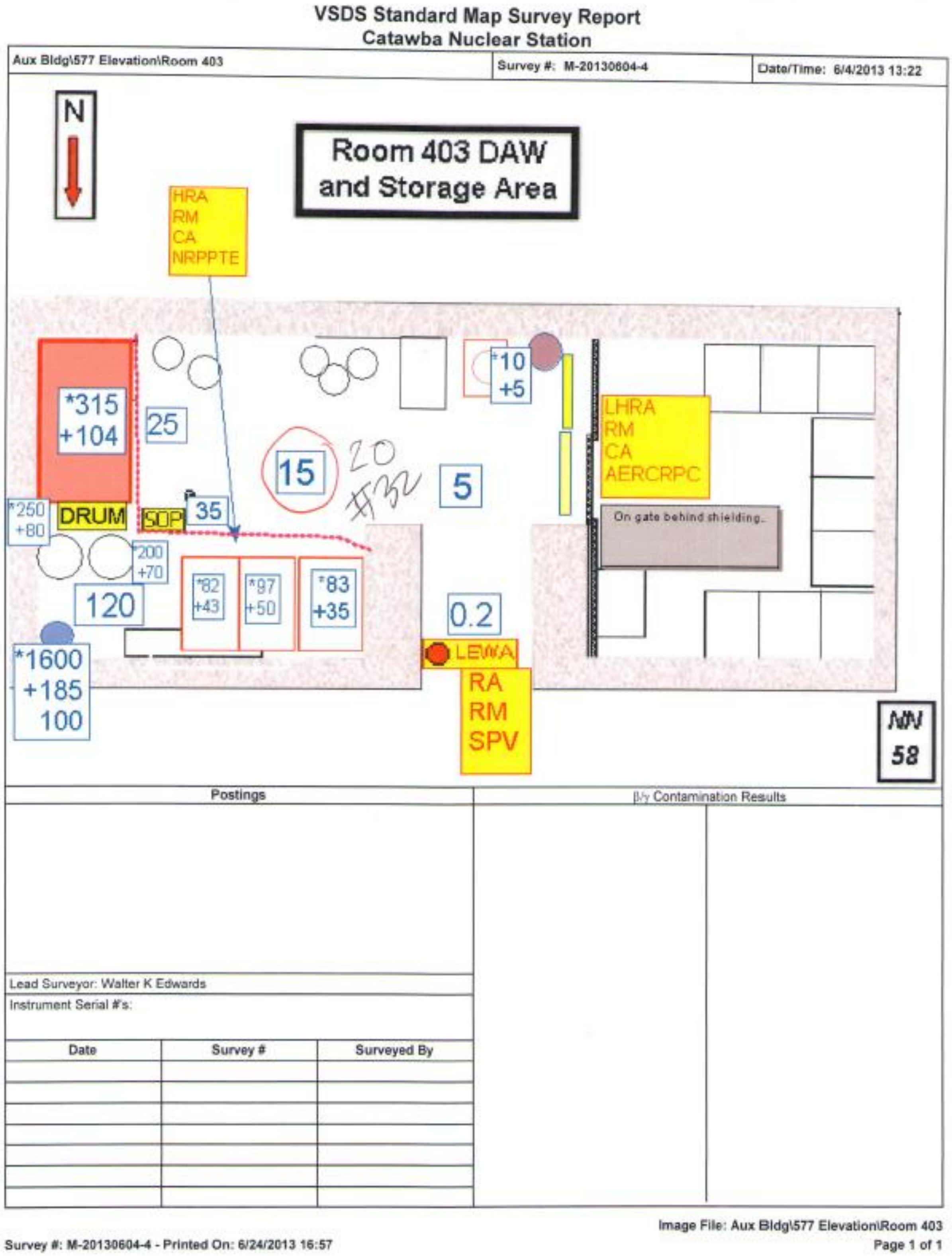
Room 403 (2)



VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 403	Survey #: M-20130604-4	Date/Time: 6/4/2013 13:22

Postings	β/γ Contamination Results	
Lead Surveyor: Walter K Edwards		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Survey #: M-20130604-4 - Printed On: 6/24/2013 16:57

