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LAW RADIOACTIVE COUPON CO_2 DECONTAMINATION TEST

C. G. May
R. A. Dewberry, Jr.
S. McDuffie
F. M. Heckendorn
S. R. Salaymeh

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Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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LIST OF ACRONYMS

RPP-WTP	River Protection Project – Waste Treatment Plant
CO_2	Carbon Dioxide
dpm	disintegrations per minute
cpm	counts per minute
Bq	Becquerel
cm	centimeters
m	meters
psi	pounds per square inch
in.	inch
ft	feet
ILAW	Immobilized Low Activity Waste
g	grams
SRTC	Savannah River Technology Center
dB	decibels
NaI	Sodium Iodide
ROI	Region of interest
MCA	multichannel analyzer
PC	personal computer
RCO	Radiological Control Operations
M	Molar

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1.0 SUMMARY OF TESTING

1.1 OBJECTIVES

The objective of this test is to confirm that CO_2 blasting is capable of effectively removing smearable contamination from the external surface of the Immobilized Low Activity Waste (ILAW) stainless steel container after glass pouring. The smearable contamination level limits specified in the approved test specification[1] are:

- 367 Bq/m^2 (220 dpm/100 cm^2) alpha and 3670 Bq/m^2 (2202 dpm/100 cm^2) beta-gamma (qualification limits)
- 100 dpm/100 cm^2 alpha and 1000 dpm/100 cm^2 beta-gamma (design limits)

The removal of smearable contamination from radioactively contaminated coupon was demonstrated by varying the following operating parameters:

- Nozzle standoff distance
- Blast air pressure
- Pellet rate
- Nozzle travel speed

Coupons were weighed before and after blasting to determine if the CO_2 blasting process removed measurable amounts of surface material from the coupons.

High-speed photography was used to capture images of the pellets exiting the blast nozzle as a means of estimating pellet shape and velocity at the blast nozzle.

Bleeding tests were performed to determine if fixed contamination remaining on coupons after blasting "bleeds out" and measures as smearable contamination under typical storage conditions and times. The bleeding tests consisted of storing blasted coupons with no detectable smearable contamination for a period of 92 days at 95˚ F. [2] Coupons were removed at 23-day intervals and re-evaluated for smearable contamination.

1.2 CONDUCT OF TESTING

The radioactive coupon blasting tests consisted of four main subtasks:

- Coupon preparation
- CO_2 blasting
- High-speed photography
- Bleeding tests

1.2.1 Coupon Preparation

Coupons measuring 2 inches x 4 inches were removed from 10 gage thickness ASTM A240 Type 304L material with a 63 rms surface finish[3]. The coupons were cut using a mechanical saw and shear as not to introduce any heat effects to the coupon surfaces. Each coupon was cleaned and stored in a clean container prior to the contamination step.

The coupons were contaminated in two ways: 1) directly (D); and 2) indirectly (I). The directly contaminated coupons were contaminated with 2.076 microcuries of Cs-137. Using a pipette, 0.3 mL of a 0.001 M cesium nitrate solution at a concentration of 6.919 microcuries per milliliter was placed directly to one side of the coupon and dried. When heated at 950^{o}C in a closed container, the Cs-137 volatilized and, upon cooling, condensed onto the surfaces of adjacent uncontaminated coupons in the container. The coupons, contaminated by condensation only, were considered indirectly contaminated coupons.

Control coupons were also prepared and used to indicate contamination levels resulting from both the direct and indirect contamination processes and to track the effects of handling and shipping on the test coupons. Initially, eight experimental coupons were contaminated (four directly, four indirectly) and both total and smearable contamination levels measured to determine if the contamination process produced coupons with contamination levels sufficient for testing.

After the contamination process was tested and approved, coupons were prepared for the blasting test. Additional control coupons were selected to identify possible effects from handling and shipping. Total contamination measurements were made before and after blasting to confirm that fixed contamination was present for the “bleeding” tests.

After contamination, the coupons were weighed. Pre-blast and post-blast weights were compared to determine if blasting caused measurable weight loss.

1.2.2 CO_2 Blasting

The test coupons were blasted with CO_2 pellets using a combination of the operating parameters identified in Paragraph 1.1. The parameter combinations were selected using a statistical model to determine the main effects of the four parameters, as well as the two-way interactions between the parameters. Clean (uncontaminated) coupons, in addition to control coupons, were also used during the blasting tests to identify if cross contamination occurred during blasting and handling.

The blasting process was performed inside a containment hut. The blasting nozzle (2 inch fan) was securely mounted on a motorized carriage that controlled nozzle distance and travel speed. Blast pressures and pellet rates were adjusted at the control panel on the blasting unit.

After blasting, both sides of each test coupon were smeared to measure the smearable contamination remaining on the coupon. After-blast counts of the total fixed and smearable contamination remaining on the coupons were performed. The coupons were reweighed to determine weight loss caused by the blasting.

1.2.3 High Speed Photography

High-speed photography was used to capture images of the pellets exiting the nozzle as a means of estimating pellet shape and pellet velocity at the blast nozzle.

1.2.4 Contamination Bleeding

Total contamination measurements were made before and after blasting to confirm that fixed contamination was present for the “bleeding” tests. The bleeding tests consisted of storing blasted coupons (indirectly contaminated) with no detectable smearable contamination for a period of 92 days at 95˚ F. Clean (uncontaminated) coupons were stored with the contaminated coupons to check for cross contamination. Two contaminated coupons and one clean coupon were removed at 23-day intervals and reevaluated for smearable contamination.

1.3 RESULTS AND PERFORMANCE AGAINST OBJECTIVES

The test produced values for smearable contamination remaining on coupons after blasting each side with a single pass. Of the twenty coupons contaminated and blasted, fifteen (nine indirectly contaminated and six directly contaminated) were decontaminated below the design requirements for beta/gamma contamination identified in the test specification. Five of the directly contaminated coupons had smearable contamination above design requirements after blasting.

Of the nine indirectly contaminated coupons blasted, all were decontaminated below the 1000 dpm/100 cm^2 design limit. The smearable contamination remaining on the coupons ranged from non-detectable (ND) to 577 dpm/100 cm^2. The counts of the acceptable directly contaminated coupons ranged from non-detectable to 684 dpm/100 cm^2.

An analysis of pre-blast and post-blast total contamination levels of the indirectly contaminated coupons indicates a correlation between cleaning efficiency and three of the four operating parameters. Changes to these three parameters show statistically significant differences in percentage of contamination removed. As blast pressure increases, the amount of removed contamination increases. Increases in nozzle standoff distance and travel speed tend to decrease contamination removal. Changes in pellet rate do not produce statistically significant differences in the removal of smearable contamination.

For directly contaminated coupons, no statistically significant differences were noted in the percentage of total contamination removal caused by changes in the four operating parameters.

During the development of the test matrix, the contamination method (direct or indirect) was not considered a factor in the blasting tests. After contamination, both directly and indirectly contaminated coupons were randomly selected as test coupons. Nine indirect and eleven direct coupons were used in the blasting tests. However, the results of the testing indicate some irregularity with the decontamination performance between the directly and indirectly contaminated coupons. Since the test matrix was not designed to separately test the two contamination methods, the amount of data generated is not sufficient to evaluate the effectiveness of the CO_2 method for removal of smearable contamination to levels below the design limits over the full parametric window of interest for either indirectly or directly contaminated coupons as a single group.

The test results, when compared to the design criteria for smearable contamination, indicate that the contamination method may have been a factor. All of the indirect coupons were successfully cleaned below design acceptance limits. All five coupons failing to meet criteria were direct coupons. If the indirect coupons best represent actual facility operations, the test results can used accordingly.

As noted in the statistical design study of the test data, reproducibility of the blasting results, especially for directly contaminated coupons, is suspect because duplicate runs of identical blasting parameters did not produce similar results.

Test results confirmed that CO_2 blasting removes a statistically significant amount of material from the coupon surfaces. The average weight loss was 0.0027 g per coupon.

The bleeding tests indicated that some of the fixed contamination bled out during the bleeding period. The coupons that showed some bleed-out did not have smearable contamination levels exceeding the design limit. There did not appear to be any relationship among the initial fixed contamination levels, time intervals, and smearable contamination bleed-out.

Sound level surveys were conducted at a distance of 3 feet from the blasting nozzle for each blasting pressure. Sound levels ranged from 116 to 119 dB. Hearing protection was required inside the blasting hut at the blasting station, but not required outside the hut.

1.4 QUALITY REQUIREMENTS

Tests performed as part of this work were performed in accordance with NQA-1 (1989) and NQA-2a (1990) Part 2.7. Task Technical and Quality Assurance Plan, WSRC-TR-2002-00119, SRT-RPP-2002-00062, Rev. 0, contains the QA matrix applicable to this work and justification for all elements that are not applicable.

1.5 ISSUES

CO_2 blasting was successful in removing the smearable contamination on the indirectly contaminated coupons to levels below contract requirements. However, if the indirectly contaminated coupons are considered as a separate group, it should be noted that the indirectly contaminated coupons did not fully represent the full parametric window of operations (because the other eleven, necessary to cover the parametric window, were directly contaminated coupons). Therefore, the reproducibility of the results and the sensitivity of the results to variations in the parameters were not fully evaluated.

Other variables that could affect the efficiency of the decontamination results such as blast nozzle orientation to the contaminated surface or length and configuration of the pellet delivery system were not evaluated as part of the scope of this test.

Decontamination results were based on a single pass of the blast nozzle per each side of the coupon. Additional passes may complete the decontamination to meet design limits.

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2.0 CD-ROM ENCLOSURES

The enclosed CD-ROM contains photographs and a video clip of the blasting experiment in progress. An electronic copy of the report is also included on the CD-ROM.

The CD-ROM should start automatically within 30 seconds when placed in your CD-ROM drive on an IBM compatible PC. If it does not, then do the following:

1. Double-left-click on MyComputer icon on your desktop
2. Right-click on your CD drive icon
3. Left-click on AutoPlay

The recommended minimum computer system is as follows:

- Pentium II running at 233 MHz
- 32 MB ram
- Windows 95 or later.

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3.0 DISCUSSION

The Waste Treatment and Immobilization Plant (WTP) will vitrify pretreated Low Activity Waste (LAW) in joule heated melters and the resulting melt will be poured into stainless steel containers. The containers will be sealed, decontaminated, and transported for final disposal. The exterior surfaces of the containers may become radioactively contaminated by a number of mechanisms, including:

- Condensation of volatile radiochemical constituents
- Contact with radioactive material from the surrounding environment

The baseline decontamination method for decontaminating the exterior container surfaces of ILAW containers is carbon dioxide (CO_2) pellet blasting. Both fixed and smearable contamination is expected to be present on the container surfaces after pouring; however, these radioactive tests are applicable to smearable contamination only. The purpose of these tests, as specified in Test Specification 24590-LAW-TSP-RT-02-005, Rev 0, and Task Technical and QA Plan, Rev 0, WSRC-TR-2001-00154, and SRT-RPP-2001-00001, is to determine if CO_2 pellet blasting will effectively remove smearable radioactive contamination to meet the following limits:

- 367 Bq/m^2 (220 dpm/100 cm^2) for alpha and 3670 Bq/m^2 (2202 dpm/100 cm^2) for beta-gamma contamination, (contractual requirements)
- 100 dpm/100 cm^2 for alpha and 1000 dpm/100 cm^2 for beta-gamma (design requirements)

3.1 CO_2 BLASTING PROCESS DESCRIPTION

CO_2 blasting is an industrial cleaning process that uses solid carbon dioxide pellets as the blasting medium. Contaminants are removed from surface material via two methods. In a manner similar to typical sand blasting, the CO_2 particles mechanically remove contaminants when they impact the surface at high velocities. The particles are accelerated by compressed air, normally in the pressure range of 80 – 150 psi. Higher pressures of up to 300 psi may be used in special circumstances. Additionally, a lifting action occurs when the CO_2 particles sublimate as they strike the container surface. Sublimation produces CO_2 gas that expands under the contaminant and removes it from the surface. The CO_2 gas returns to the atmosphere through a HEPA filter and leaves only the contaminant and particles removed from the material surface as the waste stream.

The blasting equipment used for these tests is manufactured by CAE Alpheus, Inc. The Alpheus MiniBlast™ Model PLT-5X is a portable blasting unit capable of operating within the WTP design blasting parameters for the decontamination of the ILAW containers. The Model PLT-5X is normally manufactured with a single hose for transporting both blast air and pellets to the blast nozzle. The PLT-5X used in these tests was modified to use a dual hose assembly (Figure 1).

Figure 1. Alpheus MiniBlast™ Model PLT-5X

Support equipment for blasting in radioactive environments includes an air compressor, air dryer, and containment hut with HEPA filtered ventilation system.

The CO_2 pellets were produced by CAE Alpheus, Inc., and manually loaded into an internal hopper in the PLT-5X. The size of the pellets was approximately 1/8 inch in diameter and 3/16 inch in length (Figure 2). A dual-hose system delivered the pellets to the blast nozzle. The pellets travel through one hose via transport air at approximately 40 psi. The high pressure blasting air travels through a second hose. The pellets and blast air are combined in the blasting gun nozzle before exiting the blast nozzle.

A stainless steel coupon holder was fabricated to hold coupons at the corners, therefore reducing cross contamination from one coupon to the other (Figure 3). A frame held the holder and allowed easy removal and rotation of the coupon so that both sides of the coupon could be blasted. The blast nozzle was mounted on an adjustable rack with motorized travel carriage and rigid track. The rack allowed for proper orientation of the nozzle and coupon. The travel carriage speed was controlled by a variable master drive controller with a digital readout of the travel speed.

The blasting tests were performed in a 16 ft x 16 ft hut fabricated from stainless steel panels to contain airborne contamination that resulted from the blasting. The hut was connected to the facility's HEPA ventilation system. A smaller enclosure constructed from tarpaulins was built around the blast nozzle and coupon holder for further containment of airborne contamination and to reduce CO_2 buildup in the hut during blasting (Figure 4). The smaller enclosure was connected to a separate HEPA ventilation system.

Figure 2. Typical Pellets - 1/8" diameter, approximately 1/16"-3/16" long

Figure 3. Coupon holder for coupon blasting

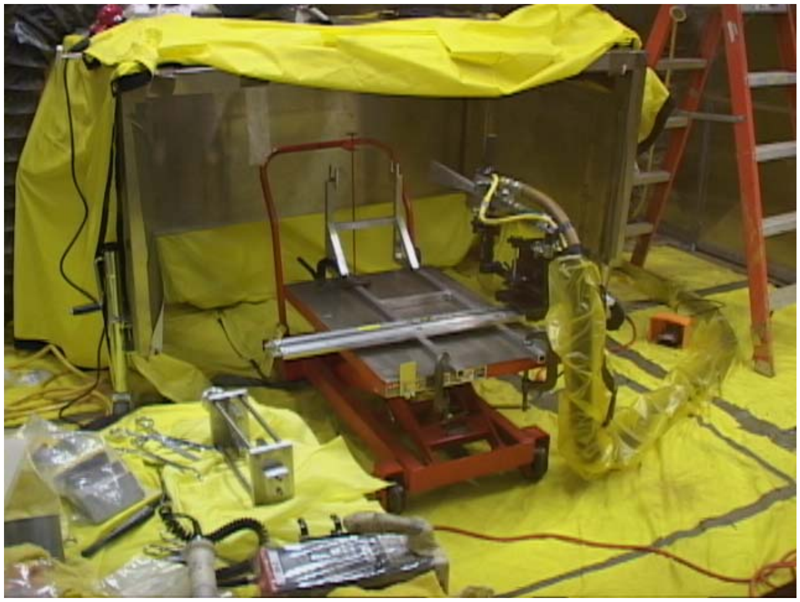


Figure 4. Small blasting enclosure with blast nozzle, motorized carriage, and track

3.2 COUPON PREPARATION

3.2.1 Coupons for Blasting

The coupons for the radioactive tests were removed from ASTM SA 240 Type 304L material with a 63 rms surface finish[3]. The coupon size was 2 inches in width x 4 inches in length with a 10 gage (0.1345 inch) thickness. The coupons were cut using a mechanical saw and shear as not to introduce any heat effects to the coupon surfaces. A numerical number was stamped on one side of each coupon for identification purposes. After cutting, the coupons were cleaned with isopropanol and a soft brush to remove cutting residue. The coupons were stored in a clean closed container until the contamination process began.

The contamination process included the following steps:

1. Selected coupons were contaminated with 2.076 microcuries of Cs-137. Using a pipette, 0.3 mL of a 0.001 M cesium nitrate solution and a concentration of 6.919 microcuries per milliliter was placed on one side of the coupons and dried.

2. Four contaminated coupons along with four clean coupons were placed in a rack inside a closed container. The coupons were arranged on the rack such that each coupon contaminated as described in Item 1 was placed next to a clean (uncontaminated) coupon.

3. The container with coupons was placed inside a digitally programmable furnace preheated to 950^{o} C. When the container was placed inside the furnace, the furnace temperature was reduced. Earlier tests using two temperature probes, one for the furnace temperature and one for the inside container temperature, proved that the inside container temperature reached 950^{o} C at the same time the furnace temperature returned to 950^{o} C.

4. The container with coupons was removed from the furnace when the temperature of the furnace reached 950^{o} C and allowed to air cool to 105^{o} C.

5. During heating, some of the Cs-137 on the surfaces of the contaminated coupons volatilized and, during cooling, condensed on the surfaces of the uncontaminated coupons. The coupons with contamination placed directly on them are identified as directly (D) contaminated and those contaminated only by volatilization/condensation are identified as indirectly (I) contaminated.

6. After cooling to 105^{o} C, the coupons were removed from the container and immediately placed in a desiccator for at least one hour in preparation for weighing.

7. The coupons were directly transferred from the desiccator to a calibrated scale with a sensitivity of 0.1 mg and weighed.

8. After weighing, the coupons were individually packaged for measuring the total activity of the coupons in accordance with Section 3.3.

9. This contamination method did not produce identical contamination levels on all coupons. The fixed and smearable contamination levels varied for each coupon. The objective was to have smearable contamination levels sufficient to test the blasting process leaving the fixed contamination for the bleeding tests.

3.2.2 Control Coupons

Control coupons were used as indicators of the effectiveness of the contamination method and also of the effects of handling, packaging, and shipping coupons for the tests. Control coupons were prepared as follows:

1. Initially, eight test coupons were prepared in accordance with Paragraph 3.2.1, Items 1-4. These eight coupons were used to determine contamination levels produced by the contamination method. The total and smearable contamination levels were measured. Customer acceptance of the first eight coupons indicated acceptance of the contamination method. The results are shown in Appendix D, Table D.1.

2. After acceptance of the contamination method, coupons were prepared for blasting in five batches of eight coupons/batch. Two control coupons, one directly and one indirectly contaminated, were selected from each batch of coupons for a total of ten control coupons. These coupons were weighed, total contamination measured, and subjected to the same handling and shipping conditions as the blasted coupons except they were not blasted. Four control coupons were returned to SRTC for reweighing and contamination measuring prior to the tests because of delays in the blasting tests. The remaining six control coupons were unpackaged during the blasting tests and exposed to the blasting containment environment and handling process. The coupons were measured for smearable contamination and repackaged for shipment back to SRTC along with the blasted coupons. The coupons were weighed and measured for total contamination levels at SRTC. Contamination levels for the control coupons are shown in Appendix D, Table D.3. Weight summaries are shown in Appendix B, Table B.1.

3. After the last batch of coupons was contaminated, eight more test coupons were prepared to determine if any significant changes occurred in the coupon contamination process. The coupons were measured for smearable and fixed contamination, but not weighed. Appendix D, Table D.2 shows these results.

3.3 CONTAMINATION MEASUREMENTS

3.3.1 Measurement System

The measurement system consists of a sodium iodide (NaI) detector and a coupon holder configured in a fixed geometry. Figure 5 shows a schematic diagram of the NaI system and the coupon position. The NaI detector system is 1-inch radius crystal with a multi-channel analyzer (MCA) that uses a portable computer with a Canberra NaI+ card installed. This card converts the personal computer (PC) to a full function MCA and contains the ancillary electronics, high voltage power supply, and amplifier required for data acquisition. Figure 6 is a photograph that shows the acquisition system including the shielded detector as well as the PC and coupon holder. The coupon holder with a coupon double bagged and mounted in the counting configuration is also shown. The holder fixes the coupon to detector distance at six inches.

