AN ABSTRACT OF THE THESIS OF

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Title: Evaluating the Efficiency of Decon Gel 1101 for Removal of Cs-137, Co-60, and Eu-154 on Common Commercial Construction Materials

Abstract approved:

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Kathryn A. Higley

Decon Gel 1101, is an uncomplicated, low odor, peelable polymer hydrogel for use with radiological decontamination, manufactured by Cellular Bioengineer Inc. The gel allows for single or multiple material applications to contaminated surfaces. As the gel dries it binds the contaminant by encapsulating and lifting the contaminant into the gel. The result is a non-sticky rubber-like substance that is easily removed.

Through a series of evaluations conducted with Decon Gel 1101, the removal efficiency for materials contaminated with liquid forms of Cs-137, Co-60, and Eu-154 was determined on concrete (both old and new), painted concrete, porcelain tile (with and without grout), granite (with grout), and vinyl composite tile. Initial application with all three nuclides on un-grouted porcelain tile and vinyl composite tile showed greater than 95% removal from the material surface and 80% or greater encapsulated

in the gel itself. Both the porcelain and granite grouted tiles showed large standard deviations between repetitions, removing between 25% and 85% of the contaminate from the material, with between 25% and 65% encased in the gel. Painted concrete resulted in greater than 95% removal from the material surface and between 45% and 85% contained in the gel. Results for both the old and new concrete were similar: between 27% and 71% removal from the material surface and between 19% and 40% encapsulated in the gel.

Evaluating the Efficiency of Decon Gel 1101 on Removal of Cs-137, Co-60, and Eu-154 on Common Commercial Construction Materials

by
Jama D. VanHorne-Sealy

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Evaluating the Efficiency of Decon Gel 1101 for Removal of Cs-137, Co-60, and Eu-154 on Common Commercial Construction Materials

1. Introduction

In the last seven years, life for much of the US has changed dramatically. This post-9/11 world has focused on terrorism deterrence, prevention and consequence management. While the first two are the most preferable approaches to terrorism, proper consequence management can act as a deterrent. Situations that are dealt with in a prompt effective manner can be perceived as having minimal effect on the community. This is mind, a decontamination method that would quickly and effectively return a radiologically contaminated site to background levels would be an asset in the consequence management arsenal.

While there are several approaches to decontamination, gels provide a particularly easy to use method. They can be used by almost anyone, requiring little to no scientific knowledge or technical expertise. In an emergency situation, local personnel could be trained to use the decontamination gel, reducing precious time and minimizing cost.

The focus of this research is to evaluate the functionality of a peelable decontamination gel, Decon Gel 1101, manufactured by Cellular Bioengineering, Inc.[*] This product is just being introduced to the open market. Preliminary tests have been conducted by the manufacturer and outside agencies, but independent assessments are limited.

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[*] Cellular Bioengineering Inc. 1946 Young Street, Suite 480, Honolulu, HI 96826

A series of tests were conducted at Oregon State University with Decon Gel 1101 to evaluate its removal efficiency with materials contaminated by liquid forms of ^{137}Cs, ^{60}Co, and ^{154}Eu. Materials contaminated in this research were selected due to their use in common commercial construction: old concrete; newly poured concrete; painted concrete; porcelain tile with and without grout; granite with grout; and vinyl composite tile.

Between seven to nine replicates of each radionuclide and sample material were contaminated, decontaminated and analyzed. If a test surface had detectable activity following the first decontamination effort, a second application of gel was applied. Analysis was accomplished using a 5 inch x 5 inch NaI(Tl) detector with multichannel analyzer and Genie 2000 3.1 Software[†].

[†] Canberra Industries, Inc. , 800 Research Parkway, Meriden, CT 06450

2. Background

2.1 Consequence Management

Consequence management is defined differently by government agencies but it is generally accepted to be "actions taken in the aftermath of a disaster" (Taylor, 1999). A fundamental principle of consequence management is the more rapid and effective the response, the less the impact on the society.

In a 2004 Report to Congress, Congressional Research Service consultant Dana A. Shea stated, "Some experts believe that the economic and psychological effects from a Radiological Dispersal Device (RDD) attack would outweigh the direct medical costs. These experts, weighing the current guidelines on radiological contamination and the degree of dispersal expected with a successful RDD attack, state that an RDD attack could contaminate large areas" (Shea, 2004). This line of thinking creates the need for prompt response and removal of radioactive materials.

While the need for decontamination techniques has been around since the initial determination of radiation hazards, the post 9/11 environment has necessitated the need for decontamination in a more timely and effective manner.

2.2 Decontamination Systems

Decontamination is a type of industrial cleaning that requires knowledge of chemistry, health effects of radiation and a mechanism to quantify "how clean is clean." Several techniques for radioactive material removal have been developed. The

Environmental Protection Agency classifies them into two primary categories: chemical and physical techniques (Feltcorn, 2006).

2.2.1 Chemical

There are three main types of chemical decontamination: acid or alkaline dissolution, oxidation/reduction reactions, and chelation. Acidic or alkaline dissolution involves the decontaminate solution dissolving the radiological material into solution, and is recommended for non-porous materials. Oxidation/reduction reactions, also called Redox, donate and accept electrons from one material to another. Controlling the oxidation state of the material being decontaminated can allow for greater solubility or stronger binding with other chemicals (Feltcorn, 2006). Chelation acts through a multipoint attachment to a metal ion. Chelating agents contain an organic chemical with a polydentate ligand that allows it to bind to the metal ion of the radionuclide. They encapsulate and surround the metal ion and bring it into solution. A ligand is a neutral molecule or ion with a lone electron pair. A polydentate ligand, which acts as the chelating agent, forms two or more bonds to the metal ion, or in this case the radionuclide, and pulls it into the solution (McMurry, 2004; Zumdahl, 1993).