Image File: Aux Bldg\577 Elevation\Room 403
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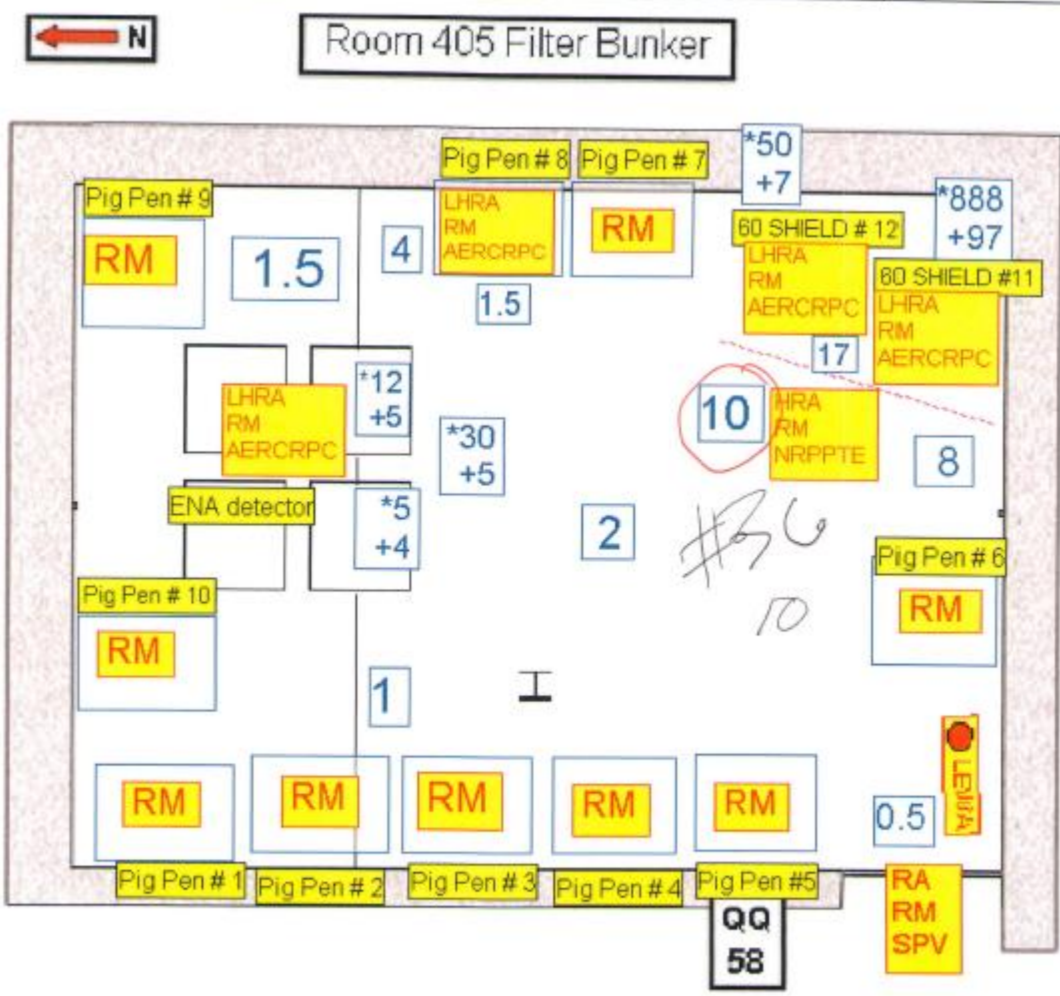
Room 405

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 405	Survey #: M-20130621-1	Date/Time: 6/21/2013 04:25



Postings	β/γ Contamination Results	
Lead Surveyor: Jasper L. Armstrong		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Survey #: M-20130621-1 - Printed On: 6/24/2013 17:27