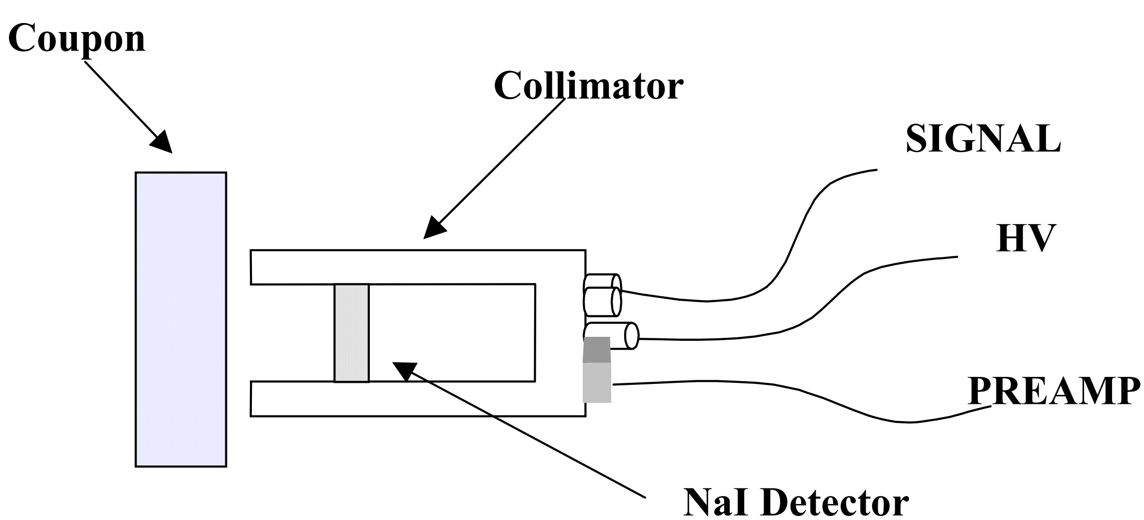


Figure 5. Schematic diagram of the NaI system

Figure 6. Coupon Counting Setup

3.3.2 Data Acquisition

The data were acquired in a geometry fixed by a sample holder that is constructed to hold the 2" x 4" coupon and to hold the 1" detector and shielding such that the source to detector distance is fixed to 6 inches. The distance and geometry were fixed such that the detector is able to view the entire coupon in approximately the point source configuration. Each coupon was stamped with a numbered identification. All coupons were placed in the coupon holder with the numbered side facing the detector in order to obtain comparable results. The detector was operated with a positive bias of 800 volts, and the multi-channel analyzer was operated with a conversion gain of 512 channels. The amplifier was adjusted to 20x0.86 so the 662 keV γ-ray from Cs-137 decay falls near channel 270 with a full width of approximately 30 channels. With a point source configuration distance of six inches away, the geometric efficiency of the detector is

Equation 1 $$\text{Eff} = \pi/4\pi(36) = 0.0069$$

where the π in the numerator is the surface area of the detector, and the denominator is just the surface area of a six-inch sphere. If we assume the source is a point emitting isotropically in all directions, at a distance of six inches, only 0.69% of the photons leaving the point source will strike the 1-inch radius detector. Using a known source we measured an acquisition efficiency of 0.00212.[6] Therefore our intrinsic efficiency for the 662-keV photopeak is approximately 30%, which is in very good agreement with our expectations.

A background acquisition was obtained with each shift of acquisitions followed by a quality control check (QC) of the system. The background count for each shift of acquisitions was a very important aspect of the measurements because coupons were generally delivered in batches of eight to thirty. Therefore the samples themselves were the main contributors to the room background. Although the detector was isolated and shielded, the background measurement was always an important component of these acquisitions. The background was generally counted for 1800 seconds or more.

Sample acquisitions consisted of 1-minute to 3-minute counts of the contaminated coupons in which a region of interest (ROI) was placed around the 662 keV γ-ray from Cs-137. The appropriate background spectrum was stripped (subtracted channel by channel) from each sample spectrum, and the ROI was fit to subtract the continuum contribution from the Cs-137 γ-ray peak. The 662 keV values were direct measurements read directly from the instrument screen with up to five significant figures. Net detection rates are listed in units of counts per minute (cpm) where the count times were measured in seconds and converted to minutes with four significant figures. Duplicate counts of multiple coupons were obtained at various dates over the duration of the experimental measurements to provide an additional demonstration that the experimental conditions did not change unacceptably.

The measurement data and analysis for the contamination levels for pre- and post-blast coupons are listed in Appendix E.

3.3.3 Smearing Technique

The smearing technique used to determine smearable contamination was done in accordance with 49 CFR 173.443 (a). A standard 5-cm circular swipe was used with moderate pressure. Both sides of the coupon were wiped with the swipe to give an approximate area of 100 cm^2. The smear was first counted with hand-held count rate meter. Swipes with no measurable counts were then counted in a laboratory scaler for more accurate measurements of lower contamination levels.

3.4 BLASTING TESTS

A series of blasting tests were developed using JMP® Statistics and Graphics Guide, Version 4.0.5 [3]. A test matrix (Table 1) designed to show the effects of varying the four parameters of primary interest as well as any two-way interactions of these parameters guided the blasting tests. The study identified each parameter change and the number of tests required to statistically support an evaluation of the blasting parameters. Initial parameters were based on design specified parameters[1, 3].

The initial parameters, with the exception of pellet rate, were varied both low and high, creating a low value, mid-point value or initial value, and high value. The pellet rate was only tested at a low and high value. The following describes the blasting parameters:

Nozzle type (fixed)	A 2" wide fan nozzle was used in the tests.
Pellet rate (variable)	Two pellet rates, 2 lbs/min and 5 lbs/min, were tested. A dial on the blasting unit control panel adjusts the pellet rate. Prior to the tests, pellets were collected at the hopper exit, before entering the transport hose, for one minute and then weighed. The dial was marked to indicate the two pellet rates for duplication during the tests.
Pellet Size (fixed)	The pellets were manufactured by CAE Alpheus. Alpheus pellets were the only ones available with a consistent size of 1/8" diameter and approximately 1/16" to 3/16" length.
Nozzle Attitude (fixed)	The blast nozzle was oriented 90^{o} to coupon surface and measured with a right angle square.
Nozzle Standoff Distance (variable)	The blast nozzle was mounted on a tool rack attached to the motorized carriage. The rack provided three-axis adjustment to set nozzle position in relation to the coupon. A ruler was used to set the nozzle standoff distance. The standoff distances for the tests were 2 in., 4 in., and 6 in.
Transport Air (fixed)	The transport air was set at the factory at approximately 40 psi.
Nozzle travel speed (variable)	A motorized carriage mounted on a rigid track fixed in relation to the coupon provided travel speed control. A digital readout on the motor control was used to set travel speeds of 30, 50, and 70 in/min. The speed was verified using a stopwatch and measuring tape.
Blast Air Pressure (variable)	A valve and gage on the blasting unit control panel varied the blast pressure. The blast air pressures were 100, 110, and 120 psi. Blast air volume was directly dependent on blast air pressure and not independently variable. The ratio of volume to pressure was approximately 2:1.
Blast air and air transport hoses	The blast air and air transport hoses were 50 ft long.

Table 1. Parameter Test Matrix

Coupon ID	Blast Air Pressure (psi)	Nozzle Standoff Distance (inches)	Travel Speed (in/min)	Pellet Rate (lb/min)	Run Order
30-D	110	4	50	2	1
69-I	120	2	30	2	2
11-I	100	6	30	2	3
19-I	100	6	70	2	4
2-I	120	6	70	2	5
23-D	100	2	70	2	6
70-D	120	6	30	2	7
37-D	100	2	30	2	8
1-I	120	2	70	2	9
22-D	110	4	50	2	10
31-D	110	4	50	5	11
73-I	120	6	30	5	12
13-I	100	2	70	5	13
34-D	100	6	70	5	14
71-D	120	2	70	5	15
21-I	100	2	30	5	16
77-D	120	2	30	5	17
25-D	100	6	30	5	18
68-I	120	6	70	5	19
36-D	110	4	50	5	20

During the blasting tests, clean coupons were used to check the presence of cross contamination from the blasting and handling process. Along with each contaminated coupon blasted, a clean coupon was attached to the coupon holder. The clean coupon was located near the blast nozzle, but out of the direct blast from the nozzle. After blasting, the clean coupon was removed along with the blasted coupon and wiped for smearable contamination. After every fourth coupon blasted, a clean coupon was placed in the coupon holder, blasted, and wiped for smearable contamination. Emphasis was place on wiping the coupon edges and corners for contamination from the holder. Finally, a clean coupon was placed in the small blast enclosure during the blasting of all coupons and removed at the completion of blasting.

All coupons, both clean and contaminated, were handled with clean tongs and gloves. After the handling of each coupon, gloves were replaced with clean ones before handling the next coupon to prevent cross contamination from contaminated gloves.

After both sides of each coupon were blasted and smeared, coupons were immediately placed in individual clean plastic bags for return to SRTC. The contamination levels of the smears were measured by the RCO technician using a hand-held count rate meter at the blasting station immediately after blasting. Smears with no detectable contamination were removed from the containment hut and counted with a laboratory scaler for more accurate counts.

The noise caused by the blasting operation was measured for each blast air pressure. A calibrated sound level meter measuring in decibels (dB) was used for the measurements. The measurements were made at the blast station inside the containment hut.

3.5 HIGH SPEED PHOTOGRAPHY

Images of CO_2 pellets, as they exited the test blasting nozzle, were videotaped with "stop action" or "high-speed" photographic technology. The technique used a specialized high-speed black-and-white video camera linked to a hard disk drive. The equipment used is listed below:

- "Olympus" High-Speed Video System, Model ENCR-MAC-1000, Item #4702A1, 4 Sec Memory, 1000 Frames Per Second
- SRTC-designed optics to provide magnification of the moving pellets to imageable size
- Very high intensity halogen light units (3 each)
- "Sony" time-lapse VHS video recorder
- Various video displays, and support equipment

Images were gathered at a rate of 1000 images/second and each image was only sampled for 1/20 th of this time period. This combination provides images that display the flight of a pellet(s) for 1/20,000 of second with hose collected images spaced at 1/1000 second intervals. A scene of interest was captured for a total of 4000 images, representing 4 seconds of pellets in flight.

The resultant groups of images were then downloaded to an analog video that allowed subsequent replay of the images one frame at a time. (Note: Digital video recording is not compatible with this type of imaging). A scale was interspersed with the pellet images to provide the absolute size reference. The two hours of video tape were analyzed to identify images where the same pellets were imaged in two consecutive images and the distance of flight could be compared to the known time of flight.

Images were taken at three different magnifications to accommodate different requirements. The highest magnification images were an attempt to capture the particle size. The lowest magnification was used to spread the field of view out so that the same particle could be captured in two consecutive images. The intermediate magnification just provides general views.

3.6 BLEEDING TESTS

Bleeding tests were performed to investigate if bleeding of fixed contaminates from the surface oxide of the coupons occurred after decontamination. The bleeding tests were performed as follows:

1. Only indirectly contaminated coupons blasted in the radioactive coupon tests were used for the bleeding tests. The smearable contamination was completely removed from the coupons by wiping with cloths moistened with isopropanol and then smear tested for smearable contamination. The coupons were also monitored for fixed contamination with a hand-held count rate meter before beginning the bleeding tests.

2. The nine indirectly contaminated coupons were placed in a holding rack. The rack was placed inside a stainless steel pan with cover. The rack, pan , and cover were placed on a hot plate to maintain a temperature of 95^{o} F for 92 days.

3. Four clean (uncontaminated) coupons were included in the bleeding tests as control coupons.

4. At 23-day intervals, two random coupons and one clean coupon were removed from the rack and smear tested for smearable contamination to determine if any fixed contamination bled to the surface of the coupon. At the end of the last 23-day period, three contaminated coupons and one clean coupon were removed.

3.7 DEVIATIONS FROM TEST PLAN

Deviations from the approved Task Technical and QA Plan, Rev 0, WSRC-TR-2001-00154 and SRT-RPP-2001-00001, are identified in Test Exception to LAW Radioactive Coupon CO_2 Blasting Test 24590-WTP-TEF-RT-02-066, and 24590-WTP-TEF-RT-03-008, Rev. 0. A summary of the deviations is as follows:

1. The temperatures and holding times in the coupon contamination process were revised from the initial plan. The initial temperatures and holding times produced coupons with excessive flaky oxides that were not similar to the surface of the 1/2-height containers poured at Duratek. Reducing the temperature to 950˚ C, eliminating the holding time, and allowing the container and coupons to cool outside the furnace in open air produced an acceptable coupon surface.

2. A clean control coupon was placed 6-8 inches (outside the blast air) from each blasted coupon for monitoring cross-contamination from the blasting. The coupon was smear tested along with the blasted coupon it represented.

3. After each fourth coupon was blasted, a clean coupon was blasted to monitor cross-contamination.

4. The test plan required each coupon to be weighed twice before and after blasting for coupon weight loss calculations. Prior to blasting, the coupons were only weighed once. This deviation was accepted by the test exception and by Nonconformance Report 2002-NCR-11000033.

5. The number of coupons for each contamination cycle was revised to eight instead of twelve. This deviation was also accepted by Nonconformance Report 2002-NCR-11000033.

6. Only indirectly contaminated coupons were used in the bleeding tests, therefore reducing the number of coupons from eighteen to nine. At 23-day intervals, two contaminated coupons and one clean coupon were removed form the enclosure and measured for smearable contamination. The clean coupons were used to monitor cross-contamination.

3.8 RESULTS

3.8.1 Contamination Removal

Table 3, Appendix A, summarizes the contamination method, the total contamination levels before and after blasting, and smearable contamination levels after blasting. The two groups of coupons are test coupons (blasted coupons) and control coupons. Control coupons were not blasted and were used to determine influences due to contamination method and the handling and shipping during the tests.

The total contamination (fixed plus smearable) is measured in counts per minute (cpm) per coupon. Smearable contamination is measured in disintegrations per minute (dpm)/100 cm^2. In both cases, contamination on both sides of the coupons was counted. The measurement setup in Paragraph 3.2.1 is designed to count contamination on both sides of the coupon. In the case of smearable contamination, both sides of the coupons were swiped with the same swipe. The total area of both sides of a 2" in x 4" in coupon equals approximately 103 cm^2. For these tests, the coupon area was rounded to 100 cm^2.

The statistical study of the data produced the following results:

- Using all of the data, there does not appear to be a statistically significant difference in the mean pre-blast total contamination levels between the direct and indirect methods of contamination for the test coupons. For the control coupons, there does appear to be a difference in the mean contamination levels. As expected, directly contaminated coupons have a higher mean level than indirectly contaminated coupons.

- The smearable contamination levels on the three indirectly contaminated control coupons were 2000, 2000, and 4000 dpm/100 cm^2. The smearable contamination levels for the three directly contaminated control coupons were 22000, 22000, and 60000 dpm/100 cm^2 (Table D.3). Thus, the smearable contamination levels of the contaminated coupons were considered sufficient for these tests.

- Results indicate a statistically significant difference in the smearable contamination levels of the directly and indirectly contaminated control coupons. As expected, the levels of smearable contamination on the directly contaminated coupons are higher than the indirect coupons.
- There appears to be a statistically significant difference in the mean post-blast total contamination levels between the directly and indirectly contaminated coupons. The levels of the directly contaminated coupons are higher than the indirect coupons.
- Analyses of pre- and post-blast data indicate a statistically significant difference in the pre- and post-blast average contamination levels for the test coupons, but not for the control coupons before and after shipping.
- Analysis of the pre- and post-blast total contamination levels of eight indirectly contaminated test coupons (Inadvertently, the pre-blast total contamination for one indirectly contaminated coupon was not measured.) indicates a statistically significant effect on contamination differences due to a change in the variable operating parameters. Variations in the blast pressure, nozzle standoff distance, and travel speed may change contamination removal from 12.5 - 27.5%.
- Based on duplicate runs of identical parameter sets, it appears that the reproducibility of the blasting test results is suspect, especially for the directly contaminated coupons.

Only five of the 20 test coupons had post-blast smearable contamination levels above the 1000 dpm/100 cm^2 design limit for beta-gamma (Table 2). All five coupons were directly contaminated. Of the nine indirectly contaminated coupons blasted, all were decontaminated well below the 1000 dpm/100 cm^2 design limit. The smearable contamination remaining on the indirect coupons ranged from non-detectable (ND) to 577 dpm/100 cm^2. The counts of the acceptable directly contaminated coupons ranged from non-detectable to 684 dpm/100 cm^2.

Additional analysis of the differences between the pre- and post-blast total contamination values were conducted. CO_2 blasting reduced the total contamination levels for both directly and indirectly contaminated coupons (Figure 7 and Figure 8). The differences were evaluated relative to the four variable operating parameters.

For the parameters values represented by the indirectly contaminated coupons, the results indicate statistically significant effects due to changes in blast pressure, nozzle standoff distance, and travel speed. As blast pressure increases, the percent of removed contamination also increases. For increases in nozzle standoff distance and travel speed, the percent change tends to decrease. The variations in the parameters increased contamination removal from 12.5 – 27.5%.

Pellet rate changes do not cause any statistically significant differences in the percent of contamination removed.

Table 2. Pre- and Post-Blast Contamination Levels

Control Coupon ID	Test Coupon ID	Total Pre-Blast (dpm/100 cm^2)	Total Post-Blast (dpm/100 cm^2)	Control Coupon Smears (dpm/100 cm^2)	Post-Blast Smears (dpm/100 cm^2)
39-D	NA	1.458E+06	1.323E+06	2.20E+04	NA
17-I	NA	6.612E+05	6.231E+05	2.00E+03	NA
NA	13-I	8.963E+05	7.097E+05	NA	2.68E+02
NA	31-D	1.316E+06	7.914E+05	NA	3.45E+04
NA	22-D	3.342E+07	2.137E+06	NA	3.67E+03
NA	25-D	1.073E+06	7.406E+05	NA	<200
29-D	NA	1.514E+06	9.713E+05	6.00E+04	NA
3-I	NA	8.251E+05	7.026E+05	4.00E+03	NA
NA	71-D	1.198E+06	8.792E+05	NA	ND
NA	1-I	9.443E+05	7.092E+05	NA	5.77E+02
NA	11-I	5.273E+05	4.207E+05	NA	<200
NA	2-I	7.578E+05	6.111E+05	NA	3.75E+02
27-D	NA	1.438E+06	1.077E+06	2.20E+04	NA
62-I	NA	8.698E+05	8.422E+05	2.00E+03	NA
NA	23-D	1.947E+06	1.112E+06	NA	1.30E+03
NA	68-I	1.091E+06	8.875E+05	NA	ND
NA	34-D	1.650E+06	8.886E+05	NA	<200
NA	69-I**	**	7.782E+05	NA	<200
NA	30-D	9.162E+05	6.358E+05	NA	1.49E+04
8-D*	NA	9.244E+05	9.272E+05	NA	NA
20-I*	NA	5.315E+05	5.140E+05	NA	NA
NA	37-D	1.884E+06	1.200E+06	NA	1.15E+03
NA	21-I	1.005E+06	7.390E+05	NA	1.55E+02
NA	73-I	6.270E+05	4.8889E+05	NA	4.57E+02
NA	36-D	9.807E+05	7.892E+05	NA	ND
74-D*	NA	1.531E+06	1.449E+06	NA	NA
33-I*	NA	7.544E+05	7.892E+05	NA	NA
NA	70-D	1.499E+06	1.235E+06	NA	6.84E+02
NA	19-I	7.909E+05	6.888E+05	NA	<200
NA	77-D	1.081E+06	6.430E+05	NA	ND

NOTE: Test coupons and control coupons are grouped together to represent the heat batches of the coupon contamination process.
* These control coupons were returned from 105-C to SRTC for re-weighing and counting during test delay. No smear measurements were made.
** No pre-blast measurements were made for Coupon 69-I.
NA – Not Applicable ND - Nondetectable