Some of the benefits of a chemical decontaminant are high decontamination factors (ratio of the proportion of contaminant to product before treatment to the proportion after treatment); little to no generation/production of airborne contaminates; generally minimal effect on equipment; and relatively low expense and quick removal. Some of the disadvantages of a chemical decontamination process include: production of liquid waste resulting in secondary costs; health hazards created by the use of strong acids and oxidizers; and poor performance on porous surfaces (Feltcorn, 2006; McMurry, 2004; USA TM 5-801-10, 1992).

2.2.2 Physical Decontamination

There are two types of physical or mechanical decontamination: surface cleaning and surface removal. Some of the advantages of physical decontamination are that it works on almost any surface and that high decontamination factors can be achieved. Some of the disadvantages include: no radionuclide specificity resulting in removal of non-specified materials with potentially significant damage to the material; resultant airborne contaminate; and substantial waste volumes. Strippable coatings are classified as physical surface cleaning (Feltcorn, 2006; USA TM 5-801-10, 1992).

2.3 Decon Gel 1101

Decon Gel 1101[*], utilizes two methods of decontamination, physical decontamination through its actions as a strippable gel and chemical decontamination through chelation and emulsification (dispersion of a liquid into a liquid) of the radionuclides[†] (Atkins, 1997).

According to the manufacturer, Decon Gel 1101 has been shown to be a safe non-damaging, user friendly, low odor, peelable polymer hydrogel. It is specified for use in removing radiological contamination as well as particulates, heavy metals, water soluble and insoluble organic compounds. The gel allows for a single material application to contaminated surfaces with no secondary activation chemical. Upon

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[*] Cellular Bioengineering, Inc. 1946 Young Street, Suite 480, Honolulu, HI 96826
[†] Edgington, G. Personal Correspondence, 1May 2008

application, the gel penetrates into cracks, pores and voids. As the gel dries, it binds the contaminant within the gel, encapsulates it and lifts it from the surface. The resultant dried gel is a tough non-sticky film that is easy to peel. The rehydratable polymer allows for any necessary recovery or analysis of the contaminant[‡]

[‡] Edgington, G. Personal Correspondence, 1May 2008

3. Literature Review

3.1 Modern Strippable Coating Methods

Decon Gel 1101 is one of the latest evolutions in strippable gels. For five decades, decontamination gels have been worked, tested and refined (Demmer, 2005).

In 2005, Idaho National Engineering and Environmental Lab (INEEL) presented the results of their tests on four of the strippable gels. This work spanned the previous twenty years. The four gels tested were ALARA 1146*, TLC Strip Coat†, PENTEK 604‡ and ElectroDecon§. The INEEL paper touted the advantages of the strippable gels as having less waste, less expense, no liquid waste and ease of application (Demmer, 2005).

The testing methodologies, detection methods and percentage removed all varied. The one consistency was substantial removal of fixed contamination, from 45% to 99%. Results rivaled standard chemical and mechanical decontamination methods (Demmer, 2005).

3.2 Decon Gel Analysis

Three previous works specific to Decon Gel were reviewed for this analysis. Each of the papers presented a similar testing and application methodology: number of counts for the radionuclide on the testing material was determined; a generous

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* Carboline, 350 Hanley Industrial Court, St. Louis, MO 63144
† Bartlett Nuclear, 60 Industrial Park Road, Plymouth , MA 02360
‡ Pentek Inc. 1026 Fourth Avenue, Coraopolis, PA 15108
§ ADA Technologies, 8100 Shaffer Parkway, Suite 130, Littleton, CO 80127

application of the strippable gel material was applied, allowed to dry and removed. A second count was determined and percentage removed from the material calculated.

3.2.1 An Improved Polymer-Based Hydrogel for Decontamination of Hard Asset

The first work reviewed tested one of the earliest precursors to the current product, Decon 188. This evaluation of the gel product was conducted with uranium, although no specific nuclide was noted. An alpha scintillation probe was used for activity determinations. The materials tested were coated concrete, wood, oxidized and painted steel, floor joint filler and Plexiglas. Testing was done in a high humidity environment, an estimated 90% humidity. The number of iterations conducted for each material varied from one to five. The materials tested varied in uranium removal, 31% for concrete to 98% for floor joint filler (Gaul, 2007).

3.2.2. Decontamination of Nuclear Medicine Isotopes from Hard Surfaces using a Peelable Polymer-Based Hydrogel

The second paper reviewed on Decon Gel, is a collection of tests conducted with Decon Gel 1101 and its precursors. The materials and radionuclides tested varied, as well as the detection equipment used for each evaluation. Medical radionuclides were tested on common medical surfaces with typical results of greater than 95% removal. Non-medical surfaces and radionuclides met with a range of results, 31% to 99% removal. Fluorine-18 was easily removed from most material, except shoe leather. Other nuclides tested include ^{3}H, ^{125}I and ^{14}C. Materials tested included Plexiglas, lead bricks, metals and vinyl floor tiles with a single iteration for each test (Eddington, 2007).

3.2.3 Sandia National Laboratories Testing of Decon Gel 1101

The final work reviewed was official correspondence from Sandia National Laboratory to the manufacturer, as to the results of a September 2007 testing with the Decon Gel 1101.