Image File: Aux Bldg\577 Elevation\Room 405
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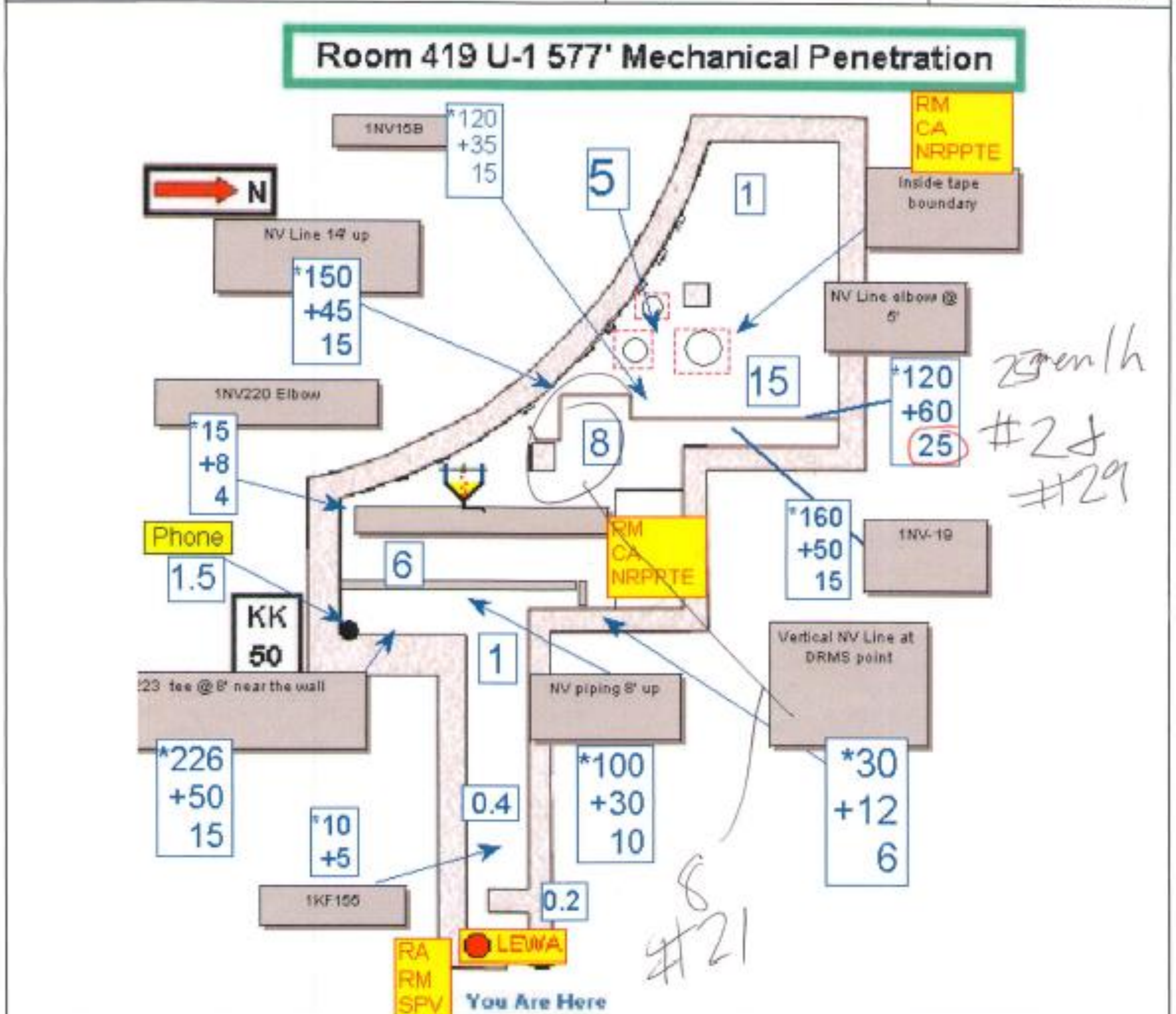
Room 419 (1)

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 419	Survey #: M-20130611-1	Date/Time: 6/11/2013 03:49



Postings	β/γ Contamination Results	
Lead Surveyor: Lynn Ferrell		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