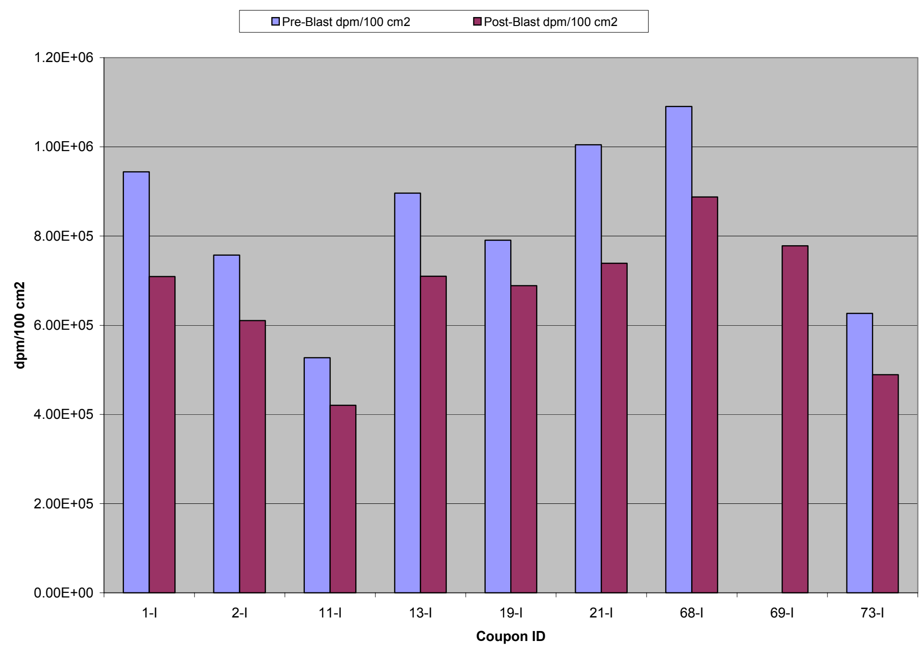


Figure 7. Pre- vs. Post-Blast Total Contamination - Indirect Coupons

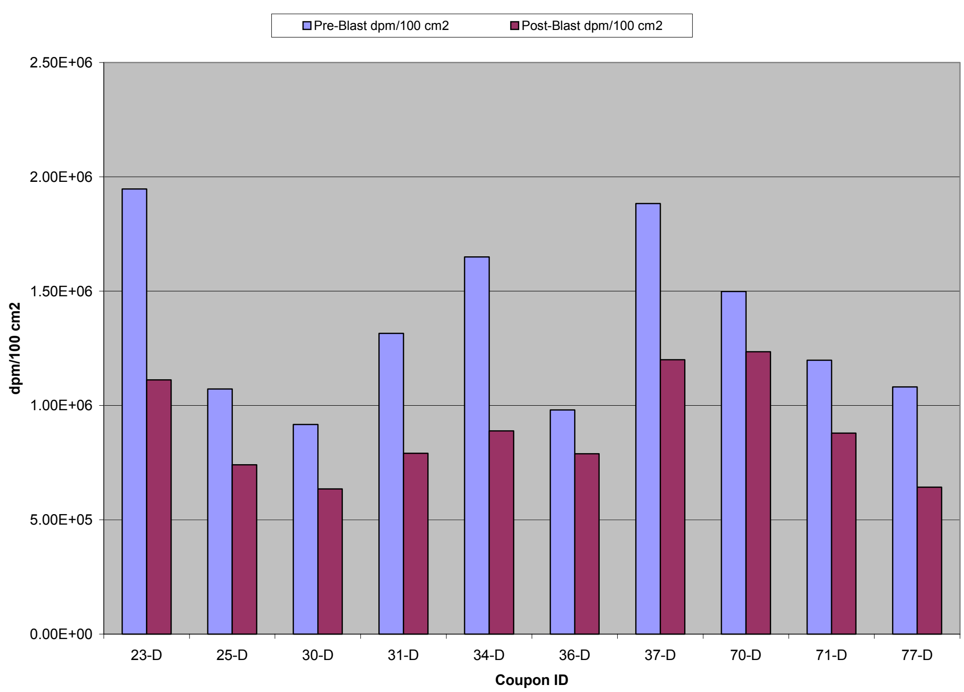


Figure 8. Pre- vs. Post-Blast Total Contamination - Direct Coupons

For directly contaminated coupons, no statistically significant differences were noted in contamination removal caused by changes in the four operating parameters. However, the total contamination levels were reduced from 17.6 – 46.2%. The pre-blast contamination level of on coupon, 22-D, appeared abnormally high compared to the other direct coupons. This may have been caused by a measurement error. The graph in Figure 8 is shown without this value.

Decontamination results reported for these tests were based on a single pass of the blasting nozzle across each side of the coupon. Additional passes may increase the decontamination efficiency to meet design limits.

As noted in the statistical design study of the test data, reproducibility of the blasting results for directly contaminated coupons is suspect because duplicate runs of identical blasting parameters did not produce the similar results. None of the clean coupons used to detect cross contamination during the blasting tests were contaminated as a result of the blasting or handling during the tests. After smearing, all coupons measured non-detectable.

It should be noted that the smearing method does not take into consideration that one side of the coupon may have considerably more smearable contamination than the other side. All coupons from these radioactive coupon tests were swiped on both sides using one wipe, therefore measuring levels for 100 cm^2. Equipment scale-up, if necessary to translate between laboratory-size coupons and full-size containers, was not explored as part of this work.

3.8.2 Indirectly Contaminated Coupon Results

During the development of the test matrix, the contamination method (direct or indirect) was not considered a factor in the blasting tests. Both direct and indirect coupons had smearable contamination and both were randomly selected as test coupons. Nine indirect and eleven direct coupons were used in the blasting tests. The test results indicate that the contamination method may have been a factor. All five coupons failing to meet criteria were direct coupons. All of the indirect coupons were successfully cleaned below contract and design limits of 2200 dpm/100 cm^2 and 1000 dpm/100 cm^2 respectively. Table 3 and Figure 9 summarize the results of the indirect coupons testing. The parameters shown in Table 3 bound those parameters proposed by the WTP Mechanical Handling group (Miller, D., CO_2 Decontamination System Parameters, Internal Memorandum 026860).

CO_2 blasting was successful in removing the smearable contamination on the indirectly contaminated coupons. As identified by the WTP Mechanical Handling group, the indirectly contaminated coupons are representative of the mechanism by which the ILAW containers will be contaminated during normal facility operations. The test matrix was not designed to test the two contamination methods separately and it should be noted that the nine indirectly contaminated coupons did not generate sufficient data to evaluate the cleaning efficiency over the full parametric window developed for this test. Assuming that the indirect method better represents the method of contamination, then the indirect test results may be used to evaluate the effectiveness of CO_2 blasting. Accordingly, the indirect results indicate successful decontamination at the parameter values tested by these nine coupons.

Table 3. Indirectly Contaminated Coupons

Coupon ID	Blast Pressure (psi)	Nozzle Distance (in)	Travel Speed (in/min)	Pellet Rate (lb/min)	Post-Blast Smearable (dpm/100 cm^2)	Smearable Removed *
69-I	120	2	30	2	<200	93%
11-I	100	6	30	2	<200	93%
19-I	100	6	70	2	<200	93%
2-I	120	6	70	2	375	86%
1-I	120	2	70	2	577	78%
73-I	120	6	30	5	457	83%
13-I	100	2	70	5	268	90%
21-I	100	2	30	5	<200	93%
68-I	120	6	70	5	<200	93%

* Note: The pre-blast smearable contamination level is calculated as the average of the three indirectly contaminated control coupons (Table 2).

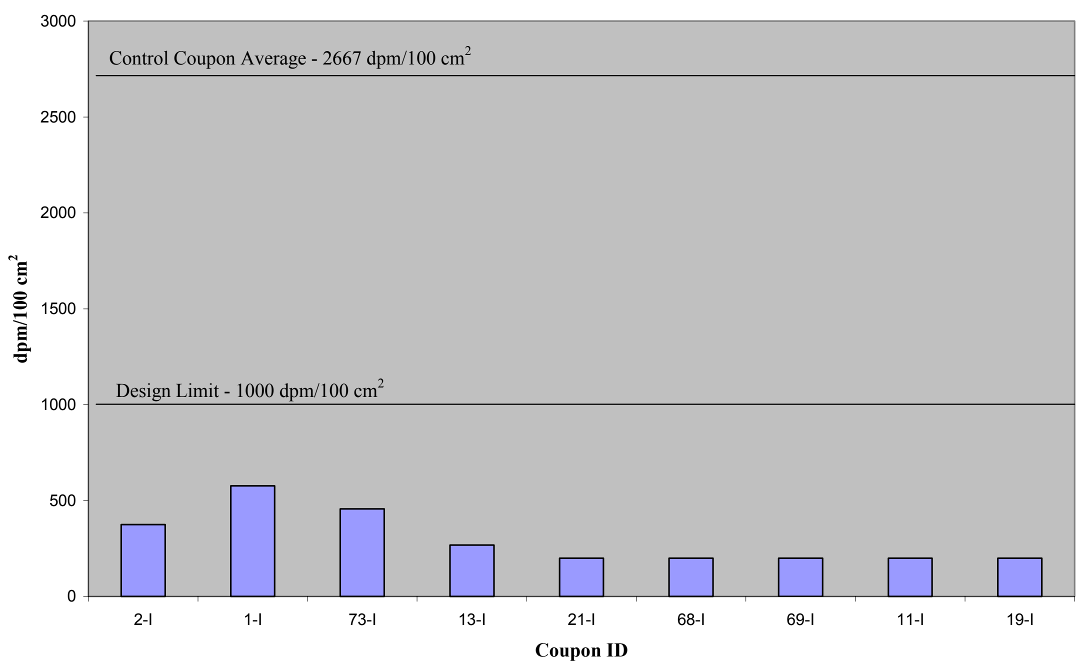


Figure 9. Indirectly Contaminated Coupons - Post-Blast Smearable Contamination

3.8.3 Weight Loss Results

Table B.1 lists the pre- and post-blast weights of both test and control coupons. The statistical comparison of the weights discussed in the statistical study (Appendix A) reveal:

- The weight losses of the blasted test coupons range from 0.0006 to 0.0082 g per coupon with an average weight loss of 0.0027 g per coupon. After subtracting the control coupons' average weight loss, the average loss per coupon is 0.0016 g, or approximately 0.1 mg/in^2.
- The weight changes of the control coupons range from –0.0031 g (gain) to 0.0040 g with an average 0.001100 g loss per coupon.
- There is no indication of a difference between the test and control coupon averages for either the pre- and post-blast weights.
- There is an indication of a statistically significant difference in the averages of the weight losses between the pre- and post-blasted test coupons.

The analysis of the measurements made on the test coupons and control coupons support the conclusion that CO_2 pellet blasting produces a statistically significant weight loss for the blasted coupons. There are no indications that changes in the blasting parameters, within the parameter window tested, have any effect on weight loss.

The weight loss models in the vendor tests were derived to provide insight into the important factor effects and possible interactions. The insight gained from the vendor's study helped to refine the parametric study for the radioactive coupon study. The model from the vendor tests was not intended to directly predict weight loss results from the radiological coupon study.

The weight loss models in the vendor tests and radiological coupon tests (no model was developed - effects were not statistically significant) were used to identify weight loss caused by changes in the blasting parameters or as interactions among the parameters. They were not to be used as a means to predict weight loss caused by the blasting process. The vendor tests and radiological coupon tests were conducted under completely different environments and should not be directly compared except to say that blasting caused significant weight losses in both cases.

3.8.4 High Speed Photography

The video images taken at the nozzle exit were used to calculate pellet velocity based on a field calibration and then converted into velocity units of Inches/Second and Feet/Second. A summary of the individual readings is provided in Table 4.

Table 4. Pellet Velocities

Tape #	Time on Tape (min/sec)	Number of Samples	Average Velocity (inches/sec)	Average Velocity (feet/sec)
3	9:00	53	6577.80	548.15
3	11:47	26	6481.82	540.15
3	14:41	37	6584.60	548.72
3	17:25	53	6665.21	555.43
3	20:34	43	6488.10	540.67
3	23:53	38	6400.49	533.37
3	0:26:51	41	6448.86	537.41
	Summary	291	6531.43	544.29

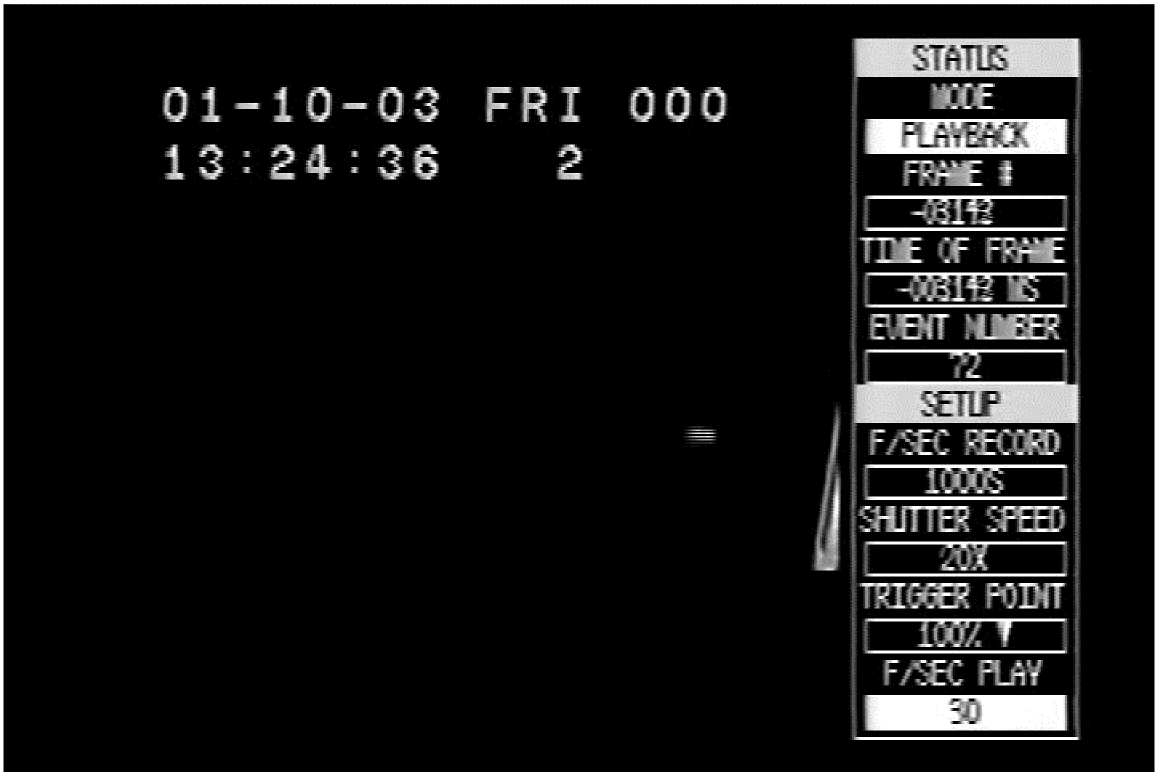
The results show good consistency between readings.. The pellet images reported are typical of images recorded at the highest camera speed. The absence of other pellets within a single image is typical at this image speed, with usually only one or two pellets present in each frame per unit time. The large quantity of pellets apparent to the human eye appear to be widely and evenly distributed when viewed at a speed of 1000 images per second.

The images seen in Figure 10 through Figure 17 are the consecutive images taken on a single pellet or group of pellets. The digital legends on the right of each scene show the image frequency (1000 of a second) and the length of the time the electronic shutter was open (1/20 of 1000 of a second or 1/20,000 of a second). The visual stop action can be seen as the pellet(s) move from left to right. The readings reported in Table 4 were based solely on pellets that could be clearly depicted in two consecutive images within the camera's field of view. The leading edge of the CO_2 blasting nozzle can be seen in the image.

The evaluation of the size and condition of the pellets after being transported through the blasting unit's air delivery system and nozzle yielded some unexpected results. The still images of the pellets at medium and high magnification do not fully convey what is shown on the video clip. The CO_2 particles that exit the nozzle are a mixture of intact pellets and fragmented pellets. The combination of the particle velocity and small size, which requires high magnification to image, results in only one or the other (i.e., intact pellets or pieces) being seen in one of the magnifications.

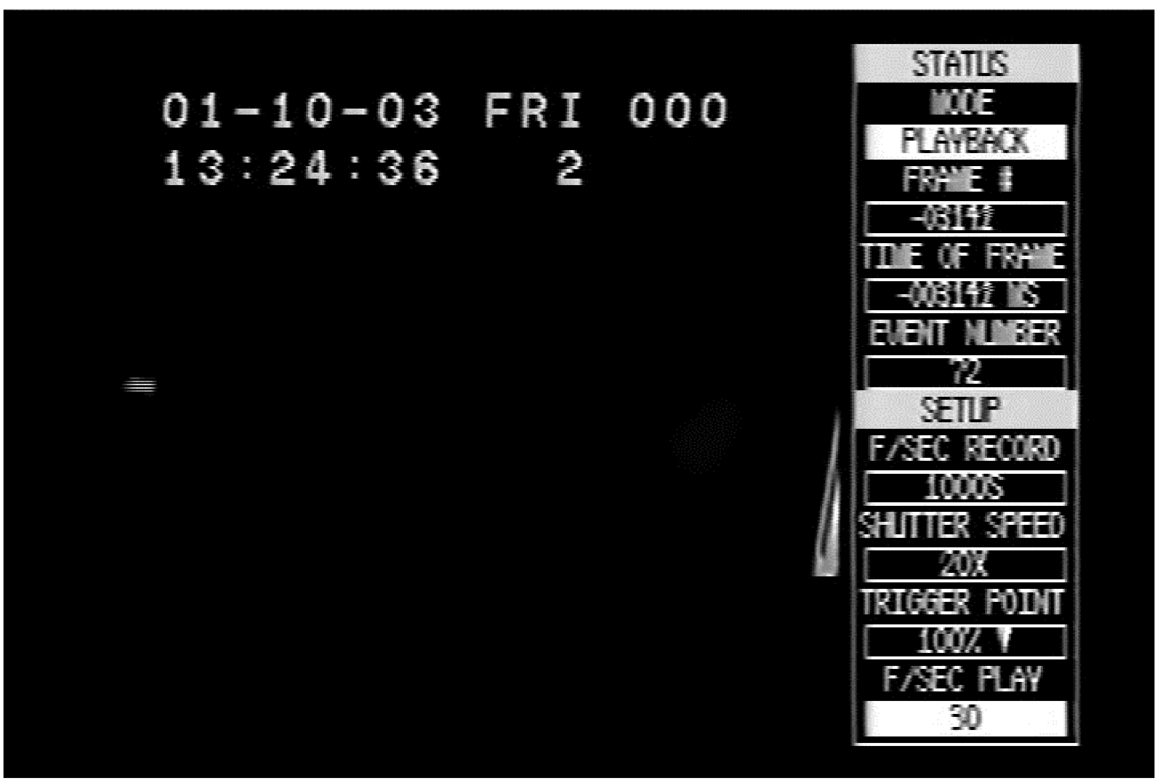
In the low magnification images, Figure 10 - Figure 13, the intact pellets can be seen clearly. In the highest magnification, Figure 14 - Figure 17, the small pieces can be clearly seen; however, at the higher magnification is it very difficult to capture a pellet image.

The average particle size in the highest magnification is approximately 0.025". Particles approximately 0.125" are shown in lower magnifications. The medium magnification images show some of the mixture of particles and pellets. Since the pellet orientation in the photographs is unknown, specific length and width cannot be specified.



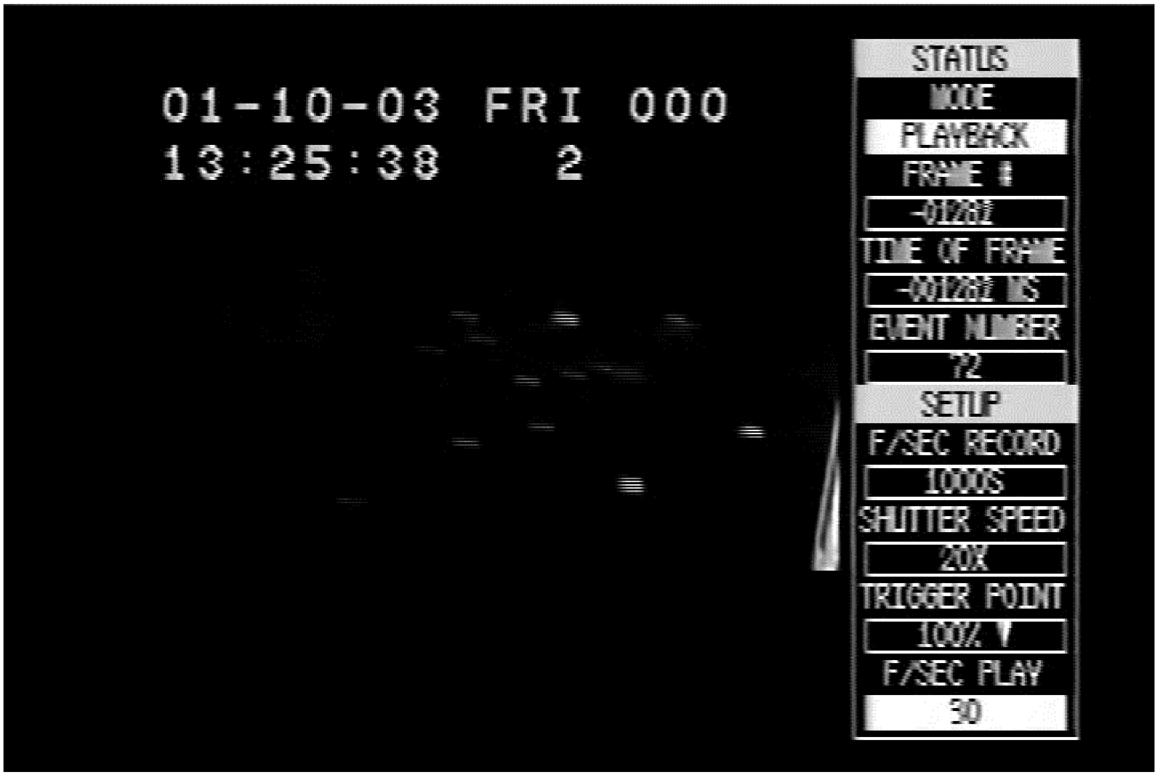
|………..SIX..INCHES………|

Figure 10. Typical Pellet in Flight, Entering from Right (Low Magnification)



|………..SIX..INCHES………|

Figure 11. Typical Pellet in Flight - Exiting to Left (Low Magnification)



|………..SIX..INCHES………|

Figure 12. Typical Pellet Group in Flight - Entering from Right (Low Magnification)

|………..SIX..INCHES………|

Figure 13. Typical Pellet Group in Flight - Exiting to Left (Low Magnification)

|.ONE.INCH.|

Figure 14. Typical Medium Magnification Pellet Fragments - Example 1

|.ONE.INCH.|

Figure 15. Typical Medium Magnification Pellet Fragments - Example 2

|………………ONE..INCH………………|

Figure 16. Typical High Magnification Pellet Fragments - Example 1

|………………ONE..INCH………………|

Figure 17. Typical High Magnification Pellet Fragments - Example 2

3.8.5 Bleeding Tests

Nine indirectly contaminated coupons were used in the bleeding tests. Both sides of each coupon were smeared for smearable contamination when the coupons were removed at the 23-day intervals. The coupon sides were identified as Top or T (coupon side with the stamped identification number and side facing up in the holding rack) and Bottom or B (side opposite stamped identification and side facing down in the holding rack). Prior to the start of the bleeding tests, the smearable contamination on the coupons was cleaned to non-detectable levels and the fixed contamination levels measured to ensure fixed contamination was present on each coupon. The smearable contamination levels of the coupons removed from the bleeding tests and the initial fixed contamination levels are listed in Table 5.