The Decon Gel 1101 testing was conducted on concrete, carbon steel, stainless steel, and Plexiglas. The radionuclides tested were ^{241}Am,^{239} Pu and ^{137}Cs. Each nuclide was dissolved in a solution with a pH of one or less. The testing materials were uniformly cut and application of a stock radionuclide was done with a pipettor. Duplicates were created and tested for each material/radionuclide. Initial counts were taken with a high purity germanium detector for ^{137}Cs and a hand held alpha scintillator for ^{241}Am and ^{239}Pu. Then a generous application of Decon Gel 1101 was applied and allowed to dry for 24 hours. No secondary coats were applied.

Cesium-137 demonstrated greater than 96% removal on all materials except concrete, which was approximately 16%. The two other radionuclides, specified in the previous paragraph, ranged from 71% to 98% removal on all surfaces except ^{239}Pu on Plexiglas, which was approximately 54% removal (Holt, 2007).

4. Materials

4.1 Nuclides

Each of the nuclides used in this experiment was selected due to classification as one of the "Nine Isotopes of Interest" by the Department of Energy (DOE) or due to its similar chemical properties to the listed nuclides. The radionuclides selected were ^{154}Eu, ^{137}Cs and ^{60}Co. Both cobalt and cesium have been tested by Sandia National Laboratory for use in RDDs and are considered to have a higher probability of use in an RDD event than many other nuclides (Argonne National Laboratory, 2005; Musolino, 2006).

4.1.1 Europium -154

Europium is a rare earth metal, a trivalent lanthanide that ignites in air at high temperature and has ductile properties. It acts like other lanthanides and the trivalent actinides and as such, europium's adsorptive properties can be assumed to be similar to americium[*]. For this experiment, ^{154}Eu was chosen for its 35.5% abundant gamma ray at 1.274 MeV, which allowed it to be detected more readily than other europium isotopes whose energies were either less abundant or very low. Europium-154 has a half-life of 8.593 years and decays via beta emission to a stable ^{154}Gd (Baum, 2002). The ^{154}Eu was obtained from the Oregon State University Radiation Center storage, with an activity of 66,230 Bq (1.79 µCi). It was in an acidic solution with a pH of approximately 0.5. Each application of 0.1ml of solution resulted in an activity of 735 Bq (0.019 µCi) deposited on the surface of interest.

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[*] Paulenova, A. Professor, Oregon State University, Personal Interview, 2 May 2008.

4.1.2 Cesium -137

Cesium is an ductile alkali metal. It is normally a solid at room temperature and below, a liquid above room temperature and generally soluble in water (CRC, 1978; Zumdahl, 1993). Cesium-137, with a 30.07 year half-life, is used in medical and industrial settings as well as in research applications. It decays by beta emission to ^{137}Ba, either meta-stable or stable form. The ^{137m}Ba converts to stable ^{137}Ba with a half-life of 2.55 minutes, producing a gamma ray emission with an energy of 0.662 MeV and a peak abundance of 89.9% (Baum, 2002).

The ^{137}Cs used in this experiment was purchased as a cesium chloride (CsCl) in 0.1M hydrochloride (HCl) in solution, pH 1. The purchased activity was 185,000 Bq (5 μCi) in 5 ml of solution. The solution was diluted to 10ml of solution which allowed for an activity of 1850 Bq (0.05 μCi) for each application of 0.1ml of solution.

4.1.3 Cobalt-60

Cobalt is a first series transitional element. It is a bluish, white metal known for its ability to form oxides and adhere to metallic surfaces, making it ideal for alloys (Zumdahl, 1993). Cobalt-60 is used in medicine, industry and research; it has a half-life of 5.27 years. It is produced mainly by neutron activation and has two 100% abundant peak gamma energies, 1.173MeV and 1.332 MeV (Shleien, 1998; Whicker, 1982). For this experiment, ^{60}Co was made via neutron activation in the Oregon State University TRIGA reactor from ^{59}Co dissolved in 0.1M nitric acid (HNO_3), pH 1, resulting in an activity of 88,800 Bq (2.4 μCi) (activity determined via High Purity

Germanium Detector). Each application of 0.1ml of solution deposited an activity of approximatly1300 Bq (0.035 µCi).

4.2 Sampling Materials

This section describes the four materials that were used in the study. The properties of each are discussed below.

4.2.1 Concrete

Figure 4.1 Old Concrete Prior to Cut

Concrete is a mixture of portland cement (silica, alumina and lime), sand, aggregate and water and has been used as a construction material since the third century B.C. (Olin, 1995).

Three versions of concrete material were tested: old concrete; newly poured concrete; and painted concrete.

Figure 4.2 Old Concrete Aggregate

The old concrete was obtained from the destruction site of a local hotel in excess of 25 years of age[†] (see Figure 4.1.). The source of the aged concrete materials is presumed to have been locally obtained and therefore similar to current

[†] Sealy, P., Site Project Manager, Personal Interview, 17 September 2007

concrete materials [‡](see Figure 4.2 and Figure 4.3). Visual inspection of the concrete shows the aggregate size to be similar to the aggregate size used in new concrete (also analyzed in this study).

Twenty-three samples of old concrete were cut for analysis. There were no indications for preexisting sealant applications; however, each cut was done to minimize the effects of any possible preexisting sealant applications. No additional sealant was applied. The concrete was cut with a commercial, water cooled, concrete saw, with a new diamond blade, to maximize the number of 2 inch x 2 inch testing surfaces (Figure 4.4).