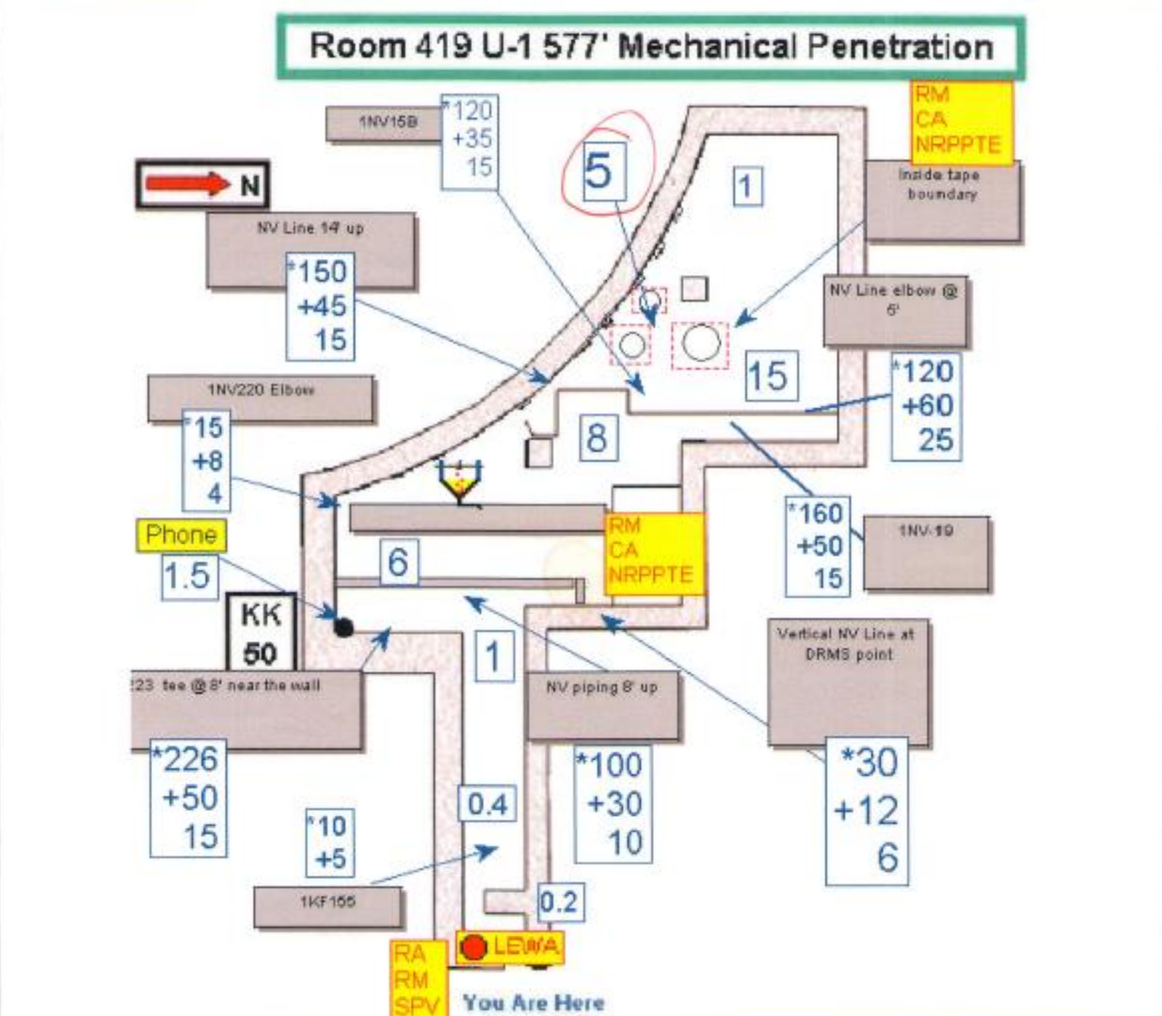
Survey #: M-20130611-1 - Printed On: 6/24/2013 15:47

Image File: Aux Bldg\577 Elevation\Room 419
Page 1 of 1

Room 419 (2)

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 419	Survey #: M-20130611-1	Date/Time: 6/11/2013 03:49



Postings	β/γ Contamination Results	
Lead Surveyor: Lynn Ferrell		
Instrument Serial #'s:		