Fixed contamination did not bleed from either side of three coupons. Three other coupons had bleeding from one side of the coupon. No coupon had bleeding that exceeded the 1000 dpm/100cm^2 design limit.

Figure 18 and Figure 19 represent plots of the smearable contamination, initial fixed contamination, and bleeding time in days. There does not appear to be a definite relationship among the data.

None of the clean control coupons placed in the holding rack with the contaminated coupons were cross-contaminated during the bleeding period.

Table 5. Bleeding Test Data

Coupon ID	Bleeding Time days	Smearable dpm/side (50 cm^2 per side)	Fixed dpm/side
13I-T	23	301	4.20E+05
13I-B	23	453	4.40E+05
21I-T	23	228	4.00E+05
21I-B	23	<200	3.80E+05
1I-T	45	<200	4.40E+05
1I-B	45	<200	3.40E+05
19I-T	45	<200	2.20E+05
19I-B	45	<200	6.00E+05
69I-T	70	453	4.80E+05
69I-B	70	<200	5.00E+05
11I-T	70	<200	1.40E+05
11I-B	70	<200	4.40E+05
68I-T	92	599	5.00E+05
68I-B	92	294	4.20E+05
2I-T	92	258	2.40E+05
2I-B	92	<200	5.00E+05
73I-T	92	221	1.60E+05
73I-B	92	209	3.00E+05

NOTE: T = Top (ID side of coupon) B = Bottom (Opposite side of ID)

3.8.6 Sound Levels

Sound level surveys were made at a 3-ft distance from the blasting nozzle for each of the blasting pressures used during the tests. The results of the survey are recorded in Table 6. Hearing protection was required inside the 16 ft x 16 ft blasting hut, but not outside the hut where the PLT-5X control panel was located.

Table 6. Sound Levels During Blasting

Blasting Pressure (psi)	Sound Level (dB)
100	116
110	117
120	119

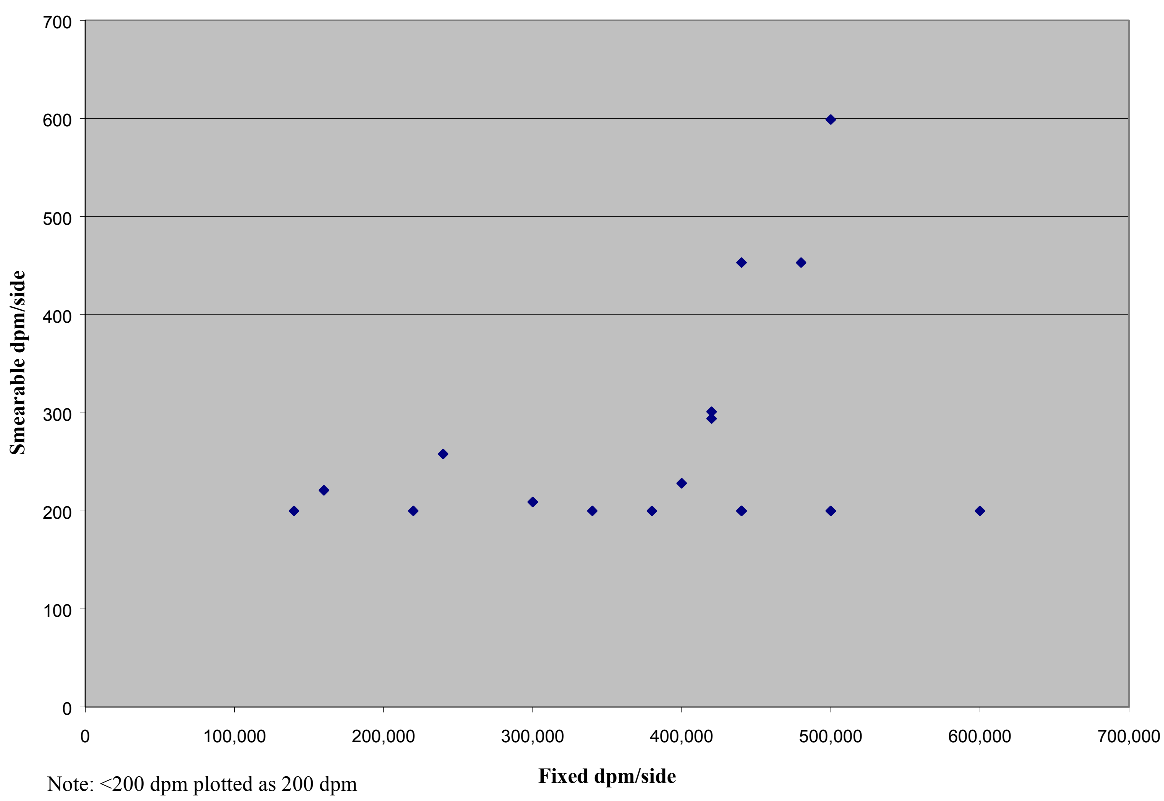


Figure 18. Bleeding Test Smearable Contamination vs. Fixed Contamination

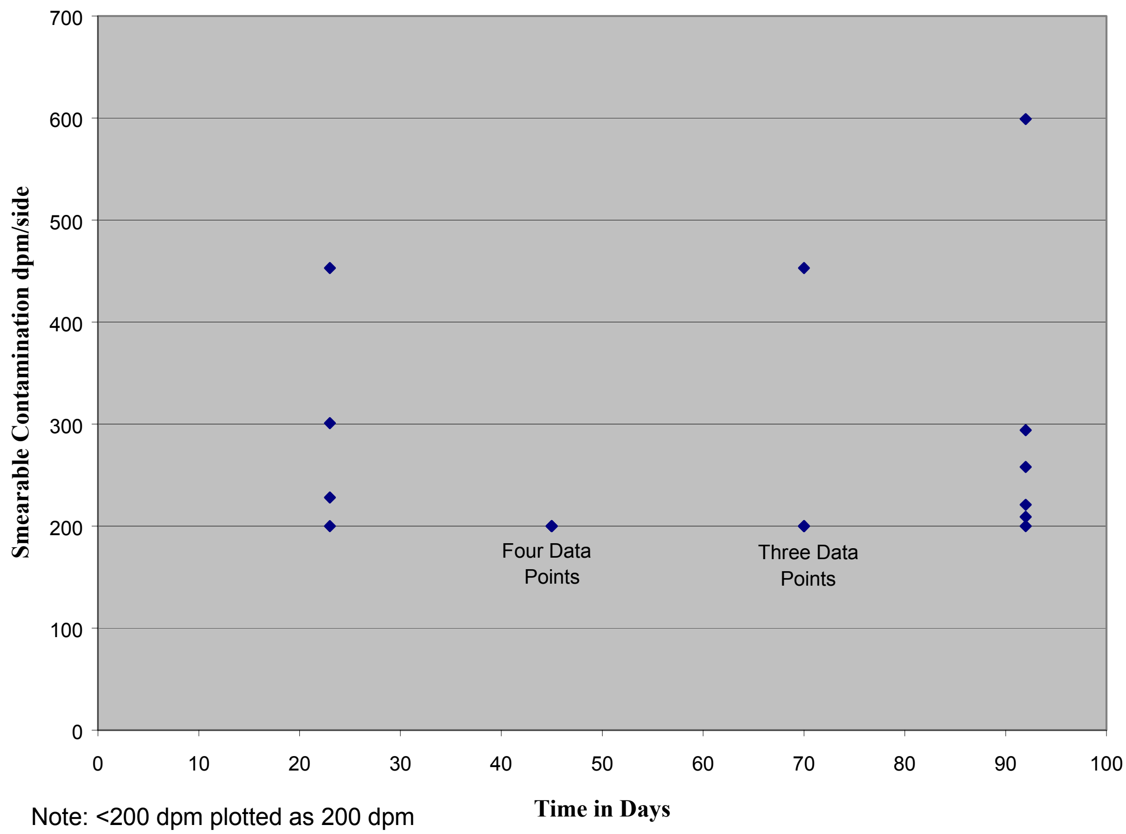


Figure 19. Bleeding Tests Smearable vs. Bleed Time

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4.0 FUTURE WORK

No future work is planned at this time.

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5.0 REFERENCES

1. Prindiville, K., LAW Radioactive Coupon CO_2 Decontamination Test, 24590-LAW-TSP-RT-02-005, Rev 1, 4/30/03.

2. Prindiville, K., Test Exception to LAW Radioactive Coupon CO_2 Blasting Tests, 24590-WTP-TEF-RT-03-008, Rev 0, 2/2/03.

3. May, C. G., "LAW Radioactive Coupon CO_2 Blasting Tests," WSRC-TR-2001-00154, SRT-RPP-2001-00001, Rev 0, 8/21/02.

4. Prindiville, K., Test Exception to LAW Radioactive Coupon CO_2 Blasting Tests, 24590-WTP-TEF-RT-02-066, Rev 0, 11/5/02.

5. Miller, D., CO_2 Decontamination System Parameters, Internal Memorandum 026860.

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SRS savannah river site

WESTINGHOUSE SAVANNAH RIVER COMPANY

INTEROFFICE MEMORANDUM

SRT-SCS-2003-00006
Revision 1

September 3, 2003

To: C. G. May, 773-42A

cc: S. P Harris, 773-42A
R. C. Tuckfield, 773-42A

From: T. B. Edwards, 773-42A, 5-5148
Statistical Consulting Section

S. P. Harris, Technical Reviewer — Date: 9/3/2003

R. C. Tuckfield, Manager
Statistical Consulting Section — Date: 9/3/2003

A Statistical Analysis of the Data from the Radioactive Coupon Testing of CO_2 Blasting to Remove Surface Contamination (U)

INTRODUCTION

The Savannah River Technology Center (SRTC) has prepared a test plan [1] in response to a test specification [2] for the River Protection Project (RPP) Waste Treatment Plant (WTP). The primary objective of the requested study is to confirm that CO_2 blasting is capable of effectively removing smearable contamination from the external surface of Immobilized Low-Actively Waste (ILAW) stainless steel containers. Radioactive coupon tests were performed as part of the effort to meet this objective.

Four factors were studied as part of this testing: pellet rate, travel speed, nozzle standoff distance, and blasting air pressure. These factors are continuous variables in that each may take any value in an interval of possible values bounded by low and high extremes. Even though pellet rate is a continuous factor, only the low and high extremes (i.e., only two levels) of the possible interval of values for this factor were considered in these tests. A statistically designed set of experimental trials [3] was developed to cover the factor space of interest for these variables. This work was performed under an SRS QA Program that has been determined to be responsive to NQA-1 (1989) and NQA-2A (1990), Part 2.7 as required by contractual agreement with WTP-RPP.

Coupons were fabricated from material representative of that used for ILAW stainless steel containers. As part of the test plan, a process was developed that consistently delivered an adequate level of contamination to the surface of these coupons. A set of control coupons was subjected to the contamination process as part of the blasting tests. The levels of contamination for the control coupons were measured by the prototypic smearing technique that also was used for the coupons that were blasted. Statistical analyses of the data resulting from these tests are provided in this memorandum to evaluate the consistency and adequacy of the contamination for the coupons being subjected to the CO_2 blasting tests.

DISCUSSION

In this section, the data resulting from these radioactive coupon tests are presented and statistically evaluated to address questions of interest for this task. Although not of primary interest, the first set of data investigated is the measured weights of the coupons, both test and control. Differences between the initial and final (pre- and post-blasting for the test coupons) weights for coupons in these two groups are studied as well as the size of these differences for the test coupon relative to the four experimental factors. The second set of data considered in this section involves measurements of the radioactive contamination levels of the test coupons. For these data, statistical comparisons are conducted to investigate for effects due to the two methods (i.e., direct and indirect) for delivering the contamination. The relative differences between the initial and final (pre- and post-blasting) contamination levels for the test coupons are studied relative to the four experimental factors. Finally, the data of primary interest, the levels of smearable contamination measured on the blasted coupons, are investigated relative to the acceptance criterion of a smearable amount of no more than 1000 dpm/100 cm^2. In addition, the repeatability of the experimental process is investigated, and the amount of smearable contamination remaining on the coupons versus the levels of the four experimental factors is investigated. The statistical analyses generated to support these investigations were conducted using JMP® Version 5.0 [4] (see [5] for information on verification and validation of JMP). The software is commercial software and is considered to have a level D software classification as defined in the WSRC 1Q Quality Assurance Manual, QAP 20-1, Rev 6.

Coupon Weights

Although not a primary measurement of interest, the weights of the test coupons were measured before and after the coupons were blasted. For the control coupons, they were packaged, shipped, and unpacked along with the test coupons. The weight of each control coupon was recorded twice for each coupon in a manner consistent with that used for the test coupons. These measurements are provided in Table 1. Included in this table are contamination method (either direct or indirect), type (test or control), test ID, coupon ID, an initial weight, two final weights along with their average, and the difference between the initial and final (average) weight.

Table 1. Radioactive Coupon Test Data Covering Weights

(Weights are in grams, g; NA – not applicable)

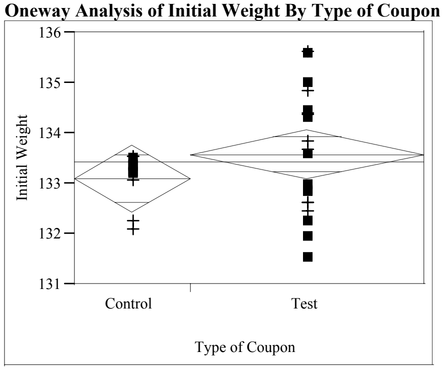
Contamination Method	Type of Coupon	Test ID	Coupon ID	Initial Weight	Final Weight-1	Final Weight-2	Final Weight Average	Weight Difference
Indirect	Test	hc11	1-I	132.6347	132.6336	132.6341	132.6339	0.0009
Indirect	Test	hc05	11-I	134.3951	134.3926	134.3934	134.3930	0.0021
Indirect	Test	hc04	13-I	134.3681	134.3663	134.3668	134.3666	0.0015
Indirect	Test	hc07	19-I	133.6735	133.6699	133.6699	133.6699	0.0036
Indirect	Test	hc15	2-I	134.8565	134.8557	134.8556	134.8557	0.0008
Indirect	Test	hc02	21-I	135.6137	135.6080	135.6084	135.6082	0.0055
Direct	Test	hc18	22-D	134.4295	134.4284	134.4282	134.4283	0.0012
Direct	Test	hc03	23-D	134.9914	134.9898	134.9904	134.9901	0.0013
Direct	Test	hc06	25-D	134.2953	134.2947	134.2945	134.2946	0.0007
Direct	Test	hc17	30-D	132.2399	132.2372	132.2380	132.2376	0.0023
Direct	Test	hc19	31-D	131.5277	131.5271	131.5272	131.5272	0.0006
Direct	Test	hc08	34-D	132.8569	132.8543	132.8550	132.8547	0.0023
Direct	Test	hc20	36-D	133.5642	133.5578	133.5578	133.5578	0.0064
Direct	Test	hc01	37-D	132.8066	132.8005	132.8010	132.8008	0.0059
Indirect	Test	hc16	68-I	132.4606	132.4590	132.4591	132.4591	0.0016
Indirect	Test	hc09	69-I	132.6227	132.6213	132.6218	132.6216	0.0011
Direct	Test	hc13	70-D	131.9345	131.9314	131.9310	131.9312	0.0033
Direct	Test	hc12	71-D	135.5557	135.5532	135.5534	135.5533	0.0024
Indirect	Test	hc14	73-I	133.8520	133.8434	133.8441	133.8438	0.0083
Direct	Test	hc10	77-D	132.9705	132.9675	132.9676	132.9676	0.0029
Indirect	Control	NA	17-I	133.5412	133.5404	133.5404	133.5404	0.0008
Direct	Control	NA	39-D	133.3588	133.3582	133.3582	133.3582	0.0006
Direct	Control	NA	27-D	133.1943	133.1928	133.1933	133.1931	0.0012
Indirect	Control	NA	62-I	133.5362	133.5350	133.5356	133.5353	0.0009
Direct	Control	NA	29-D	133.4909	133.4891	133.4893	133.4892	0.0017
Indirect	Control	NA	3-I	133.0625	133.0691	133.0620	133.0656	-0.0031
Direct	Control	NA	74-D	133.2041	133.2000	133.2002	133.2001	0.0040
Indirect	Control	NA	20-I	132.2560	132.2546	132.2540	132.2543	0.0017
Indirect	Control	NA	33-I	132.0947	132.0935	132.0934	132.0935	0.0012
Direct	Control	NA	8-D	133.3225	133.3204	133.3205	133.3205	0.0020

Figure 1 provides statistical comparisons, generated using the "Fit Y by X" platform of JMP, of the initial weights, final (average) weights, and weight differences by type of coupon. Included in these results are t-tests and corresponding analyses of variance (ANOVA's) tables that provide statistical tests for equality of means for these sets of weight measurements between the test and control coupons. At a 5% significance level, there is no indication of a difference in the averages of the initial weights for the test versus control coupons and no indication of a difference in the averages of the final weights of the two groups. However, there is an indication of a statistically significant difference (at approximately a 5% significance level) in the averages of the weight differences (initial minus final) for the two groups. Thus, there appears to be a statistically significant average weight change between the initial and final weights of the test coupons that is not seen in the control coupons.