Figure 4.3 New Concrete Aggregate

Figure 4.4 Concrete Saw

The new concrete was poured at the same site of which the old concrete was removed during construction of new facilities. Aggregate size was between ¾ inch and number 4 sieve. This equates to a range of not larger than 19mm and

Table 4.1 Pour Data and Composition Data for New Concrete

Pour Date	18-Oct-07
Cement	8.96%
Sand	33.04%
Water	15.37%
Aggregate	41.11%
Air	1.52%

‡ Scholz, T., Professor Oregon State University, Personal Interview, 15 October 2007

not smaller than 4.75mm (Liu & Evett, 2001). Pour date and composition of the new concrete are provided in Table 4.1.

The concrete was poured in six standardized 4 inch testing cylinder molds and allowed to cure in the same exterior environment as the newly poured structures for 30 days. The cylinders were then moved to the laboratory and allowed to cure for another 30 days (Figure 4.5). The cylinders were removed from the molds and cut by the same commercial concrete saw as the old concrete. The cylinders were cut down the center vertically (Figure 4.6) and into one inch slices with slight variability due to the nature of the saw.

Figure 4.5 New Concrete Prior to Cut

Figure 4.6 New Concrete Diagrammed Cuts

To minimize irregularity due to the saw operations, 54 of the most accurate cuts were selected. Twenty-seven were painted with a commercial latex paint; 2 coats with 24 hours of drying time between each coat. Twenty-seven were set aside for testing with no sealant application. This allowed for nine samples of each type for each nuclide.

4.2.2 Tiles

Three types of tiles were analyzed. These include vinyl composite, porcelain, and granite, all of which were obtained at a local construction supply store.

Figure 4.7 Vinyl Composite Tile Sheet

4.2.2.1 Vinyl Composite

Vinyl Composite Tile or VCT is a commonly used commercial flooring material made of pressed heated colored vinyl chips that form solid sheets which can vary in thickness (Figure 4.7). It is composed of ground limestone, plasticizer, mineral fibers, polyvinyl chloride resin and pigments (Olin, 1995). One-eighth inch is the most common and was used for testing. They can be cut into varying sizes and 12 inch tiles were cut into 2 inch x 2 inch pieces for testing purposes (Figure 4.8). Normally they are applied to flooring with an adhesive, then waxed and buffed to allow for additional resilience. No wax was applied nor buffing done to the tested materials.

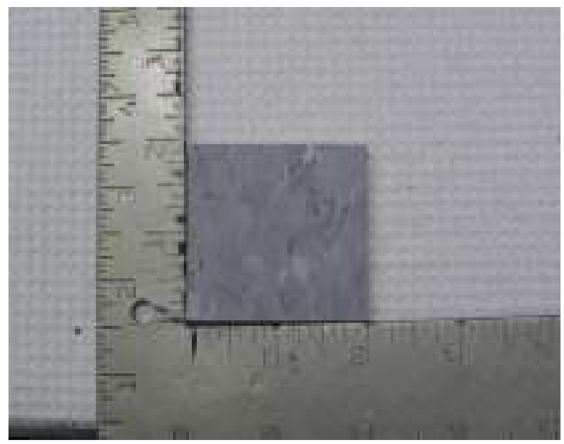

Figure 4.8 Vinyl Composite Tile Cut

4.1.2.2 Porcelain

Porcelain is a ceramic material with regulatory manufacturing standards governed by ANSI 137.1 (Olin, 1995). Porcelain tile is normally created from a mixture of clays that is heated, then pressed. This results in a tile that is dense, hard, fine-grained, nonporous, white ceramic ware when fired at a high temperature. The feldspar (a group of rock forming minerals) melts to form a natural glass and with the kaolin (essentially hydrated aluminum silicate), which is heat resistant, holds the structure (Budavari, 1996; Hornbostel, 1978). Because it is the hardest ceramic product, porcelain is used for electrical insulators and laboratory equipment. Porcelain tiles usually have a water absorption of less than 0.5%. Glazing the tiles makes them much harder and more wear and damage resistant. The porcelain tiles used for this experiment were double baked, according to sales personnel, to decrease permeability (Burton, 1921; Merritt, 1975).

Twenty seven individual 2 inch x 2 inch porcelain tiles were set aside for use (Figure 4.9). Additionally, 108 porcelain tiles were laid out with ⅛ inch tiles spacers to form 27 four tile squares. The tiles were attached to a large piece of plywood with

Figure 4.9 Single Porcelain Tile

Figure 4.10 Four Porcelain Tiles

AcrylPro Ceramic Tile Adhesive, following the manufacturer's instructions. (Figure 4.10) The adhesive was allowed to dry for 24 hours. Sanded tile grout (composed of portland cement, fine-graded sand and water) was mixed to manufacturer's instructions and applied to the spaces between the tiles (Olin, 1995). Residual grout was removed from the tile surfaces and was allowed to dry for 72 hours. Additional tile surface grout removal was done after the first 24 hours had passed. TileLab Grout Sealer was then applied per manufacture's instructions and allowed to dry for 30 minutes. A second coat of the sealant was applied, as recommended by the manufacturer and allowed to dry for 3 hours.