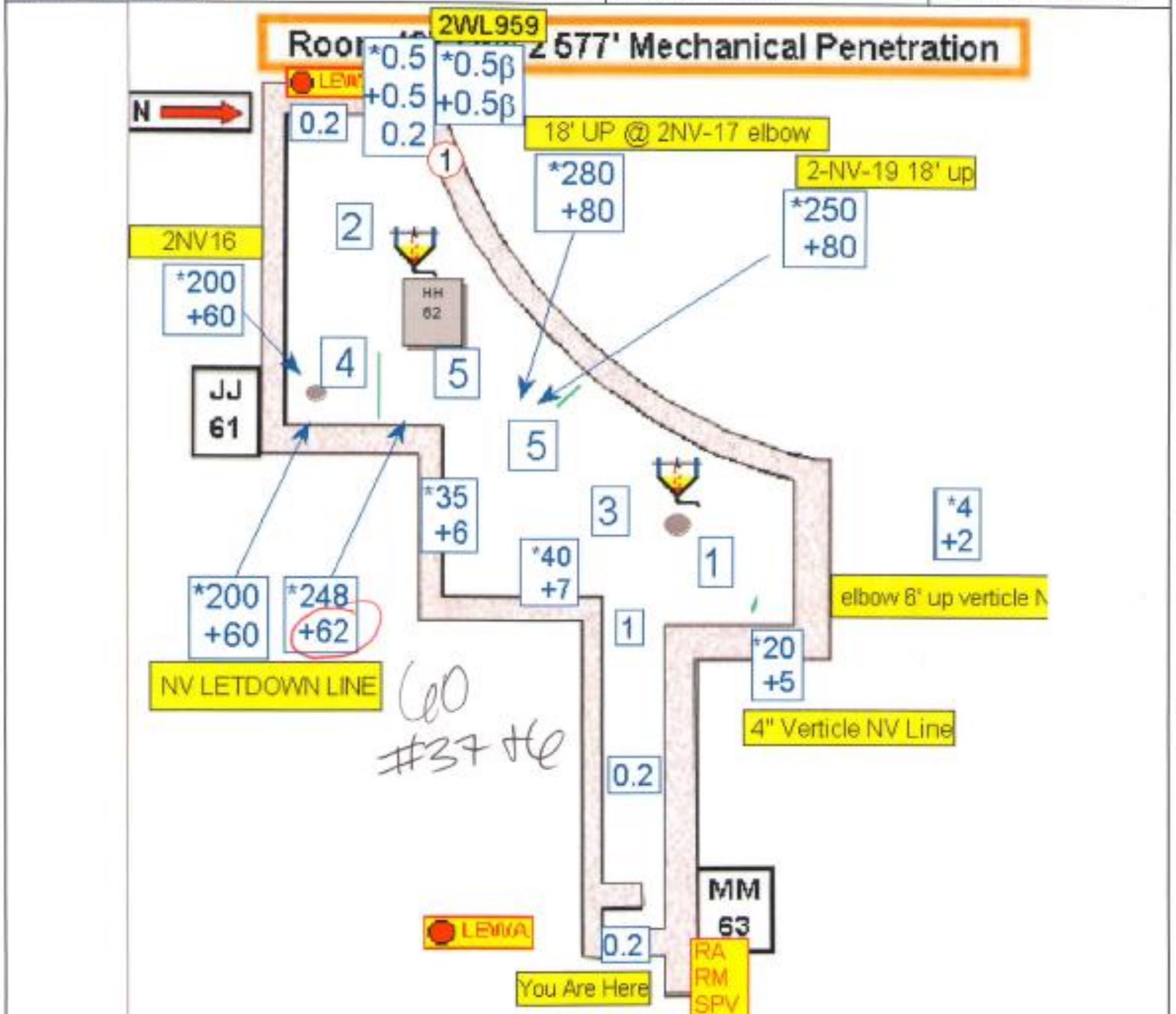
Date	Survey #	Surveyed By

Image File: Aux Bldg\577 Elevation\Room 419

Room 427 (1)

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 427	Survey #: M-20130612-3	Date/Time: 6/12/2013 11:11