Figure 1. Weight Comparisons Between Test and Control Coupons

(In this figure and throughout this memo, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Oneway Analysis of Initial Weight By Type of Coupon



Oneway Anova
Summary of Fit

Rsquare	0.048105
Adj Rsquare	0.014109
Root Mean Square Error	1.033915
Mean of Response	133.4237
Observations (or Sum Wgts)	30

t Test

Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	-0.47634	-1.190	28	0.2442
Std Error	0.40043			
Lower 95%	-1.29659			
Upper 95%	0.34392			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	-0.4763	-1.513	27.6496	0.1416
Std Error	0.3148			
Lower 95%	-1.2971			
Upper 95%	0.3444			

Analysis of Variance

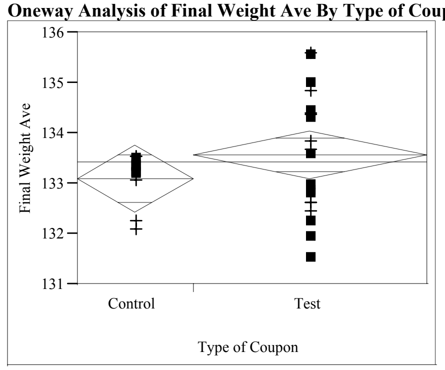
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Coupon	1	1.512634	1.51263	1.4150	0.2442
Error	28	29.931474	1.06898		
C. Total	29	31.444107			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Control	10	133.106	0.32695	132.44	133.78
Test	20	133.582	0.23119	133.11	134.06

Std Error uses a pooled estimate of error variance

Oneway Analysis of Final Weight Ave By Type of Coupon



Oneway Anova
Summary of Fit

Rsquare	0.04766
Adj Rsquare	0.013647
Root Mean Square Error	1.034164
Mean of Response	133.4211
Observations (or Sum Wgts)	30

t Test

Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	-0.47413	-1.184	28	0.2465
Std Error	0.40053			
Lower 95%	-1.29457			
Upper 95%	0.34632			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	-0.4741	-1.506	27.6485	0.1435
Std Error	0.3149			
Lower 95%	-1.2950			
Upper 95%	0.3468			

Analysis of Variance

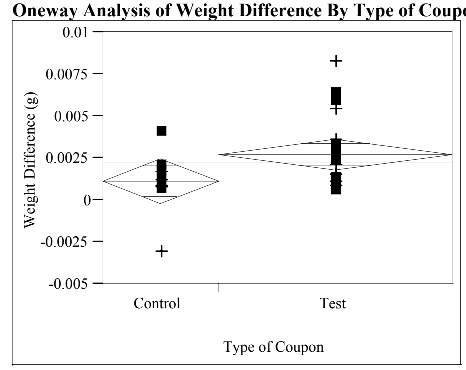
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Coupon	1	1.498630	1.49863	1.4012	0.2465
Error	28	29.945869	1.06950		
C. Total	29	31.444499			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Control	10	133.105	0.32703	132.44	133.77
Test	20	133.579	0.23125	133.11	134.05

Std Error uses a pooled estimate of error variance

Oneway Analysis of Weight Difference By Type of Coupon



Oneway Anova
Summary of Fit

Rsquare	0.128995
Adj Rsquare	0.097888
Root Mean Square Error	0.002041
Mean of Response	0.002193
Observations (or Sum Wgts)	30

t Test

Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	-0.00161	-2.036	28	0.0513
Std Error	0.00079			
Lower 95%	-0.00323			
Upper 95%	0.00001			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	-0.00161	-2.187	21.9106	0.0397
Std Error	0.00074			
Lower 95%	-0.00325			
Upper 95%	0.00003			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Coupon	1	0.00001728	0.000017	4.1468	0.0513
Error	28	0.00011668	0.000004		
C. Total	29	0.00013396			

Means for Oneway Anova

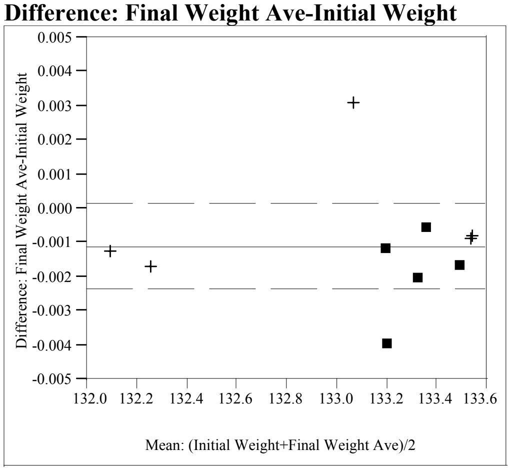
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Control	10	0.001120	0.00065	-0.0002	0.00244
Test	20	0.002730	0.00046	0.0018	0.00367

Std Error uses a pooled estimate of error variance

The initial and final weights of the test coupons correspond directly to the pre- and post-blasting weights for these coupons. Thus, the statistically significant average weight change between the initial and final weights of the test coupons (that is not seen in the control coupons) suggests that the blasting process was responsible (since the control coupons did not undergo any blasting). Figure 2 provides additional information (results generating using the "Matched Pairs" platform of JMP) in support of this conclusion. In the figure, the initial and final weights of the control and test coupons are considered in turn. The statistical tests indicate that, at a 5% significance level, the average difference between initial and final weights of the control coupons are not statistically significant while the average difference between the initial and final weights of the test coupons is statistically significant. Thus, the measurements taken on the weights of the test and control coupons suggest that the blasting process did lead to statistically significant weight losses for the test conditions (i.e., the factor levels) studied here.

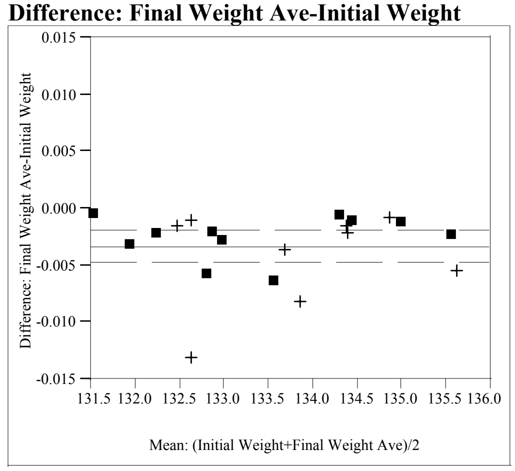
Figure 2. Paired Comparisons between the Initial vs Final Weights by Type of Coupon
(Weights are in grams (g) and a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Type of Coupon=Control
Matched Pairs
Difference: Final Weight Ave-Initial Weight



Final Weight Ave	133.105	t-Ratio	-1.98708
Initial Weight	133.106	DF	9
Mean Difference	-0.0011	Prob > |t|	0.0782
Std Error	0.00056	Prob > t	0.9609
Upper95%	0.00015	Prob < t	0.0391
Lower95%	-0.0024		
N	10		
Correlation	0.99999		

Type of Coupon=Test
Matched Pairs
Difference: Final Weight Ave-Initial Weight



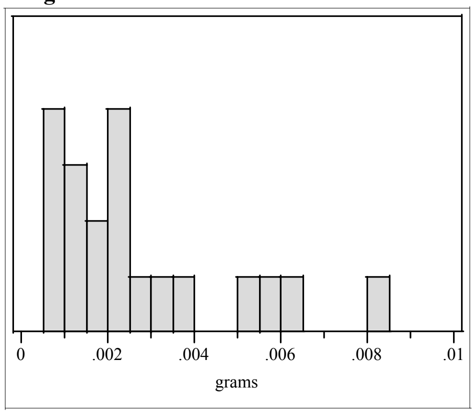
Final Weight Ave	133.579	t-Ratio	-4.745
Initial Weight	133.582	DF	19
Mean Difference	-0.0033	Prob > |t|	0.0001
Std Error	0.0007	Prob > t	0.9999
Upper95%	-0.0019	Prob < t	<.0001
Lower95%	-0.0048		
N	20		
Correlation	1		

Coupon Weight Loss and Experimental Design

The results of the previous section suggest that the CO_2 blasting process did remove (statistically significant amounts of) surface material from the test coupons. Figure 3 provides a histogram and corresponding summary statistics for the weight loss values of the 20 test coupons.

Figure 3. Weight Loss Summary Statistics for the Test Coupons
(Weights are in grams, g)

Weight Difference



Quantiles

100.0%	maximum	0.00825
99.5%		0.00825
97.5%		0.00825
90.0%		0.00635
75.0%	quartile	0.00352
50.0%	median	0.00218
25.0%	quartile	0.00116
10.0%		0.00071
2.5%		0.00055
0.5%		0.00055
0.0%	minimum	0.00055

Moments

Mean	0.00273
Std Dev	0.0021644
Std Err Mean	0.000484
upper 95% Mean	0.003743
lower 95% Mean	0.001717
N	20

Thus, the weight losses seen in these tests covered an interval from 0.0006 to 0.0082 g per coupon with an average weight loss of 0.0027 g per coupon. Four factors were studied in this set of trials and the supporting experimental design (along with the corresponding weight loss data) is provided in Table 2.

Table 2. Coded Experimental Design and Weight Loss Results

Contamination Method	Coupon ID	Test ID	Blast Air Pressure (coded)	Nozzle Standoff Distance (coded)	Travel Speed (coded)	Pellet Rate (coded)	Weight Loss (g)
Direct	37-D	hc01	-1	-1	-1	-1	0.0059
Indirect	21-I	hc02	-1	-1	-1	1	0.0055
Direct	23-D	hc03	-1	-1	1	-1	0.0013
Indirect	13-I	hc04	-1	-1	1	1	0.0016
Indirect	11-I	hc05	-1	1	-1	-1	0.0021
Direct	25-D	hc06	-1	1	-1	1	0.0007
Indirect	19-I	hc07	-1	1	1	-1	0.0036
Direct	34-D	hc08	-1	1	1	1	0.0023
Indirect	69-I	hc09	1	-1	-1	-1	0.0012
Direct	77-D	hc10	1	-1	-1	1	0.0030
Indirect	1-I	hc11	1	-1	1	-1	0.0009
Direct	71-D	hc12	1	-1	1	1	0.0024
Direct	70-D	hc13	1	1	-1	-1	0.0033
Indirect	73-I	hc14	1	1	-1	1	0.0083
Indirect	2-I	hc15	1	1	1	-1	0.0009
Indirect	68-I	hc16	1	1	1	1	0.0016
Direct	30-D	hc17	0	0	0	-1	0.0023
Direct	22-D	hc18	0	0	0	-1	0.0012
Direct	31-D	hc19	0	0	0	1	0.0006
Direct	36-D	hc20	0	0	0	1	0.0064

A statistical model was used to investigate for possible effects of the factors controlled in this study on these amounts of removed surface material. The model was of the form given in equation (1).

Equation 1.

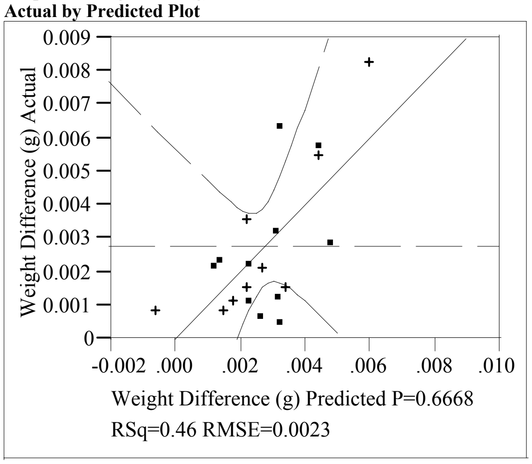
$$
\begin{aligned}
y_{RESPONSE} = {} & \beta_0 + \beta_1 \text{ (pellet rate)} + \beta_2 \text{ (travel speed)} + \beta_3 \text{ (nozzle standoff distance)} \\
& + \beta_4 \text{ (blasting air pressure)} \\
& + \beta_5 \text{ (pellet rate)(travel speed)} \\
& + \beta_6 \text{ (pellet rate) (nozzle standoff distance)} \\
& + \beta_7 \text{ (pellet rate) (blasting air pressure)} \\
& + \beta_8 \text{ (travel speed) (nozzle standoff distance)} \\
& + \beta_9 \text{ (travel speed) (blasting air pressure)} \\
& + \beta_{10} \text{ (nozzle standoff distance) (blasting air pressure)} + \varepsilon
\end{aligned}
$$

In equation (1), y is used to represent a response of interest (in this case weight loss), ε represents the modeling error term, and the β's represent unknown coefficients in the model. These unknown coefficients, which may or may not be of statistical and/or practical importance, are to be estimated from the data generated from these tests. Figure 4 provides the results generated by JMP from the fitting of equation (1) to the weight loss data.

Figure 4. Weight Loss versus Processing Factors for the Test Coupons

(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Response Weight Loss (g)
Actual by Predicted Plot



Summary of Fit

RSquare	0.456559
RSquare Adj	-0.14727
Root Mean Square Error	0.002318
Mean of Response	0.00273
Observations (or Sum Wgts)	20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	0.00004064	0.0000041	0.7561
Error	9	0.00004837	0.0000054	Prob > F
C. Total	19	0.00008901		0.6668

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	7	0.00003065	0.0000044	0.4944
Pure Error	2	0.00001772	0.0000089	Prob > F
Total Error	9	0.00004837		0.7974
				Max RSq
				0.8010

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.00273	0.000518	5.27	0.0005
blast pressure	-0.000097	0.00058	-0.17	0.8709
nozzle standoff distance	0.0000656	0.00058	0.11	0.9123
blast pressure*nozzle standoff distance	0.0007594	0.00058	1.31	0.2226
travel speed	-0.000966	0.00058	-1.67	0.1300
blast pressure*travel speed	-0.000284	0.00058	-0.49	0.6354
nozzle standoff distance*travel speed	0.0002031	0.00058	0.35	0.7340
pellet rate	0.00048	0.000518	0.93	0.3786
blast pressure*pellet rate	0.0007406	0.00058	1.28	0.2333
nozzle standoff distance*pellet rate	-0.000022	0.00058	-0.04	0.9707
travel speed*pellet rate	-0.000241	0.00058	-0.42	0.6877

As seen by all of the p-values (the values in the column with the heading "Prob>t" in the figure) being greater than 0.05, there are no statistically significant (at a 5% significance level) terms in the fitted equation. That is, there appears to no relationship between the factors under investigation in this and the amount of weight loss, the amount of surface material removed by blasting. Or stated another way, there was statistically significant weight loss for the test coupons which is attributed to the blasting; but within the parametric window studied, the amount of weight loss is statistically the same relative to the factor settings explored in this investigation.

Test and Control Coupon Contamination versus Contamination Method

The protocol used to contaminate coupons (both test and control) for this study involved a group of the coupons, at a time, being placed in a sealed container in a furnace. Several of the coupons in the group were directly contaminated and the remaining coupons in the group were contaminated (indirectly) via vaporization as the sealed container was heated. The coupon identifiers (IDs) reflect the contamination method via a suffix of "I" for indirect or "D" for direct. In this section, measurement data associated with the contamination of the coupons (both test and control) are investigated for significance differences due to the contamination method. These data are presented in Table 3, which provides descriptive columns as well as contamination levels in counts per minute before and after blasting and smearable contamination in dpm/100 cm^2 after blasting for the test coupons and without blasting for the control coupons.

Table 3. Contamination Measurements for Test and Control Coupons

(NA – Not Applicable)

Contamination Method	Type of Coupon	Test ID	Coupon ID	Before Blasting Process - Counts/min	After Blasting Process - Counts/min	After Blasting Process - Smear dpm/100 cm^2
Indirect	Test	hc11	1-I	1711	1285	577
Indirect	Test	hc05	11-I	955.5	762.2	<200
Indirect	Test	hc04	13-I	1624	1286	268
Indirect	Test	hc07	19-I	1433	1248	<200
Indirect	Test	hc15	2-I	1373	1107	375
Indirect	Test	hc02	21-I	1821	1339	155
Direct	Test	hc18	22-D	60560	3872	3671
Direct	Test	hc03	23-D	3528	2015	1302
Direct	Test	hc06	25-D	1944	1342	<200
Direct	Test	hc17	30-D	1660	1152	14900
Direct	Test	hc19	31-D	2384	1434	34500
Direct	Test	hc08	34-D	2989	1610	<200
Direct	Test	hc20	36-D	1777	1430	None Detected
Direct	Test	hc01	37-D	3413	2175	1150
Indirect	Test	hc16	68-I	1976	1608	None Detected
Indirect	Test	hc09	69-I	Not Measured	1410	<200
Direct	Test	hc13	70-D	2716	2238	684
Direct	Test	hc12	71-D	2170	1593	None Detected
Indirect	Test	hc14	73-I	1136	885.9	457
Direct	Test	hc10	77-D	1959	1165	None Detected
Indirect	Control	NA	17-I	1198	1129	2000
Indirect	Control	NA	20-I	963.0	931.4	Not Measured
Direct	Control	NA	27-D	2606	1952	22000
Direct	Control	NA	29-D	2743	1760	60000
Indirect	Control	NA	3-I	1495	1273	4000
Indirect	Control	NA	33-I	1367	1430	Not Measured
Direct	Control	NA	39-D	2642	2397	22000
Indirect	Control	NA	62-I	1576	1526	2000
Direct	Control	NA	74-D	2674	2626	Not Measured
Direct	Control	NA	8-D	1675	1680	Not Measured

Note that the control coupons did not participate in the blasting process and their contamination levels reflect only influences due to the contamination methods and the handling and shipping during this testing. Also, note that the smearable contamination was not measured for 4 of the control coupons. Finally, the post-blasting data were taken after the smears were taken.

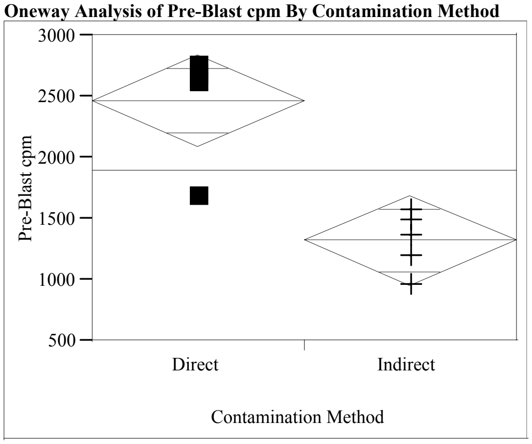
Figure 5 provides comparisons of the pre-blast contamination measurements (reported in counts per minute, cpm) per coupon from the directly and indirectly contaminated coupons for each group (i.e., test and control) of coupons. For the control coupons, there does appear to be a statistically significant (at the 5% significance level) difference in the mean contamination levels delivered (i.e., the pre-blast levels) by the direct and indirect methods. For the test coupons, there does not appear to be a statistically significant (at the 5% significance level) difference in these means. The same comparisons were conducted in the natural logarithms of the pre-blast contamination measurements. These results, which are not shown here, indicate that the contamination delivered by the direct method as seen in the log values is statistically higher, on average, than that delivered by the indirect method for both the control and the test coupons.

Figure 5. Pre-Blast Contamination by Contamination Method and Coupon Group

(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Type of Coupon=Control

Oneway Analysis of Pre-Blast cpm By Contamination Method



Oneway Anova

Summary of Fit

Rsquare	0.760681
Adj Rsquare	0.730766
Root Mean Square Error	360.0231
Mean of Response	1893.9
Observations (or Sum Wgts)	10

t Test

Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	1148.20	5.043	8	0.0010
Std Error	227.70			
Lower 95%	623.13			
Upper 95%	1673.27			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	1148.20	5.043	6.21592	0.0021
Std Error	227.70			
Lower 95%	595.70			
Upper 95%	1700.70			

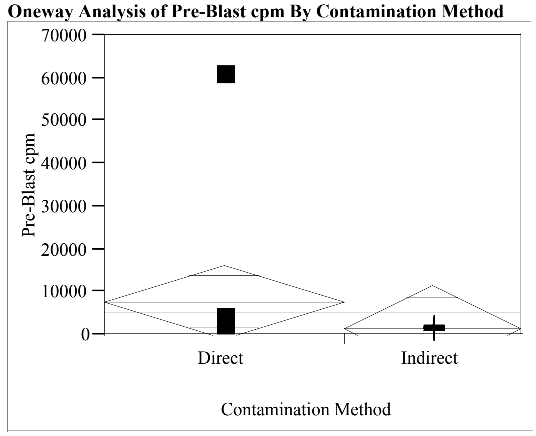
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Direct	5	2468.00	161.01	2096.7	2839.3
Indirect	5	1319.80	161.01	948.5	1691.1

Std Error uses a pooled estimate of error variance

Type of Coupon=Test

Oneway Analysis of Pre-Blast cpm By Contamination Method



Oneway Anova

Summary of Fit

Rsquare	0.055288
Adj Rsquare	-0.00028
Root Mean Square Error	13447.76
Mean of Response	5112.079
Observations (or Sum Wgts)	19

t Test

Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	6232.68	0.997	17	0.3325
Std Error	6248.64			
Lower 95%	-6950.80			
Upper 95%	19416.15			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	6233	1.179	10.0107	0.2657
Std Error	5287			
Lower 95%	-7688			
Upper 95%	20153			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Direct	11	7736.36	4054.7	-818	16291
Indirect	8	1503.69	4754.5	-8527	11535

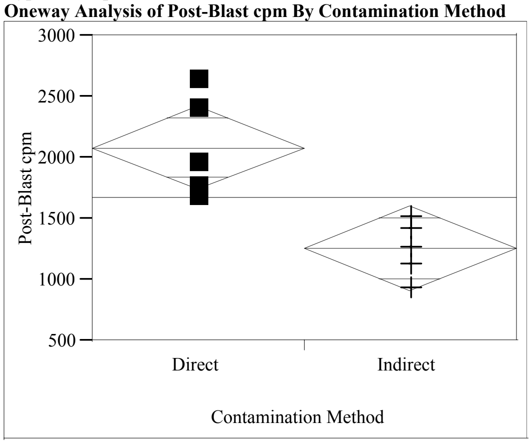
Std Error uses a pooled estimate of error variance

Figure 6 provides a similar look at the post-blast contamination levels measured in counts per minute (cpm) per coupon. These contamination levels were measured after blasting for the test coupons and after the smears were taken for both the test and control coupons. For both the control and test coupon groups, there appears to be a statistically significant difference (at the 5% significance level) in the mean post-blast, contamination levels between the directly and indirectly contaminated coupons. This is true even for the control coupons, which were not subjected to the blasting process itself, but only to the prototypical shipping and handling associated with this testing. Even more, the difference (825 cpm) in average contamination between the directly and indirectly contaminated coupons seen in these data for the test coupons is not statistically different than the difference (606 cpm) in average contamination between the directly and indirectly contaminated coupons seen in these data for the control coupons. This can be seen by comparing the confidence intervals for these differences that are provided in Figure 6. The same comparisons were conducted in the natural logarithms of the post-blast contamination measurements. These results, which are not shown here, indicate the same statistically significant differences (at the 5% significance level) in the mean post-blast, contamination levels between the directly and indirectly contaminated coupons for both the test and control groups.