4.2.2.3 Granite

Granite is quartz or feldspar rock that is nearly impervious to water. Granite does not have the strict ANSI standards that ceramics have and, as such, other igneous rocks can be sold as "granite" (Olin, 1995). For the purposes of this experiment, granite tile in two sizes 1 inch x 1 inch (Figure 4.11) and 2 inch x 2 inch (Figure 4.12) were purchased. Both sizes were laid out and adhered in the same four tile manner as the

Figure 4.11 One inch Granite Tile

Figure. 4.12 Two inch Granite Tile

porcelain, with the center 2 inch x 2 inch area being the focus of contamination and experimentation. The 1 inch x 1 inch tiles had a marginally rougher surface than the 2 inch x 2 inch tiles.

4.3 Sodium Iodide (NaI(Tl)) Detector System

A Harshaw 5 inch x 5 inch sodium iodide, thallium doped, detector was used in conjunction with a Canberra multi-channel analyzer and Genie 2000 3.0 software.

4.3.1 Detector

For the detection of radioactive materials in this experiment scintillation detection was used. Scintillation detectors work through the collection of electrons and their conversion into light photons. The larger the detector crystal is, the more efficient the detector will be, all other things being equal (Knoll, 2000).

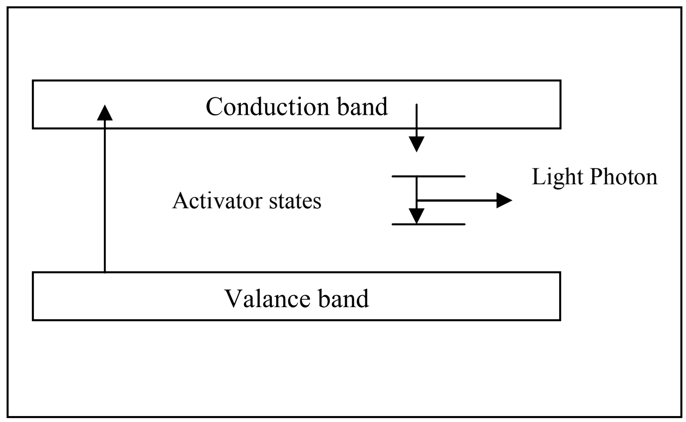

Figure 4.13 Conduction Band Theory

There are two main types of scintillation detectors, inorganic and organic. NaI (Tl) detectors are inorganic. Inorganic crystal scintillators have a lattice structure and work by what is called the band theory (Figure 4.13). There are two separate energy bands, the valance and conduction bands. The area that bound electrons normally occupy is called the valance band. The state above the valence band is the conduction band. The area inbetween is the forbidden band or band gap. Free electrons move to the conduction band through excitation of the crystal lattice. When radiation is deposited in the scintillation crystal some of the electrons in a full valance band will be excited and moved to the conduction band. This leaves a hole or vacancy in the valance band. Electrons in the conduction band immediate de-excite and go directly back to the valance band emitting ultraviolet light that is not readily detectable. To remedy this, an activator or dopant is added and act as an intermediate energy state down to the valance band. The energy is now less than that of the full forbidden gap, thus producing a visible photon that can be amplified in the photomultiplier tube (PMT) (Knoll, 2000). Essentially, the scintillator receives the gamma photon, begets a larger number of UV photons, which beget a lesser number of photoelectrons, which are then multiplied in PMT.

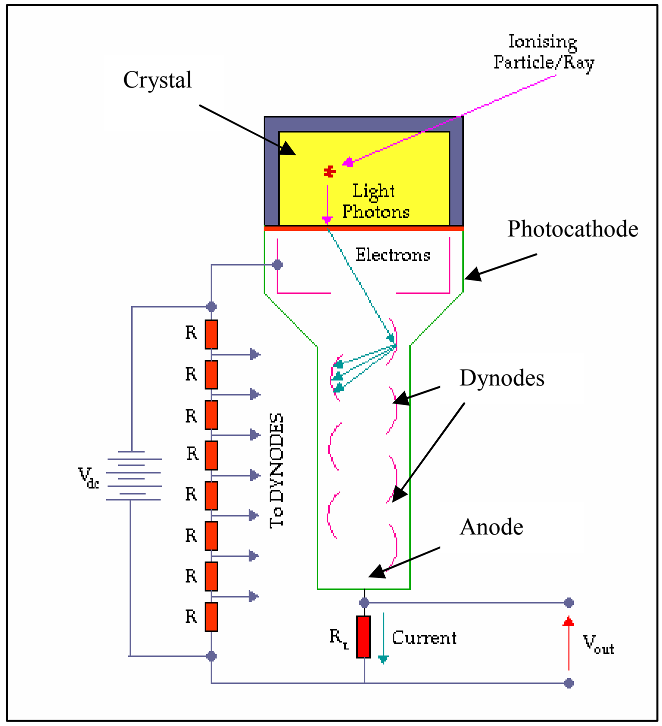

Figure 4.14 Crystal Detector System
(Adapted from Maher, 2007)

In a NaI(Tl) crystal, the hygroscopic crystal is encased in a hermetically sealed aluminum container with one end made of glass, or quartz, which will allow the transmission of light into the PMT; see Figure 4.14 (Knoll, 2000).