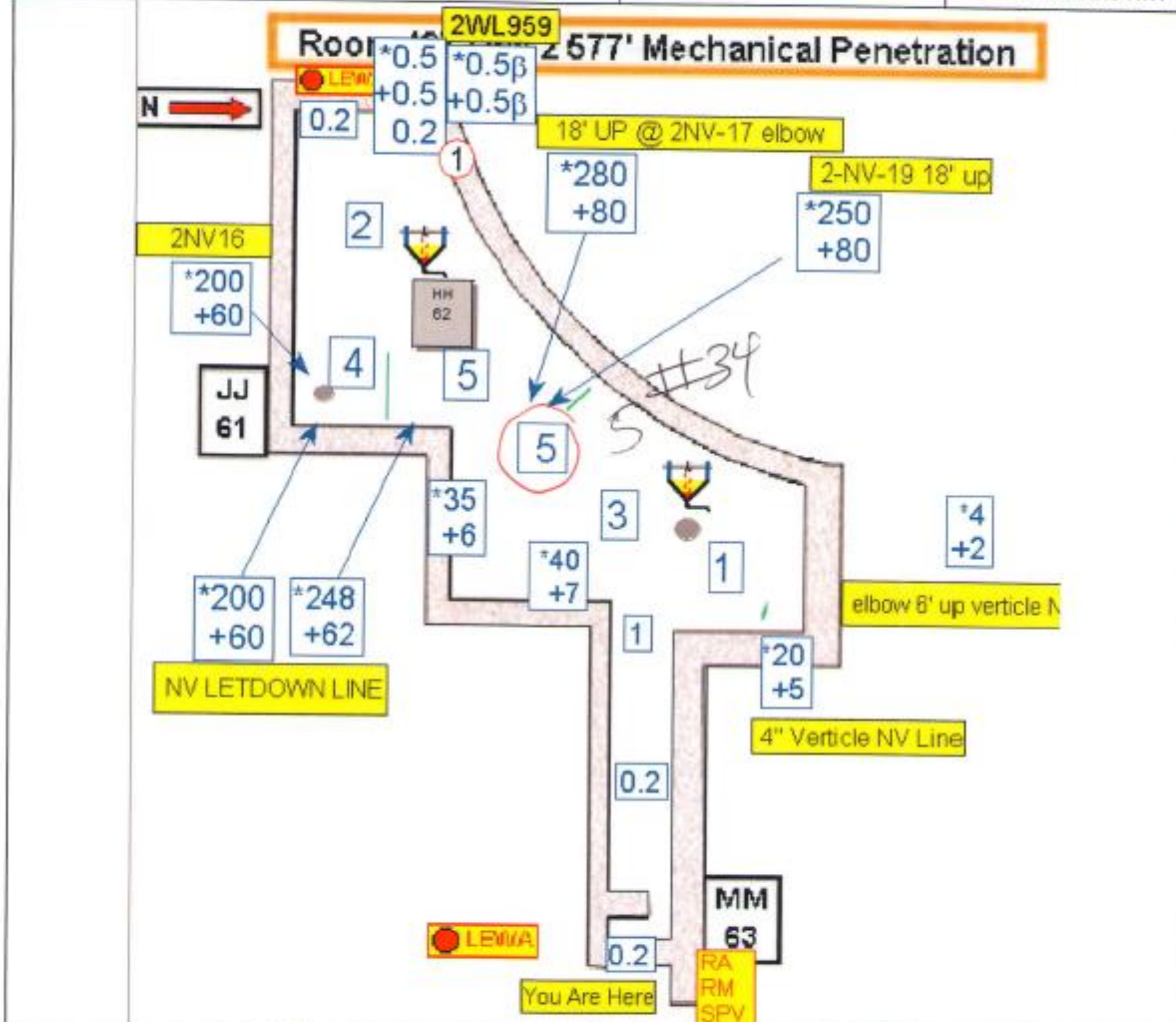
Postings	β/γ Contamination Results	
	1) <1k DPM/100 cm2	
Lead Surveyor: Joseph Lamarre		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Room 427 (2)

VSDS Standard Map Survey Report
Catawba Nuclear Station

Aux Bldg\577 Elevation\Room 427	Survey #: M-20130612-3	Date/Time: 6/12/2013 11:11



Postings	β/γ Contamination Results	
	1) <1k DPM/100 cm2	
Lead Surveyor: Joseph Lamarre		
Instrument Serial #'s:		

Date	Survey #	Surveyed By

Survey #: M-20130612-3 - Printed On: 6/25/2013 17:04

Image File: Aux Bldg\577 Elevation\Room 427
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APPENDIX D: Data