Figure 6. Post-Blast Contamination by Contamination Method and Coupon Group

(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Type of Coupon=Control
Oneway Analysis of Post-Blast cpm By Contamination Method



Oneway Anova
Summary of Fit

Rsquare	0.653546
Adj Rsquare	0.610239
Root Mean Square Error	335.8358
Mean of Response	1670.44
Observations (or Sum Wgts)	10

t Test
Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	825.120	3.885	8	0.0046
Std Error	212.401			
Lower 95%	335.322			
Upper 95%	1314.918			

UnEqual Variances

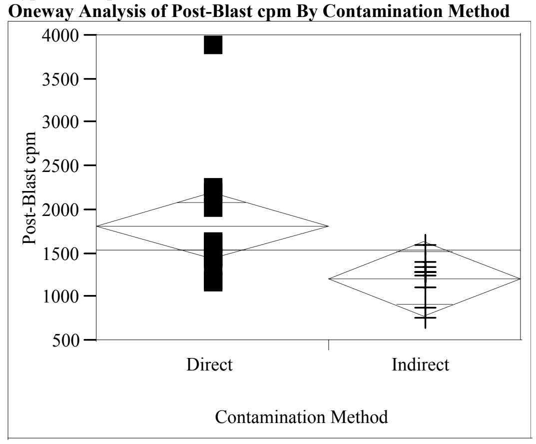
	Difference	t Test	DF	Prob > |t|
Estimate	825.12	3.885	6.39285	0.0072
Std Error	212.40			
Lower 95%	313.04			
Upper 95%	1337.20			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Direct	5	2083.00	150.19	1736.7	2429.3
Indirect	5	1257.88	150.19	911.5	1604.2

Std Error uses a pooled estimate of error variance

Type of Coupon=Test
Oneway Analysis of Post-Blast cpm By Contamination Method



Oneway Anova
Summary of Fit

Rsquare	0.216096
Adj Rsquare	0.172546
Root Mean Square Error	605.246
Mean of Response	1547.855
Observations (or Sum Wgts)	20

t Test
Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	605.979	2.228	18	0.0389
Std Error	272.038			
Lower 95%	34.448			
Upper 95%	1177.509			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	605.98	2.423	12.6375	0.0312
Std Error	250.11			
Lower 95%	16.56			
Upper 95%	1195.40			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Direct	11	1820.55	182.49	1437.2	2203.9
Indirect	9	1214.57	201.75	790.7	1638.4

Std Error uses a pooled estimate of error variance

Figure 7 provides a comparison between the pre-blast and post-blast contamination levels, both measured in counts per minute (cpm) per coupon. The values for coupon ID 22-D were excluded from the analysis of Figure 7. The pre-blast value for this coupon (see Table 3) was much larger than those values seen for the other coupons, and with this value present, there was no indication of a statistically significant difference in the average pre- and post-blasting contamination levels.

The data from both the test and control coupons are included in the analysis of Figure 7. The analysis also includes the data from coupons contaminated by the direct and indirect methods. The results from Figure 7 indicate a statistically significant (at the 5% significance level) difference between the pre- and post-contamination levels for these data. The analysis is conducted using the "Matched Pairs" platform available in JMP. For these data the post-blast contamination per coupon is, on average, 469 cpm less than the pre-blast contamination.

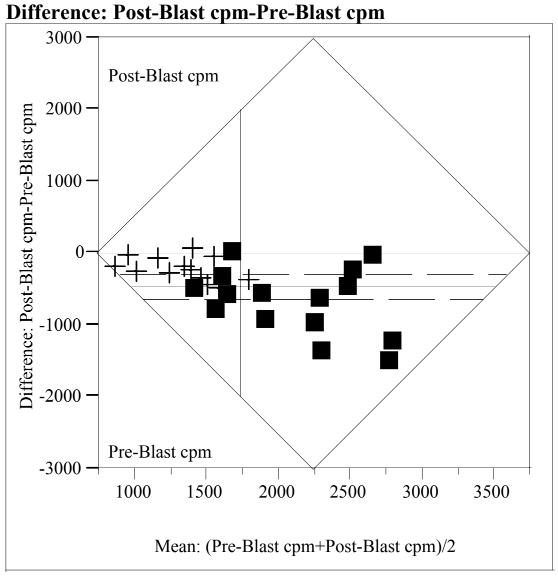
The same comparison was conducted in the natural logarithms of the pre- and post-blast contamination measurements. For this analysis, which is not shown here, the results indicate the same statistically significant difference (at the 5% significance level) between the pre- and post-contamination levels for these data.

Figure 7. Pre- vs Post-Blast Contamination

In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Matched Pairs

Difference: Post-Blast cpm-Pre-Blast cpm



Post-Blast cpm	1513.55	t-Ratio	-5.89142
Pre-Blast cpm	1982.45	DF	27
Mean Difference	-468.89	Prob > |t|	<.0001
Std Error	79.5891	Prob > t	1.0000
Upper95%	-305.59	Prob < t	<.0001
Lower95%	-632.2		
N	28		
Correlation	0.81898		

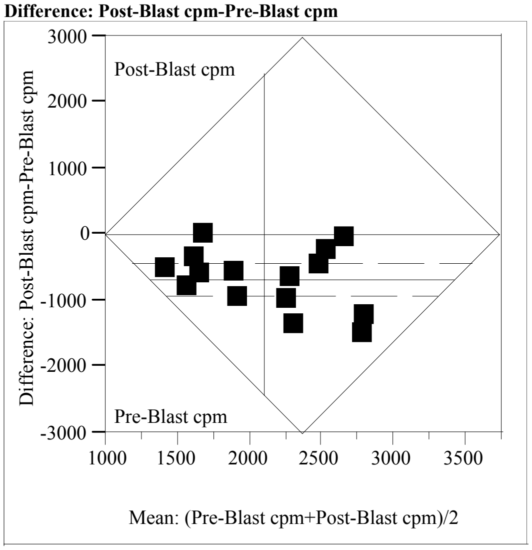
Figure 8 provides similar comparisons between the pre- and post-blasting contamination levels by contamination method (i.e., for those coupons contaminated via the direct method as a group and for those coupons contaminated via the indirect method as a group). Once again, the "Matched Pairs" platform of JMP was used to conduct these analyses which indicate statistically significant (at a 5% significance level) differences between the pre- and post-blasting average contamination levels for both groups of coupons with the post-blasting average being less than the pre-blasting average.

The same comparisons were conducted in the natural logarithms of the pre- and post-blast contamination measurements. The results, which are not shown here, indicate the same statistically significant differences (at the 5% significance level) between the pre- and post-contamination levels for these data.

Figure 8. Pre- vs Post-Blast Contamination by Contamination Method

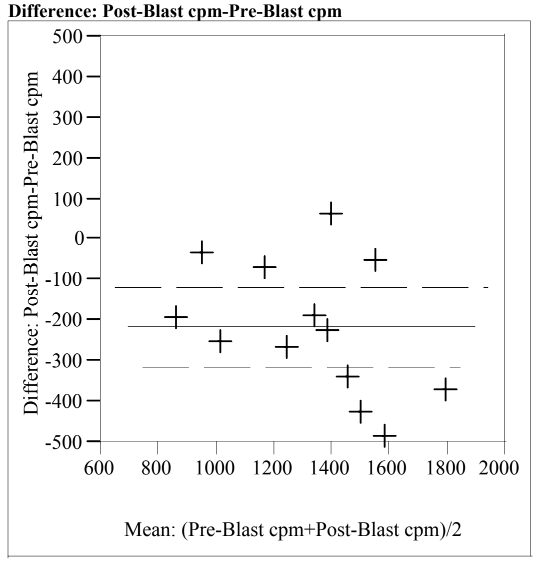
(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Contamination Method=Direct
Matched Pairs
Difference: Post-Blast cpm-Pre-Blast cpm



Post-Blast cpm	1771.27	t-Ratio	-5.82222
Pre-Blast cpm	2458.67	DF	14
Mean Difference	-687.4	Prob > |t|	<.0001
Std Error	118.065	Prob > t	1.0000
Upper95%	-434.18	Prob < t	<.0001
Lower95%	-940.62		
N	15		
Correlation	0.6451		

Contamination Method=Indirect
Matched Pairs
Difference: Post-Blast cpm-Pre-Blast cpm



Post-Blast cpm	1216.19	t-Ratio	-4.79347
Pre-Blast cpm	1432.96	DF	12
Mean Difference	-216.77	Prob > |t|	0.0004
Std Error	45.2217	Prob > t	0.9998
Upper95%	-118.24	Prob < t	0.0002
Lower95%	-315.3		
N	13		
Correlation	0.85729		

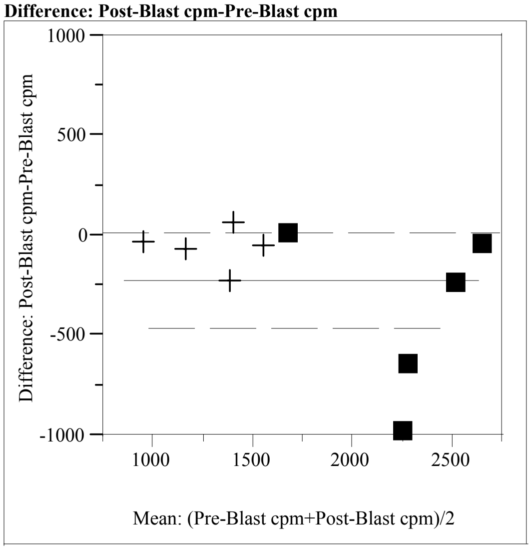
Figure 9 provides similar comparisons between the pre- and post-blasting contamination levels for the test coupons and for the control coupons. Once again, the “Matched Pairs” platform of JMP was used to conduct these analyses which indicate a statistically significant (at a 5% significance level) difference between the pre- and post-blasting average contamination levels for the test coupons but not for the control coupons.

The same comparisons were conducted in the natural logarithms of the pre- and post-blast contamination measurements. The results, which are not shown here, indicate the same statistically significant difference (at the 5% significance level) between the pre- and post-contamination levels both for the test coupons and for the control coupons.

Figure 9. Pre- vs Post-Blast Contamination for the Test and for the Control Coupons

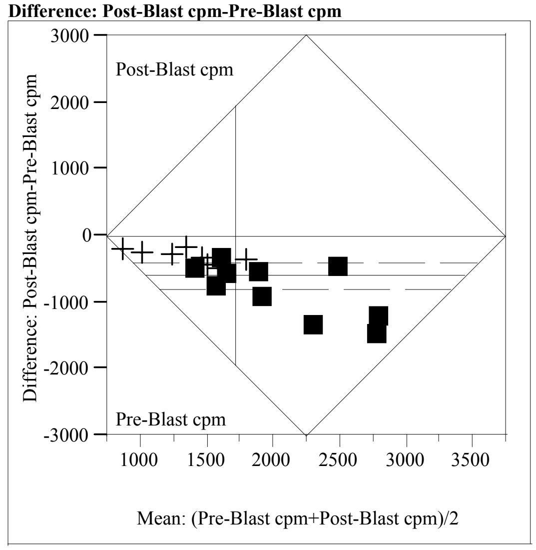
(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Type of Coupon=Control
Matched Pairs
Difference: Post-Blast cpm-Pre-Blast cpm



Post-Blast cpm	1670.44	t-Ratio	-2.10056
Pre-Blast cpm	1893.9	DF	9
Mean Difference	-223.46	Prob > |t|	0.0651
Std Error	106.381	Prob > t	0.9675
Upper95%	17.1912	Prob < t	0.0325
Lower95%	-464.11		
N	10		
Correlation	0.88096		

Type of Coupon=Test
Matched Pairs
Difference: Post-Blast cpm-Pre-Blast cpm



Post-Blast cpm	1426.39	t-Ratio	-6.28996
Pre-Blast cpm	2031.64	DF	17
Mean Difference	-605.24	Prob > |t|	<.0001
Std Error	96.2239	Prob > t	1.0000
Upper95%	-402.23	Prob < t	<.0001
Lower95%	-808.26		
N	18		
Correlation	0.89569		

Additional analyses of the differences between the pre- and post-blast cpm values for the test coupons were conducted. The differences were expressed relative to (as a percentage of) the pre-blast values. These percent differences were analyzed relative to the four process factors for the directly contaminated coupons and for the indirectly contaminated coupons. Figure 10 provides the results of these analyses. For the directly contaminated coupons, there is no indication of statistically significant effects in the differences due to the four process factors.

It is a different story for the indirectly contaminated coupons. The results for these coupons indicate statistically significant effects (at a 5% significance level) over the contamination differences due to blast pressure, nozzle standoff distance, and travel speed. Pellet rate is the only factor for which a statistically significant effect is not seen. The signs of the estimated effects are also of interest. Note that the estimates for the effects of both nozzle standoff distance and travel speed are negative. Thus, as nozzle standoff distance or travel speed is increased, the percent change between the pre- and post-blast contamination counts tends to decrease. For blast pressure, the estimated coefficient is positive; indicating that as this pressure is increased, the percent difference tends to increase. Thus, the signs of the statistically estimated coefficients reflect the practical expectations for the effects of these three process factors.

Figure 10. Models for Pre- versus Post-Contamination Differences by Contamination Method for the Test Coupons

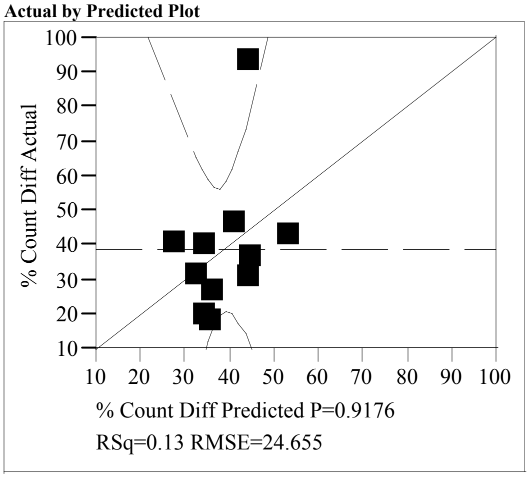
(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Contamination Method=Direct

Response % Count Diff

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.128051
RSquare Adj	-0.45325
Root Mean Square Error	24.65495
Mean of Response	38.59697
Observations (or Sum Wgts)	11

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	535.6146	133.904	0.2203
Error	6	3647.1991	607.867	Prob > F
C. Total	10	4182.8137		0.9176

Parameter Estimates

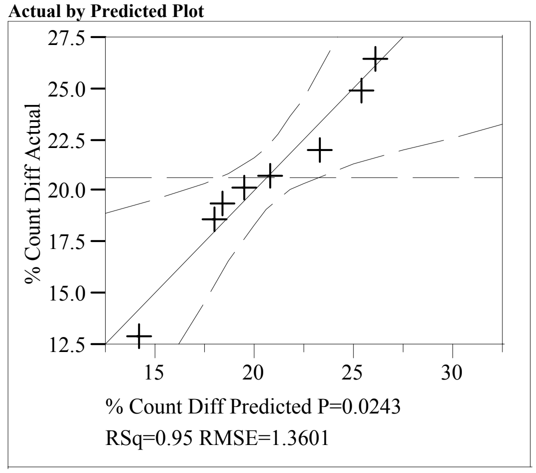
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	39.056572	7.737289	5.05	0.0023
blast pressure	-3.428639	9.833923	-0.35	0.7393
nozzle standoff distance	-0.933098	9.833923	-0.09	0.9275
travel speed	4.2941168	9.833923	0.44	0.6776
pellet rate	-5.123248	7.737289	-0.66	0.5325

Contamination Method=Indirect

Response % Count Diff

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.953607
RSquare Adj	0.89175
Root Mean Square Error	1.36005
Mean of Response	20.66659
Observations (or Sum Wgts)	8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	114.06421	28.5161	15.4163
Error	3	5.54921	1.8497	Prob > F
C. Total	7	119.61342		0.0243

Parameter Estimates

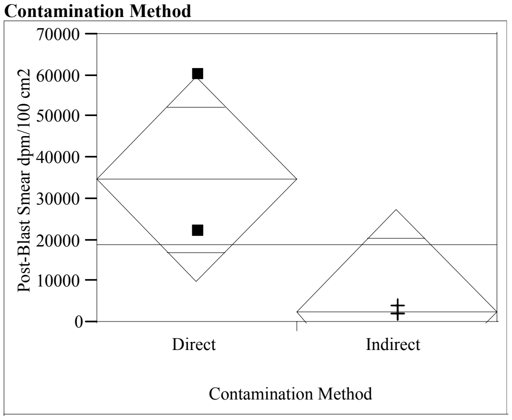
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.20557	0.526745	42.16	<.0001
blast pressure	2.1000682	0.526745	3.99	0.0283
nozzle standoff distance	-3.511022	0.548254	-6.40	0.0077
travel speed	-2.644913	0.548254	-4.82	0.0170
pellet rate	-0.225293	0.526745	-0.43	0.6977

Figure 11 provides comparisons of the post-blast smearable contamination levels measured in dpm/100 cm^2. For the control coupons, there appears to be a statistically significant difference (at an approximate 6% significance level) in the mean post-blast, smearable contamination levels between the directly and indirectly contaminated coupons. Recall that the smearable contamination for 4 of the control coupons was not measured, which causes some loss of sensitivity in investigating for these differences. For the test coupons, there is no indication of a statistically significant difference in the mean post-blast, smearable contamination levels between the directly and indirectly contaminated coupons. The same comparisons were conducted in the natural logarithms of the post-blast contamination measurements. These results, which are not shown here, indicate a statistically significant difference (at the 5% significance level) in the smearable, contamination levels between the directly and indirectly contaminated coupons for the control group.

Figure 11. Smearable Contamination by Contamination Method for the Test and for the Control Coupon Groups

(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Type of Coupon=Control
Oneway Analysis of Post-Blast Smear dpm/100 cm2 By Contamination Method



Oneway Anova
Summary of Fit

Rsquare	0.614072
Adj Rsquare	0.517591
Root Mean Square Error	15534.91
Mean of Response	18666.67
Observations (or Sum Wgts)	6

t Test
Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	32000.0	2.523	4	0.0652
Std Error	12684.2			
Lower 95%	-3217.0			
Upper 95%	67217.0			

UnEqual Variances

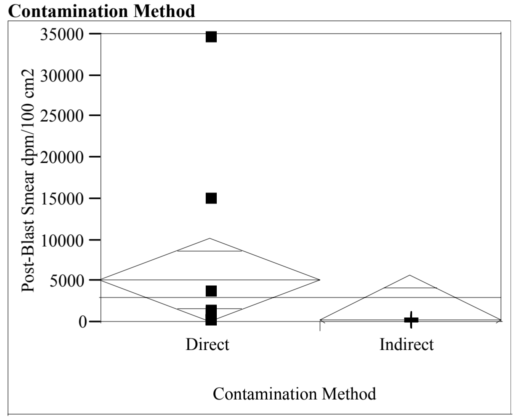
	Difference	t Test	DF	Prob > |t|
Estimate	32000	2.523	2.01108	0.1270
Std Error	12684			
Lower 95%	-22289			
Upper 95%	86289			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Direct	3	34666.7	8969.1	9765	59569
Indirect	3	2666.7	8969.1	-22235	27569

Std Error uses a pooled estimate of error variance

Type of Coupon=Test
Oneway Analysis of Post-Blast Smear dpm/100 cm2 By Contamination Method



Oneway Anova
Summary of Fit

Rsquare	0.094873
Adj Rsquare	0.044588
Root Mean Square Error	7948.451
Mean of Response	2946.95
Observations (or Sum Wgts)	20

t Test
Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	4907.18	1.374	18	0.1864
Std Error	3572.56			
Lower 95%	-2598.49			
Upper 95%	12412.86			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	4907	1.526	10.0071	0.1579
Std Error	3216			
Lower 95%	-3052			
Upper 95%	12867			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Direct	11	5155.18	2396.5	120	10190
Indirect	9	248.00	2649.5	-5318	5814

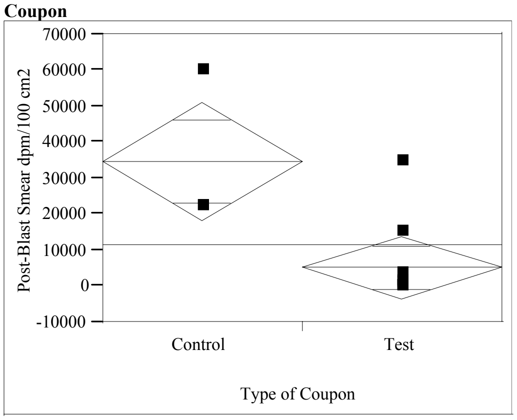
Std Error uses a pooled estimate of error variance

Figure 12 provides comparisons, between the test and control coupon groups, for the post-blast smearable contamination levels measured in dpm/100 cm^2. These comparisons between the test and control coupons are made for the coupons contaminated by the direct method and for the coupons contaminated by the indirect method. For the coupons contaminated by either method, there appears to be a statistically significant difference (at an approximate 6% significance level) in the mean post-blast, smearable contamination levels between the test and control coupon groups. The same comparisons were conducted in the natural logarithms of the post-blast smearable contamination measurements. These results, which are not shown here, indicate statistically significant differences (at the 5% significance level) in the smearable, contamination levels between the test and control coupon groups.