The PMT has two main sections, the photocathode and the dynodes. These are necessary components for proportional multiplication of electrons representing the ionizing particle interaction. The photocathode not only counts the scintillation but measures its magnitude and time of arrival. Since the light emitted by the crystal is in the blue or near ultraviolet range, this short wavelength results in higher efficiency (Burle Industries, 1989). The photocathode receives incident light (photon) from the detector and in response ejects electrons. The light transfers its energy to an electron, which moves to the surface of the materials and if it has enough energy (approximately 3 to 4 eV) will escape the photocathode. Once ejected the electrons multiplication procedure can begin. The free electrons are then focused toward a series of dynodes. The first dynode is positively charged (in comparison to the photocathode). A series of resistors run parallel to the dynodes, applying an increasing voltage along the dynode series. Typically, there are 10 dynodes in a PMT with a resultant multiplication factor of 10^3 to 10^8. This gives rise to the proportional multiplication of the electrons. To help maintain the constant potential there are capacitors strung in parallel with the resistors in the last few dynodes. It should be noted that at this point constant energy flow is very important to the PMT and a sudden surge or change in voltage during the multiplication would alter the number of electrons produced. At the end of the dynode series is an anode, where the charge is collected. This serves as the output for the PMT and the input to the Multi-Channel Analyzer (Burle Industries, 1989; Knoll, 2000). Promptly following the gamma ray deposition, a huge “cascade” of electrons rushes to the anode, resulting in a pulse whose magnitude is proportional to the initial energy of the interaction.

Resolution of a system is determined by both the scintillator and the PMT. Resolution of a NaI(Tl) system is usually defined as % resolution = (FWHM/ photopeak energy) * 100. FWHM is the measured Full Width at Half Maximum value for the photopeak in keV (Knoll, 2000).

4.3.2 Multi-Channel Analyzer with Genie 2000 3.0 Software

The Multi-Channel Analyzer (MCA) uses multiple windows or energy bins, variations of 2^n, and for this case, 1024 channels were used (1024 channels were recommended for a NaI(Tl) detector with this software). The multiple channels of the MCA allow for quantification and identification of pulses from the detector which are binned based on the amplitude of each pulse. For each gamma ray that deposits its distinct energy in the detector, an electronic pulse is sent to the MCA and the more electrons, the larger the amplitude of the pulse. This allows for quantification of the gamma emitter. Inside the MCA is an analog to digital converter (ADC). The ADC sorts the pulses into discrete windows or channels. The energy spectrum is distributed over the 1024 channels for this study. This creates a correlation between channel number and energy of the gamma ray for nuclide identification (Knoll, 2000).

The Genie 2000 Spectroscopy software gave a visual representation of the spectral analysis that is conducted via an algorithm in the software. It interacted with the MCA to start and stop data acquisition, determine dead time (the minimal amount of time needed for recovery of a system between two recordable events) and compensate for it via live and real time settings. Genie 2000 also allowed for peak search and algorithmic net count analysis by subtracting background during peak analysis (Canberra, 2006; Knoll, 2000).

5. Methods

5.1 Record Keeping

Through the entire process notes were taken and recorded in a paper notebook. All spectral data analysis was recorded. Additionally, net count, Full Width at Half Maximum, and uncertainty for each peak analysis were entered into a secondary computer in spreadsheet format.

5.2 Laboratory Methodology

The methodology is mostly taken from similar testing of the same product by Sandia National Laboratories (Holt, 2007). The work used an alpha scintillator and high purity germanium detector for detection analysis. The procedural plan of this experiment is shown in algorithmic form in Figure 5.1.