Pack	Pulled	Placed	TLD (mrem)	V3 (mrem)	V4 (mrem)	Difference from TLD V3	Difference from TLD V4	Difference between V4 and V3	V3 % diff from TLD	V4 % diff from TLD	Approx. dose rate from TLD
1	7/3/13	6/26/13	1065	1532.8	1508.6	467.8	443.6	-24.2	43.92	41.65	6.34
2	7/3/13	6/26/13	5870	6704.7	5963.0	834.7	93.0	-741.7	14.21	1.58	34.94
3	7/3/13	6/26/13	389	345.7	457.3	-43.3	68.3	111.6	-11.13	17.56	2.32
4	7/3/13	6/26/13	714	705.0	811.2	-9.0	97.2	106.2	-1.26	13.61	4.25
5	7/3/13	6/26/13	616	727.4	834.0	111.4	218.0	106.6	18.08	35.39	3.67
6	6/27/13	6/26/13	525	646.3	685.9	121.3	160.9	39.6	23.10	30.65	21.89
7	7/3/13	6/26/13	1526	1566.3	2094.6	40.3	568.6	528.3	2.64	37.26	9.08
8	7/3/13	6/26/13	877	874.1	994.2	-2.9	117.2	120.1	-0.33	13.36	5.22
9	7/3/13	6/26/13	1081	1130.0	1293.9	49.0	212.9	163.9	4.53	19.69	6.43
10	7/3/13	6/26/13	405	428.7	566.9	23.7	161.9	138.2	5.85	39.98	2.41
11	7/3/13	6/26/13	1201	1306.7	1795.6	105.7	594.6	488.9	8.80	49.51	7.14
12	7/3/13	6/26/13	2135	2906.2	2156.8	771.2	21.8	-749.4	36.12	1.02	12.71
13	7/3/13	6/26/13	3375	3820.6	4162.1	445.6	787.1	341.5	13.20	23.32	20.09
15	7/3/13	6/26/13	1482	1645.1	1735.6	163.1	253.6	90.5	11.01	17.11	8.82
16	7/3/13	6/26/13	163	171.9	219.0	8.9	56.0	47.1	5.46	34.36	0.97
17	7/3/13	6/26/13	426	521.7	505.1	95.7	79.1	-16.6	22.46	18.57	2.54
18	7/3/13	6/26/13	373	447.8	494.6	74.8	121.6	46.8	20.05	32.60	2.22
19	7/3/13	6/26/13	702	741.1	911.2	39.1	209.2	170.1	5.57	29.80	4.18
21	7/3/13	6/26/13	774	826.5	1053.6	52.5	279.6	227.1	6.78	36.12	4.61
22	7/3/13	6/26/13	1009	1128.2	1867.7	119.2	858.7	739.5	11.81	85.10	6.01
23	7/3/13	6/26/13	1820	2138.5	2158.5	318.5	338.5	20.0	17.50	18.60	10.83
28	7/3/13	6/26/13	917	1063.3	818.7	146.3	-98.3	-244.6	15.95	-10.72	5.46
29	7/3/13	6/26/13	3050	3294.1	3551.4	244.1	501.4	257.3	8.00	16.44	18.15
30	7/3/13	6/26/13	766	831.2	982.6	65.2	216.6	151.4	8.51	28.28	4.56
31	7/3/13	6/26/13	648	699.5	811.4	51.5	163.4	111.9	7.95	25.22	3.86
32	7/3/13	6/26/13	2216	2405.3	2717.0	189.3	501.0	311.7	8.54	22.61	13.19
33	7/3/13	6/26/13	376	386.0	483.7	10.0	107.7	97.7	2.66	28.64	2.24
34	7/3/13	6/26/13	763	830.6	1000.9	67.6	237.9	170.3	8.86	31.18	4.54
36	7/3/13	6/26/13	5099	6029.5	6176.7	930.5	1077.7	147.2	18.25	21.14	30.35
37	6/27/13	6/26/2013	573	655.5	798.0	82.5	225.0	142.5	14.40	39.27	23.88
38	7/3/2013	6/26/2013	1029	1225.1	1374.2	196.1	345.2	149.1	19.06	33.55	6.13
39	7/3/2013	6/26/2013	1754	1692.8	4642.1	-61.2	2888.1	2949.3	-3.49	164.66	10.44
40	7/3/2013	6/26/2013	523	590.9	733.8	67.9	210.8	142.9	12.98	40.31	3.11