Figure 12. Smearable Contamination by Contamination Method for the Test and for the Control Coupon Groups

(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Contamination Method=Direct
Oneway Analysis of Post-Blast Smear dpm/100 cm2 By Type of Coupon



Oneway Anova
Summary of Fit

Rsquare	0.494377
Adj Rsquare	0.452241
Root Mean Square Error	13227.51
Mean of Response	11479.07
Observations (or Sum Wgts)	14

t Test
Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	29511.5	3.425	12	0.0050
Std Error	8615.6			
Lower 95%	10739.7			
Upper 95%	48283.2			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	29511	2.258	2.2641	0.1376
Std Error	13068			
Lower 95%	-3708			
Upper 95%	62731			

Analysis of Variance

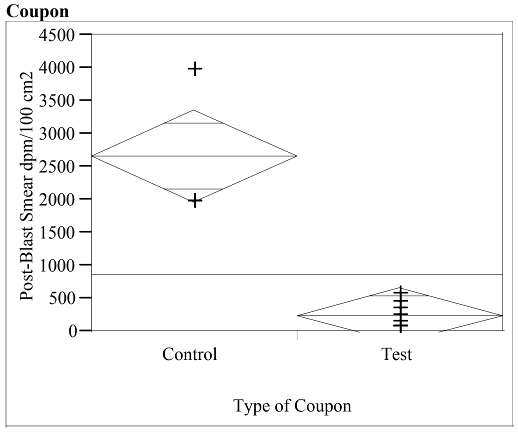
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Coupon	1	2052901097	2.0529e+9	11.7331	0.0050
Error	12	2099603572	174966964		
C. Total	13	4152504669			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Control	3	34666.7	7636.9	18027	51306
Test	11	5155.2	3988.2	-3534	13845

Std Error uses a pooled estimate of error variance

Contamination Method=Indirect
Oneway Analysis of Post-Blast Smear dpm/100 cm2 By Type of Coupon



Oneway Anova
Summary of Fit

Rsquare	0.817856
Adj Rsquare	0.799642
Root Mean Square Error	541.4224
Mean of Response	852.6667
Observations (or Sum Wgts)	12

t Test
Assuming equal variances

	Difference	t Test	DF	Prob > |t|
Estimate	2418.67	6.701	10	<.0001
Std Error	360.95			
Lower 95%	1614.42			
Upper 95%	3222.91			

UnEqual Variances

	Difference	t Test	DF	Prob > |t|
Estimate	2418.67	3.613	2.03319	0.0671
Std Error	669.42			
Lower 95%	889.68			
Upper 95%	3947.66			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Type of Coupon	1	13162384	13162384	44.9016	<.0001
Error	10	2931383	293138.27		
C. Total	11	16093767			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Control	3	2666.67	312.59	1970	3363.2
Test	9	248.00	180.47	-154	650.1

Std Error uses a pooled estimate of error variance

Also, note in Table 3 that all of the levels of smearable contamination for the control coupons (for which this measurement was conducted) were above the limit of 1000 dpm/100 cm^2 (the critical value for this measurement). This is the critical value in that the contamination delivery system was intended to contaminate the coupons with smearable contamination above this level and the blasting system was intended to remove the smearable contamination so that no more than this level remained on the coupon after blasting. For the 6 control coupons that were measured, the smallest smearable contamination was measured to be 2000 dpm/100 cm^2, twice the level needed for this testing. Based upon these data, it does appear that sufficient smearable contamination was delivered to the coupons used in this study.

For the test coupons, a review of the data in Table 3 provides an interesting fact: 5 of the 20 test coupons had measured smearable contamination above the 1000 dpm/100 cm^2 level. Thus, these coupons were not sufficiently cleaned of their smearable contamination by the blasting process used in this testing. An additional observation from Table 3 is that each of these 5 coupons was contaminated via the direct method, while none of these 5 coupons were contaminated with the indirect method. No special blocking or grouping of the coupons was included in the design to explore differences due to the contamination methods. In fact, the design task was approached under the assumption of no such difference [3].

Experimental Factors versus Smearable Contamination

In a previous section, there was a discussion regarding the fact that 5 of the 20 test coupons exceeded the 1000 dpm/100 cm^2 limit (i.e., they were insufficiently cleaned by the blasting process). Although all of these coupons were contaminated by the direct method, it was felt that there was still a need to attempt to model the post-blast, smearable contamination via equation (1). The data in Table 4 were used for this modeling effort. Note that in this table the "<200" and "None Detected" values for the smearable contamination were replaced by the value of 100 dpm/100 cm^2, one-half of the detection limit.

Another interesting observation is provided by the last four rows of Table 4. Test Ids hc17 and hc18 are duplicate runs as are hc19 and hc20. However, note that the smearable results from hc17 (14,900 dpm/100 cm^2) and hc18 (3.671 dpm/100 cm^2) and those from hc19 (34,500 dpm/100 cm^2) and hc20 (100 dpm/100 cm^2) show little repeatability among these two sets of duplicates. Thus, without the benefit of additional information, it appears as if the reproducibility of these results, even under a direct-only contamination delivery system, is suspect.

Table 4. Experimental Factors (coded) versus Smearable Contamination

Contamination Method	Coupon ID	Test ID	Blast Air Pressure (coded)	Nozzle Standoff Distance (coded)	Travel Speed (coded)	Pellet Rate (coded)	After Blasting Process - Smearable dpm/100 cm^2
Direct	37-D	hc01	-1	-1	-1	-1	1150
Indirect	21-I	hc02	-1	-1	-1	1	155
Direct	23-D	hc03	-1	-1	1	-1	1302
Indirect	13-I	hc04	-1	-1	1	1	268
Indirect	11-I	hc05	-1	1	-1	-1	100
Direct	25-D	hc06	-1	1	-1	1	100
Indirect	19-I	hc07	-1	1	1	-1	100
Direct	34-D	hc08	-1	1	1	1	100
Indirect	69-I	hc09	1	-1	-1	-1	100
Direct	77-D	hc10	1	-1	-1	1	100
Indirect	1-I	hc11	1	-1	1	-1	577
Direct	71-D	hc12	1	-1	1	1	100
Direct	70-D	hc13	1	1	-1	-1	684
Indirect	73-I	hc14	1	1	-1	1	457
Indirect	2-I	hc15	1	1	1	-1	375
Indirect	68-I	hc16	1	1	1	1	100
Direct	30-D	hc17	0	0	0	-1	14900
Direct	22-D	hc18	0	0	0	-1	3671
Direct	31-D	hc19	0	0	0	1	34500
Direct	36-D	hc20	0	0	0	1	100

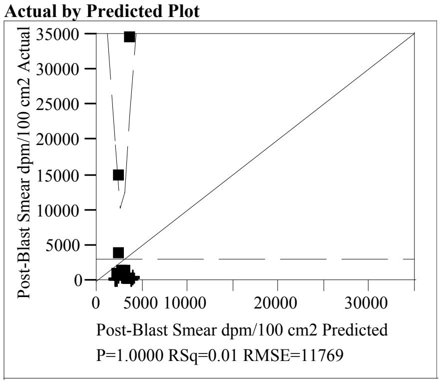
Several different approaches were used in this modeling effort; however, the results presented in Figure 13, which uses all of the test data, were typical. They show no statistically significant (at a 5% significance level) term in the fitted model. There were insufficient data to attempt to fit equation (1) to the results from just the directly or just the indirectly contaminated coupons.

Figure 13. Post-Blast Smearable Contamination versus Experimental Factors

(In this figure, a plus is used to represent an indirectly contaminated coupon and a solid square is used to represent a directly contaminated coupon.)

Response Post-Blast Smear dpm/100 cm2

Actual by Predicted Plot



Summary of Fit

RSquare	0.007821
RSquare Adj	-1.0946
Root Mean Square Error	11768.95
Mean of Response	2946.95
Observations (or Sum Wgts)	20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	9826446.05	982644.6	0.0071
Error	9	1246573321	138508147	Prob > F
C. Total	19	1256399767		1.0000

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	7	591848100	84549729	0.2583
Pure Error	2	654725221	327362610	Prob > F
Total Error	9	1246573321		0.9263
				Max RSq
				0.4789

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2946.95	2631.617	1.12	0.2918
blast pressure	-48.875	2942.237	-0.02	0.9871
nozzle standoff distance	-108.5	2942.237	-0.04	0.9714
travel speed	4.75	2942.237	0.00	0.9987
pellet rate	651.05	2631.617	0.25	0.8102
blast pressure*nozzle standoff distance	200.875	2942.237	0.07	0.9471
blast pressure*travel speed	-28.375	2942.237	-0.01	0.9925
nozzle standoff distance*travel speed	-88	2942.237	-0.03	0.9768
blast pressure*pellet rate	65.625	2942.237	0.02	0.9827
nozzle standoff distance*pellet rate	125.25	2942.237	0.04	0.9670
travel speed*pellet rate	-35.25	2942.237	-0.01	0.9907

CONCLUSIONS

The data resulting from the radioactive coupon tests were presented and statistically evaluated in this memorandum. Statistical tests for equality of means of weight measurements between the test and control coupons were conducted. At a 5% significance level, there was no indication of a difference in the averages of the initial weights for the test versus control coupons and no indication of a difference in the averages of the final weights of the two groups. However, there was an indication of a statistically significant difference (at a 5% significance level) in the averages of the weight differences (initial minus final) for the two groups. Thus, there did appear to be a statistically significant average weight change between the initial and final weights of the test coupons that was not seen in the control coupons. Thus, the measurements taken on the weights of the test and control coupons suggested that the blasting process did lead to statistically significant weight losses under the test conditions (i.e., the factor levels) studied here. However, additional statistical analyses suggested that the amount of weight loss for the test coupons was statistically the same relative to the factor settings explored in this study (i.e., over the parametric window studied here).

Comparisons of the pre- and post-blast contamination measurements (reported in counts per minute, cpm) were conducted for the directly and indirectly contaminated coupons for each group (i.e., test and control) of coupons. For the control coupons, there did appear to be a statistically significant (at the 5% significance level) difference in the mean contamination levels delivered (i.e., the pre-blast levels) by the direct and indirect methods. For the test coupons, there did not appear to be a statistically significant (at the 5% significance level) difference in the mean contamination levels delivered (i.e., the pre-blast levels) by the direct and indirect methods. For both the control and test coupon groups, there did appear to be a statistically significant difference (at the 5% significance level) in the mean post-blast, contamination levels between the directly and indirectly contaminated coupons. This was true even for the control coupons, which were not subjected to the blasting process itself, but only to the prototypical shipping and handling associated with this testing. Even more, the difference in average contamination between the directly and indirectly contaminated coupons seen in these data for the test coupons was not statistically different from the difference in average contamination between the directly and indirectly contaminated coupons seen in these data for the control coupons.

The relative differences between the initial and final (pre- and post-blasting) contamination levels for the test coupons were studied relative to the four experimental factors. For the directly contaminated coupons, there was no indication of statistically significant effects in the differences due to the four process factors. The results for the indirect coupons indicated statistically significant effects (at a 5% significance level) over the contamination differences due to blast pressure, nozzle standoff distance, and travel speed. Pellet rate was the only factor for which a statistically significant effect was not seen. The signs of the statistically estimated coefficients reflected the practical expectations for the effects of these three process factors.

For the control coupons, there did appear to be a statistically significant difference (at an approximate 10% significance level) in the mean, smearable contamination levels between the directly and indirectly contaminated coupons. However, the smearable contamination for 4 of the control coupons was not measured, which caused some loss of sensitivity in investigating for these differences. For the test coupons, there was no indication of a statistically significant difference in the mean, smearable contamination levels between the directly and indirectly contaminated coupons.

For the 6 control coupons that were measured, the smallest smearable contamination was measured to be 2000 dpm/100 cm^2, twice the level needed for this testing. Based upon these data, it does appear that sufficient smearable contamination was delivered to the coupons used in this study.

For the test coupons, 5 of the 20 test coupons had measured smearable contamination above the 1000 dpm/100 cm^2 level. Thus, these coupons were not sufficiently cleaned of their smearable contamination by the blasting process used in this testing. All 5 of these coupons were contaminated via the direct method, while no insufficiently cleaned coupons were contaminated with the indirect method. No special blocking or grouping of the coupons was included in the design to explore differences due to the contamination methods, since no differences were anticipated.

For modeling purposes, however, there were insufficient data from either of these contamination methods alone to fit the equation to fully cover the parametric window for this blasting process as intended by the experimental design.

Two sets of duplicate test conditions were included in the design for this study. The results from these 4 experiments showed little repeatability among these two sets of duplicates. Thus, without the benefit of additional information, it appears as if the reproducibility of these four results, all of which were contaminated by the direct method, is suspect.

REFERENCES

[1] May, C. G., "LAW Radioactive Coupon CO2 Blasting Tests," WSRC-TR-2001-00154, SRT-RPP-2001-00001, Rev 0, August 21, 2002.

[2] Prindiville, K., "LAW Radioactive Coupon CO2 Decontamination Test," 24590-LAW-TSP-RT-02-005, Rev. 0, April 29, 2002.

[3] Edwards, T. B., A Statistical Design Supporting the Radioactive Coupon Testing of the Process to Remove Surface Contamination (U)," SRT-SCS-2002-00043, June 26, 2002 (Appears as an Appendix in [1]).

[4] SAS Institute, Inc., **JMP® Statistics and Graphics Guide**, Version 5, SAS Institute, Inc., Cary, NC, 2002.

[5] Baker, R.A., et al., "Software Verification & Validation for Commercial Statistical Packages Utilized by the Statistical Consulting Section of SRTC (U)," WSRC-RP-00422, Revision 3, August 28, 2002.

APPENDIX B
COUPON WEIGHT SUMMARY

Table B.1 - Coupon Weight Summary

Coupon ID	Initial Weight	Final Weight-1	Final Weight-2	Final Weight Ave	Weight Difference
1-I	132.6347	132.6336	132.6341	132.6339	0.0009
2-I	134.8565	134.8557	134.8556	134.8557	0.0008
11-I	134.3951	134.3926	134.3934	134.3930	0.0021
13-I	134.3681	134.3663	134.3668	134.3666	0.0015
19-I	133.6735	133.6699	133.6699	133.6699	0.0036
21-I	135.6137	135.6080	135.6084	135.6082	0.0055
22-D	134.4295	134.4284	134.4282	134.4283	0.0012
23-D	134.9914	134.9898	134.9904	134.9901	0.0013
25-D	134.2953	134.2947	134.2945	134.2946	0.0007
30-D	132.2399	132.2372	132.2380	132.2376	0.0023
31-D	131.5277	131.5271	131.5272	131.5272	0.0006
34-D	132.8569	132.8543	132.8550	132.8547	0.0023
36-D	133.5642	133.5578	133.5578	133.5578	0.0064
37-D	132.8066	132.8005	132.8010	132.8008	0.0059
68-I	132.4606	132.4590	132.4591	132.4591	0.0016
69-I	132.6227	132.6213	132.6218	132.6216	0.0011
70-D	131.9345	131.9314	131.9310	131.9312	0.0033
71-D	135.5557	135.5532	135.5534	135.5533	0.0024
73-I	133.8520	133.8434	133.8441	133.8438	0.0083
77-D	132.9705	132.9675	132.9676	132.9676	0.0029
Control Coupon ID					
3-I	133.0625	133.0691	133.0620	133.0656	-0.0031
8-D	133.3225	133.3204	133.3205	133.3205	0.0020
17-I	133.5412	133.5404	133.5404	133.5404	0.0008
20-I	132.2560	132.2546	132.2540	132.2543	0.0017
27-D	133.1943	133.1928	133.1933	133.1931	0.0012
29-D	133.4909	133.4891	133.4893	133.4892	0.0017
33-I	132.0947	132.0935	132.0934	132.0935	0.0012
39-D	133.3588	133.3582	133.3582	133.3582	0.0006
62-I	133.5362	133.5350	133.5356	133.5353	0.0009
74-D	133.2041	133.2000	133.2002	133.2001	0.0040

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APPENDIX C
PRE- AND POST-BLAST CONTAMINATION SUMMARY

Table C.1 - Pre- and Post-Blast Contamination Summary

Coupon ID	Pre-Blast Total		Post-Blast Total		After Blast Smear
	cpm/100 cm^2	dpm/100 cm^2	cpm/100 cm^2	dpm/100 cm^2	dpm/100 cm^2
1-I	1711	9.443E+05	1285	7.092E+05	5.77E+02
2-I	1373	7.578E+05	1107	6.111E+05	3.75E+02
11-I	955.5	5.273E+05	762	4.207E+05	<200
13-I	1624	8.963E+05	1286	7.097E+05	2.68E+02
19-I	1433	7.909E+05	1248	6.888E+05	<200
21-I	1821	1.005E+06	1339	7.390E+05	1.55E+02
68-I	1976	1.091E+06	1608	8.875E+05	nd
69-I	*N/A	*N/A	1410	7.782E+05	<200
73-I	1136	6.270E+05	885.9	4.889E+05	4.57E+02
22-D	60560	3.342E+07	3872	2.137E+06	3.67E+03
23-D	3528	1.947E+06	2015	1.112E+06	1.30E+03
25-D	1944	1.073E+06	1342	7.406E+05	<200
30-D	1660	9.162E+05	1152	6.358E+05	1.49E+04
31-D	2384	1.316E+06	1434	7.914E+05	3.45E+04
34-D	2989	1.650E+06	1610	8.886E+05	<200
36-D	1777	9.807E+05	1430	7.892E+05	nd
37-D	3413	1.884E+06	2175	1.200E+06	1.15E+03
70-D	2716	1.499E+06	2238	1.235E+06	6.84E+02
71-D	2170	1.198E+06	1593	8.792E+05	nd
77-D	1959	1.081E+06	1165	6.430E+05	nd
Control Coupons					**Smears-No Blast**
3-I	1495	8.251E+05	1273	7.026E+05	4.00E+03
17-I	1198	6.612E+05	1129	6.231E+05	2.00E+03
62-I	1576	8.698E+05	1526	8.422E+05	2.00E+03
27-D	2606	1.438E+06	1952	1.077E+06	2.20E+04
29-D	2743	1.514E+06	1760	9.713E+05	6.00E+04
39-D	2642	1.458E+06	2398	1.323E+06	2.20E+04
8-D*	1675	9.244E+05	1680	9.272E+05	N/A
20-I*	963	5.315E+05	931.4	5.140E+05	N/A
33-I*	1286	7.097E+05	1430	7.892E+05	N/A
74-D*	2674	1.476E+06	2626.4	1.450E+06	N/A

* NOTE: These coupons returned to SRTC for intermediate checks during tests delay.
Only total contamination levels measured.
N/A - Not Applicable nd - nondetectable

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APPENDIX D
CONTROL COUPONS CONTAMINATION LEVELS

Table D.1 Initial 8 Control Coupons

Coupon ID	Total Cpm/ coupon	Total dpm/ 100 cm^2	Smears dpm/ 100 cm^2
6-D	2028	1.119E+06	5.26E+04
10-D	1711	9.445E+05	3.68E+04
15-D	2261	1.248E+06	4.05E+04
16-D	2831	1.563E+06	6.23E+04
4-I	1098	6.057E+05	1.70E+03
5-I	355.6	1.963E+05	6.82E+02
90-I	786.1	4.338E+05	2.41E+03
100-I	597	3.295E+05	2.44E+03

Table D.2 Final 8 Control Coupons

Coupon ID	Total Cpm/ coupon	Total dpm/ 100 cm^2	Smears dpm/ 100 cm^2	Smears Top and Bottom dpm/ 50 cm^2
65-I	2484	1.371E+06	3.89E+03	Top 3270 Btm 616
28-D	4274	2.359E+06	9.01E+04	Top 69300 Btm 20819
66-I	3077	1.698E+06	2.19E+03	Top 1200 Btm 982
38-D	4155	2.293E+06	2.97E+04	Top 26200 Btm 3434
35-D	3865	2.133E+06	3.81E+04	Top 34300 Btm 2720
24-D	3597	1.985E+06	1.18E+04	Top 4670 Btm 7080
61-I	2655	1.465E+06	1.39E+03	Top 604 Btm 787
67-I	2634	1.454E+06	2.72E+03	Top 2290 Btm 421

Table D.3 Control Coupons

Coupon ID	Before Ship Total cpm/ coupon	Before Ship Total dpm/100 cm^2	After Ship Total cpm/ coupon	After Ship Total dpm/100 cm^2	Smears dpm/100 cm^2
29-D	2743	1.514E+06	1760	9.713E+05	6.00E+04
3-I	1495	8.251E+05	1273	7.026E+05	4.00E+03
17-I	1198	6.612E+05	1129	6.231E+05	2.00E+03
27-D	2606	1.438E+06	1952	1.077E+06	2.20E+04
39-D	2642	1.458E+06	2397	1.323E+06	2.20E+04
62-I	1576	8.698E+05	1526	8.422E+05	2.00E+03
74-D*	2774	1.531E+06	2626	1.449E+06	N/A
20-I*	963	5.315E+05	931.4	5.140E+05	N/A
33-I*	1367	7.544E+05	1430	7.892E+05	N/A
8-D*	1675	9.244E+05	1680	9.272E+05	N/A

* NOTE: Coupons shipped to 105-C, then returned to SRTC for reweighing and counting during test delay
N/A - Not Applicable
Dpm/100 cm^2 is calculated conversion of cpm/100 cm^2 (551.9 x cpm/100 cm^2)

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APPENDIX E
MEASUREMENT DATA AND ANALYSIS

Table E.1 lists results for the initial set of acquisitions to demonstrate that the direct and indirect method of applying Cs-137 contamination sufficiently contaminates coupons for the blasting tests. To demonstrate that effect, eight coupons, were contaminated in accordance with Paragraph 3.2.1, Items 1-4. After contamination, the total contamination level on both sides of each coupon was counted using the method identified in Paragraph 3.3.1.