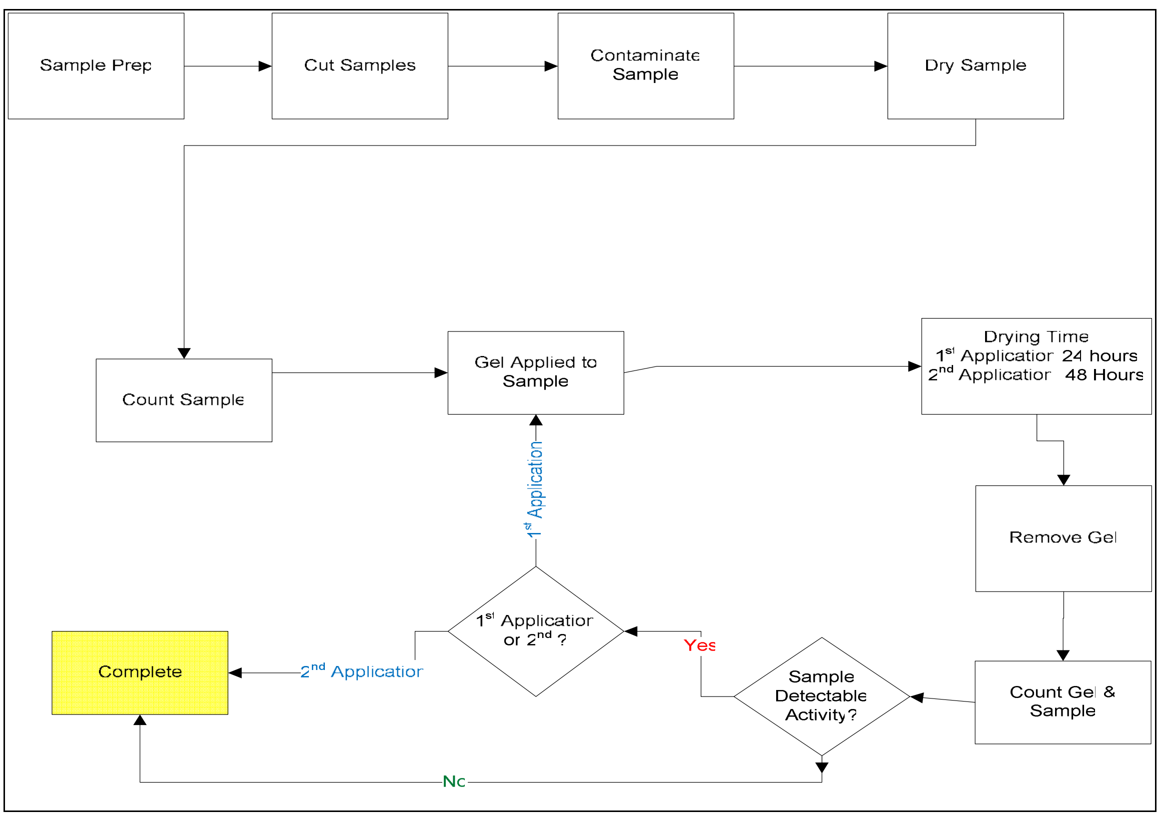

Figure 5.1 Procedural Plan

5.2.1 Sample Preparation

After each sample material was prepped and cut for experimentation, as stated in Chapter 3, if the material was larger than the 2 in. x 2 in. testing area required, a 2 in. x 2in. area was marked off with a permanent marker to show the contamination area and to standardize the surface area contaminated. Each sample was uniquely numbered.

5.2.2 Sample Contamination

Each radionuclide solution was deposited on the surface using a pipettor*. A test run of 0.1 ml of water was conducted on each material to ensure that the volume would be adequate on the 2 in. x 2 in. area. Samples were contaminated using the radionuclide solutions described in Chapter 3. The samples were placed on a table and allowed to dry to 24 hours while temperature and hygrometry were monitored. Each sample was counted and activity determined prior to gel application.

5.2.3 Sample Coating Application and Removal

After initial counts were taken, the sample areas were covered with the Decon Gel 1101. The gel was poured from the bottle to the surface of the sample. The gel was spread over the surface using a trowel and the excess gel was allowed to drip off the edges of the sample materials. Adequate gel was applied to ensure that lack of decontamination material was not a detriment to removal (see Figure 5.2).

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* For ^{154}Eu a Biohit Proline 100-1000100-1000 µl mechanical pipettor was used. For ^{137}Cs and ^{60}Co on Eppendorf Research Pro 5-100100-1000 µl Digital pipettor was used.

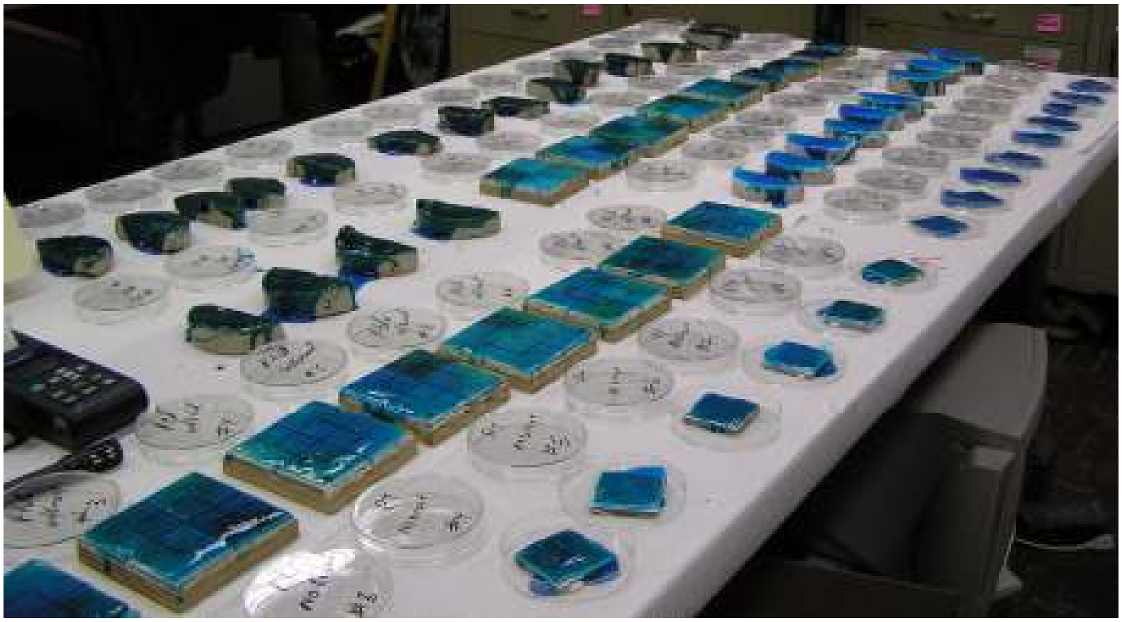

Figure 5.2 Samples During Drying Time

For the first application of the gel a 24 hour drying time was used. After this, the gels were removed, and both the gel and sample material were counted and analyzed. If any residual activity could be detected via NaI(Tl) detector on the test material, a second application of the gel was applied and allowed to dry for 48 hours. Then, the second gel application was removed, and both the gel and material were counted and analyzed again.

5.2.4 Analytical Method and Data Workup

Each sample was counted on a 5 inch x 5 inch NaI detector with a multi-channel analyzer described in Chapter 3. Optimum count time was determined for each nuclide from the applied nuclide activity and peak energy detectability: ten minutes for the ^{154}Eu, five minutes for both the ^{137}Cs and the ^{60}Co. Since the intensity of ^{154}Eu most abundant energy, 0.123 MeV, was very low, its second most abundant energy, 1.274 MeV, was used at 35.5% abundance, necessitating a longer count time.