All eight coupons were then smeared and recounted for total contamination levels. The smears were counted using a RCO β–γ count rate meter to determine smearable contamination on each coupon. The total activity measured on the unsmeared coupons is listed in column F, the total activity measured on the smeared coupons is listed in column L, and the activity measured by RCO on the swipe is listed in column M. In each case the quantity dpm (F) – dpm (L) should provide a measure of the activity detected on the RCO smear. Eliminating coupons 4-U and 90-U for which there is clearly some unknown problem, we can obtain a value

Equation 2 [dpm(F) – dpm(L)]/(dpm(M) = correlation factor

for each coupon. For all six coupons in this initial set this correlation factor has an average value and one sigma standard deviation of 9.24(2.38). This suggests our experiment is successfully tracking the Cs-137 activity through the count, bake, smear, count process. The very strong correlation of what was removed by smearing (difference between our pre-smeared and smeared counts) and the value measured on the RCO swipe demonstrates our experimental technique is realistically measuring the removal of Cs-137 contamination through the process.

Table E.2 contains the results of acquisitions of 40 contaminated coupons. Of these coupons, 20 were blasted in the test, 10 were selected as control coupons, and 10 coupons were extras and not used. This table shows the measured counts per minute obtained in acquisitions obtained in October 2002 for each coupon. Four of these coupons (used as control coupons) were then recounted in December 2002 with the identical setup in order to demonstrate that system conditions had not changed appreciably prior to counting the blasted coupons (Table E.6). The ratios of the "-dup" counts to the original counts are listed in the seventh column for these four duplicate acquisitions. The agreement is excellent, with the ratios averaging to 0.9997(343). Thus our conditions had not changed at all, and the system has a demonstrated precision of 3.4%.

Table E.4 lists the results of acquisitions on 26 coupons after CO_2 blasting and subsequent smearing by RCO and six control coupons returned to SRTC after blasting tests. In the last column we have denoted the ratio of activity in the blasted coupon to the pre-blasted coupon. For all 24 coupons measured by this technique we observe an average of 0.7489(1165), demonstrating that approximately 25% of the Cs-137 activity was removed by CO_2 blasting.

Analysis of Results

RCO provided a list of selected measurements of the coupons probed both before and after the CO_2 blasting step was performed (Table E.4). It is apparent from Table E.5 that the CO2 blasting technique removed (15±9)% of all of the Cs-137 contamination on these coupons. This is in good agreement with our measurements that indicate (25±12)% of all Cs-137 contamination was removed by blasting and subsequent smearing.

Using the data of Table E.5, we are also able to compare the ratio of the measured Cs-137 content by γ-PHA to the RCO measurements using the jfldl; probe. We determine the ratio

Equation 3 **dpm(column 11)/(RCO Post Decon Probe) = R**

for each of the coupons in Table E5. That ratio is listed in the last column of Table E5, and the average and one sigma standard deviation {2.12(0.67)} is listed at the bottom of that column. We observe that our γ-PHA measurements of the Cs-137 activity remaining after blasting and smearing correlates very well with the RCO probe measurements with a precision of 16%.

It is important to realize that the ratios measured in Equation 2 and Equation 3 are two very different values. The ratio in Equation 2 is a measure of what was removed from the coupons by smearing only, and the ratio in Equation 3 is a measure of what remains on the coupon after blasting and smearing. There is no expectation that those two ratios should yield the same value. The ratio in Equation 2 compares the difference in our pre- and post-smear γ-PHA values with an RCO measure of the actual swipe. The ratio in Equation 3 compares our γ-PHA measurement of the blasted coupons with an RCO probe measurement of the coupon. The large difference in magnitude between the ratios in Equation 2 and Equation 3 must not be interpreted as evidence of flawed experimental values. Rather, the excellent correlation within both ratios should be interpreted as strong support of the experimental values.

Table E.1. Initial 8 Control Coupon Measurement Data

	First Count (Before Smear)					Second Count (After Smear)					
	B	C	D	E	F	G	H	I	K	L	M
Coupon #	662 KeV Area	% Error	Count Time (m)	cpm/ coupon	dpm per coupon	662 KeV Area (S)	% Error	Count Time (m)	cpm/ coupon	dpm per coupon	RCO Smears (dpm/ coupon)
BKG	1091	9.24	10.00	109.1	N/A	824	11.34	10.00	82.4	N/A	N/A
6-D	20282	0.75	10.00	2028	1.119E+06	12949	0.96	10.00	1295	7.147E+05	5.26E+04
10-D	17113	0.83	10.00	1711	9.443E+05	12980	0.94	10.00	1298	7.164E+05	3.68E+04
15-D	22605	0.73	10.00	2261	1.248E+06	16193	0.83	10.00	1619	8.937E+05	4.05E+04
16-D	28313	0.63	10.00	2831	1.562E+06	19715	0.78	10.00	1972	1.088E+06	6.23E+04
4-I	10975	1.06	10.00	1098	6.060E+05	11382	1.02	10.00	1138	6.282E+05	1.70E+03
5-I	3556	1.8	10.00	355.6	1.963E+05	3405	1.8	10.00	340.5	1.879E+05	6.82E+02
90-I	7861	1.28	10.00	786.1	4.338E+05	8387	1.21	10.00	838.7	4.629E+05	2.41E+03
100-I	5970	1.36	10.00	597	3.295E+05	5601	1.47	10.00	560.1	3.091E+05	2.44E+03
STD1	7528	1.12	1.000	7528	N/A	7191	1.32	1.000	7191	N/A	N/A
STD1 side 2	9525	1.12	1.000	9525	N/A	9526	1.06	1.000	9526	N/A	N/A
STD2	16534	0.86	1.000	16534	N/A	16700	0.83	1.000	16700	N/A	N/A

uCi/ coupon	2.0757
dps/ coupon	76800.9
dpm/ coupon	4608054
dpm/cpm	551.9

Dpm/100 cm^2 is calculated conversion of cpm/100 cm^2 (551.9 x cpm/100 cm^2)
Count times reported to four significant figures.

Table E.2. Pre-Blast Coupon Measurement Data

2nd Set Coupon #	662 KeV Area	% Error	Count Time (m)	cpm
bkg1017	6104	3.66	50.00	122.1
72-D	4238	1.72	2.000	2119
12-I	2333	2.33	2.000	1167
8-I	3349	1.9	2.000	1675
74-D	5348	1.52	2.000	2674
70-D	5431	1.57	2.000	2716
19-I	2865	12.03	2.000	1433
14-I	3200	1.93	2.000	1600
33-I	2734	2.29	2.000	1367
78-D	5799	1.46	2.000	2900
bkg1015	3884	4.57	33.33	116.5
21-I	3641	1.75	2.000	1821
20-I	1926	2.48	2.000	963
36-D	3554	1.92	2.000	1777
32-D	3695	1.79	2.000	1848
37-D	6826	1.74	2.000	3413
73-I	2271	2.41	2.000	1136
26-I	2328	2.24	2.000	1164
3rd Set Coupon #	**662 KeV Area**	**% Error**	**Count Time (m)**	**cpm**
bkg1017	6887	3.24	50.00	137.7
11-I	1911	2.74	2.000	955.5
77-D	3917	1.77	2.000	1959
2-I	2745	2.22	2.000	1373
1-I	3421	1.91	2.000	1711
79-D	4398	1.68	2.000	2199
29-D	5486	1.4	2.000	2743
3-I	2989	2.4	2.000	1495
71-D	4339	1.74	2.000	2170

Table E.2. Pre-Blast Coupon Measurement Data - continued

4th Set Coupon #	662 KeV Area	% Error	Count Time (m)	cpm
bkg1021long	10342	3.25	60.00	172.4
13-I	3248	1.78	2.000	1624
17-I	2395	2.07	2.000	1198
22-D	121120	0.97	2.000	6056
23-D	7055	1.24	2.000	3528
25-D	3887	1.74	2.000	1944
27-D	5211	1.51	2.000	2606
30-D	3320	1.96	2.000	1660
31-D	4767	1.5	2.000	2384
39-D	5148	1.52	33.33	154.5
60-I	2880	1.98	2.000	1440
62-I	3151	1.93	2.000	1576
68-I	3952	1.76	2.000	1976
7-I	2659	2.15	2.000	1330
9-I	2589	2.11	2.000	1295
34-D	5978	1.4	2.000	2989
26-I	3729	1.73	2.000	1865

Count times reported to four significant figures.

Table E.3. Post-Blast Coupon Measurement Data

Blasted Set Coupon #	662 KeV Area	% Error	Count Time (m)	cpm	Post-blast/ Pre-blast
bg1227	488	23.88	33.33	14.641	N/A
13i	1286	3.13	1.000	1286	0.7919
27d	1952	2.37	1.000	1952	0.7492
3i	1273	3.08	1.000	1273	0.8518
62i	1526	2.75	1.000	1526	0.9686
69i	1410	2.95	1.000	1410	N/A
21d	1339	2.92	1.000	1339	0.7353
36d	1430	2.79	1.000	1430	0.8047
17i	1129	3.16	1.000	1129	0.9428
31d	1434	2.81	1.000	1434	0.6016
1i	1285	2.94	1.000	1285	0.7512
70d	2238	2.22	1.000	2238	0.8242
25d	1342	3	1.000	1342	0.6905
23d	2015	2.48	1.000	2015	0.5712
29d	2346	2.16	1.333	1760	0.6415
19i	1664	2.52	1.333	1248	0.8712
2i	1475	2.87	1.333	1107	0.8060
39d	3196	1.84	1.333	2397	15.5190
11i	1016	3.55	1.333	762	0.7975
68i	2144	2.37	1.333	1608	0.8138
30d	1535	2.76	1.333	1152	0.6935
34d	2146	2.33	1.333	1610	0.5385
71d	2123	2.33	1.333	1593	0.7339
22d	5161	1.47	1.333	3872	0.0639
77d	1553	2.62	1.333	1165	0.5947
37d	2899	1.97	1.333	2175	0.6370
73i	1181	3.12	1.333	886	0.7801
Average Remaining (deviation)					0.7480 (0.1165)

Count times reported to four significant figures.

Table E.4. Post-Blast Total Contaminations Comparison

Coupon ID	dpm (column 11, Table E.5)	RCO Probe dpm	R (Equation 3)
30-D	6.354E+05	3.06E+05	2.08
69-I	7.782E+05	3.82E+05	2.04
ll-I	4.207E+05	3.00E+05	1.40
19-I	6.888E+05	4.20E+05	1.64
2-I	6.111E+05	4.05E+05	1.51
23-D	1.112E+06	7.22E+05	1.54
70-D	1.235E+06	5.54E+05	2.23
37-D	1.200E+05	5.60E+05	2.15
1-I	7.092E+05	3.46E+05	2.05
22-D	2.136E+06	1.28E+06	1.67
31-D	7.914E+05	5.54E+05	1.43
73-I	4.889E+05	2.70E+05	1.81
13-I	7.097E+05	3.60E+05	1.97
21-I	7.390E+05	2.00E+05	3.69
25-D	7.406E+05	3.20E+05	2.32
34-D	8.886E+05	3.80E+05	2.34
36-D	7.892E+05	2.00E+05	3.94
68-I	8.875E+05	4.00E+05	2.22
71-D	8.792E+05	4.00E+05	2.20
Average R (deviation)			2.12 (0.67)

Table E.5. Coupon Total Contamination Summary

	Pre- Blast Total					Post-Blast Total					
Coupon ID	**662 KeV Area**	**% Error**	**Count Time (m)**	**cpm/100 cm^2**	**Pre-Blast dpm/100 cm^2**	**662 KeV Area**	**% Error**	**Count Time (m)**	**cpm/100 cm^2**	**Post-Blast dpm/100 cm^2**	**After Blast Smear dpm/100 cm^2**
1-I	3421	1.91	2.000	1711	9.443E+05	1285	2.94	1.000	1285	7.092E+05	5.77E+02
2-I	2745	2.22	2.000	1373	7.578E+05	1475	2.87	1.333	1107	6.111E+05	3.75E+02
11-I	1911	2.74	2.000	955.5	5.273E+05	1016	3.55	1.333	762.2	4.207E+05	<200
13-I	3248	1.78	2.000	1624	8.963E+05	1286	3.13	1.000	1286	7.097E+05	2.68E+02
19-I	2865	12.03	2.000	1433	7.909E+05	1664	2.52	1.333	1248	6.888E+05	<200
21-I	3641	1.75	2.000	1821	1.005E+06	1339	2.92	1.000	1339	7.390E+05	1.55E+02
68-I	3952	1.76	2.000	1976	1.091E+06	2144	2.37	1.333	1608	8.875E+05	nd
69-I	N/A	N/A	N/A	N/A	N/A	1410	2.95	1.000	1410	7.782E+05	<200
73-I	2271	2.41	2.000	1136	6.270E+05	1181	3.12	1.333	885.9	4.889E+05	4.57E+02
22-D	121120	0.97	2.000	60560	3.342E+07	5161	1.47	1.333	3872	2.137E+06	3.67E+03
23-D	7055	1.24	2.000	3528	1.947E+06	2015	2.48	1.000	2015	1.112E+06	1.30E+03
25-D	3887	1.74	2.000	1944	1.073E+06	1342	3	1.000	1342	7.406E+05	<200
30-D	3320	1.96	2.000	1660	9.162E+05	1535	2.76	1.333	1152	6.358E+05	1.49E+04
31-D	4767	1.5	2.000	2384	1.316E+06	1434	2.81	1.000	1434	7.914E+05	3.45E+04
34-D	5978	1.4	2.000	2989	1.650E+06	2146	2.33	1.333	1610	8.886E+05	<200
36-D	3554	1.92	2.000	1777	9.807E+05	1430	2.79	1.000	1430	7.892E+05	nd
37-D	6826	1.74	2.000	3413	1.884E+06	2899	1.97	1.333	2175	1.200E+06	1.15E+03
70-D	5431	1.57	2.000	2716	1.499E+06	2238	2.22	1.000	2238	1.235E+06	6.84E+02
71-D	4339	1.74	2.000	2170	1.198E+06	2123	2.33	1.333	1593	8.792E+05	nd
77-D	3917	1.77	2.000	1959	1.081E+06	1553	2.62	1.333	1165	6.430E+05	nd

N/A - Not Applicable nd - nondetectable Count times reported to four significant figures.

Table E.5. Coupon Total Contamination Summaries (continued)

	Pre-Test Total					Post-Test Total					
Control Coupon ID	662 KeV Area	% Error	Count Time (m)	cpm/100 cm^2	dpm/100 cm^2	662 KeV Area	% Error	Count Time (m)	cpm/100 cm^2	dpm/100 cm^2	Smears-No Blast dpm/100 cm^2
3-I	2989	2.4	2.000	1495	8.251E+05	1273	3.08	1.000	1273	7.026E+05	4.00E+03
17-I	2395	2.07	2.000	1198	6.612E+05	1129	3.16	1.000	1129	6.231E+05	2.00E+03
20-I	1926	2.48	2.000	963	5.315E+05	4657	1.56	5.000	931.4	5.140E+05	N/A
33-I	2571	2.34	2.000	1286	7.097E+05	7152	1.28	5.000	1430	7.892E+05	N/A
62-I	3151	1.93	2.000	1576	8.698E+05	1526	2.75	1.000	1526	8.422E+05	2.00E+03
8-D	3349	1.9	2.000	1675	9.244E+05	8401	1.15	5.000	1680	9.272E+05	N/A
27-D	5211	1.51	2.000	2606	1.438E+06	1952	2.37	1.000	1952	1.077E+06	2.20E+04
29-D	5486	1.4	2.000	2743	1.514E+06	2346	2.16	1.333	1760	9.713E+05	6.00E+04
39-D	5148	1.52	33.33	154.5	8.527E+04	3196	1.84	1.333	2398	1.323E+06	2.20E+04
74-D	5348	1.52	2.000	2674	1.476E+06	13132	0.92	5.000	2626	1.449E+06	N/A

N/A - Not Applicable
Dpm/100 cm^2 is calculated conversion of cpm/100 cm^2 (551.9 x cpm/100 cm^2)
Count times reported to four significant figures.

Table E.6. Control Coupons Recount

	662 KeV Area	% Error	Count Time (m)	Cpm/ coupon	1st Count cpm/coupon	2nd Count/ 1st Count	Uncer-tainty
blasbg1204	953	12.3	23.72	40.19	N/A	N/A	N/A
20-I-dup*	4657	1.56	5.000	931.4	963	0.9672	0.0283
33-I-dup*	7152	1.28	5.000	1430	1367	1.0461	0.0274
74-d-dup*	13132	0.92	5.000	2626	2674	0.9822	0.0175
8-d-dup*	8401	1.15	5.000	1680	1675	1.0034	0.0223

Count times reported to four significant figures.

Table E.7. Total Contamination Summary

Coupon ID	Pre-Blast Total		Post-Blast Total		Post Blast Smear dpm/100 cm^2	Total removed	% Removed
	cpm/100 cm^2	dpm/100 cm^2	cpm/100 cm^2	dpm/100 cm^2			
1-I	1711	9.443E+05	1285	7.092E+05	5.77E+02	2.351E+05	24.9%
2-I	1373	7.578E+05	1107	6.111E+05	3.75E+02	1.467E+05	19.4%
11-I	955.5	5.273E+05	762.2	4.207E+05	<200	1.066E+05	20.2%
13-I	1624	8.963E+05	1286	7.097E+05	2.68E+02	1.870E+05	20.8%
19-I	1433	7.909E+05	1248	6.888E+05	<200	1.021E+05	12.9%
21-I	1821	1.005E+06	1339	7.390E+05	1.55E+02	2.660E+05	26.4%
68-I	1976	1.091E+06	1608	8.875E+05	nd	2.030E+05	18.6%
69-I	*	*	1410	7.782E+05	<200	*	*
73-I	1136	6.270E+05	885.9	4.889E+05	4.57E+02	1.381E+05	22.0%
22-D	60560	3.342E+07	3872	2.137E+06	3.67E+03	3.128E+07	93.6%
23-D	3528	1.947E+06	2015	1.112E+06	1.30E+03	8.350E+05	42.9%
25-D	1944	1.073E+06	1342	7.406E+05	<200	3.320E+05	30.9%
30-D	1660	9.162E+05	1152	6.358E+05	1.49E+04	2.804E+05	30.6%
31-D	2384	1.316E+06	1434	7.914E+05	3.45E+04	5.246E+05	39.9%
34-D	2989	1.650E+06	1610	8.886E+05	<200	7.614E+05	46.2%
36-D	1777	9.807E+05	1430	7.892E+05	nd	1.910E+05	19.5%
37-D	3413	1.884E+06	2175	1.200E+06	1.15E+03	6.840E+05	36.3%
70-D	2716	1.499E+06	2238	1.235E+06	6.84E+02	2.640E+05	17.6%
71-D	2170	1.198E+06	1593	8.792E+05	nd	3.198E+05	26.6%
77-D	1959	1.081E+06	1165	6.430E+05	nd	4.380E+05	40.5%

* No pre-blast data available for post-blast calculations.
N/A - Not Applicable