The peak energy area was used to calculate the activity of the sample, using the peak energies net counts and detector efficiency. Calibration samples were used to determine efficiency and validate peak energies. Calibration check and backgrounds were performed routinely. An uncontaminated sample of each material was analyzed to account for naturally occurring radionuclides in the materials.

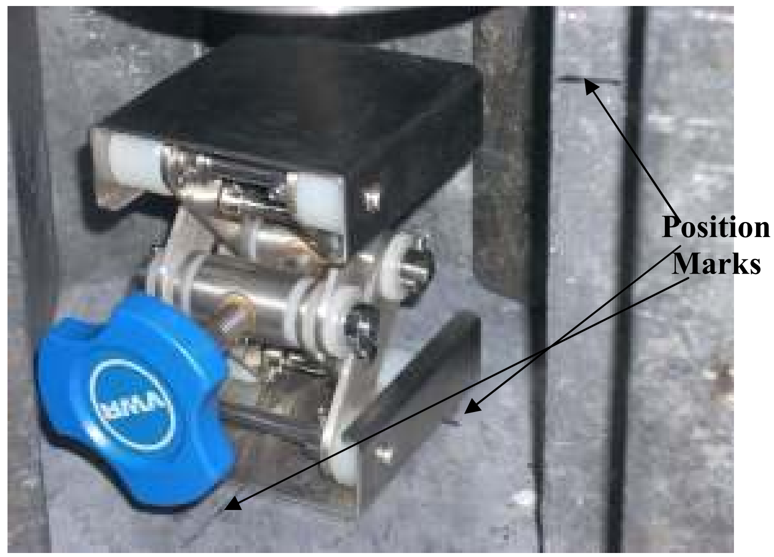

Figure 5.2 Scissor Jack in Detector

Initially, with the first nuclide tested, a platform of stacked Petri dishes was used to adjust height in order to maintain the geometry for counting efficiency, but greater consistency in geometry was obtained through the use of a scissor jack on the second and third nuclides, as shown in Figure 5.2.

Percent decontamination was calculated using two methods.

Method 1: $\% \, Decontamination = \left(\frac{A_{\circ Material} - A_{F,Material}}{A_{\circ Material}} \right) * 100$

Method 2: $\% \, Decontamination = \left(\frac{A_{Gel}}{A_{\circ Material}} \right) * 100$

$A_{\circ Material}$ = Counts on the material prior to decontamination

$A_{F,\,Material}$ = Counts on the material after decontamination

A_{Gel} = Counts in the gel

The first method is the same method used by Sandia National Laboratories and allowed for more realistic comparison of the data (Holt, 2007). The second method used was an alternative to demonstrate the actual amount of activity removed in the gel. This is discussed further in Chapter 7.

5.2.5 Uncertainty in Counting

The uncertainty values used in this experiment were calculated by the Genie 2000 3.0 software on the NaI(Tl) system and listed in the Results section as a percentage of the net count. A complete listing of the uncertainty values used is provided in Appendix C. The equation, taken from Genie 2000 3.1 Customization Tools Manual found on page 298, to calculate the uncertainty is

$$“\sigma_{area} = \sqrt{\left(\frac{A}{h}\right)^2 \sigma_h^2 + \sum_i \left(\frac{f_i A_i}{h_i}\right)^2 \sigma_{h_i^2}}$$

A it the area of the peak of interest,

h is the calculated height of the peak of interest,

σ_h is the calculated uncertainty of the peak height of the peak of interest,

A_i is the area of the ith interfering peak,

h_i is the calculated height of the ith interfering peak,

f_i is the fraction of the ith peak area that lies within the window of the peak of interest.

The uncertainty of peak location and peak width are assumed to be zero for all peaks” (Canberra, 2006).

This method of uncertainty was tested against the standard method for calculating uncertainty. Identified as "Spreadsheet Data" Tables 5.1 and 5.2.

$$\sigma = \sqrt{\sigma_{total}^2 + \sigma_{background}^2}$$ (Knoll, 2000)

The comparison was done using high and low activities of ^{60}Co and ^{137}Cs. It showed that the higher the activity, the closer the calculated uncertainty was with the software calculated uncertainty. This can be seen in Table 5.1 and 5.2. Additionally, there were interfering peaks that are taken into consideration in the software calculation that are not in the standard calculation, and this is could account for some of the difference between the calculation uncertainties.

Table 5.1 ^{60}Co Comparison of Uncertainty Methods

^{60}Co Higher Activity	Gross Counts	Background Counts	Net Counts	Uncertainty
Genie 2000 Data	53837	32982	20855	241.25
Spreadsheet Data	56152	16800	39352	270.09
^{60}Co Lower Activity	Gross Counts	Background Counts	Net Counts	Uncertainty
Genie 2000 Data	3945	2834	1111	143.84
Spreadsheet Data	3277	2700	577	77.31

Table 5.2 ^{137}Cs Comparison of Uncertainty Methods

^{137}Cs Higher Activity	Gross Counts	Background Counts	Net Counts	Uncertainty
Genie 2000 Data	113980	11636	102344	333.19
Spreadsheet Data	108754	7500	101254	340.96
^{137}Cs Lower Activity	Gross Counts	Background Counts	Net Counts	Uncertainty
Genie 2000 Data	6750	5382	1368	47.4
Spreadsheet Data	6295	3750	2545	100.22

The software uncertainty was reported in the Appendix data tables, since it has been accepted as reputable with the scientific community.

6. Results

6.1 Evaluation of Decon Gel 1101 with ^{154}Eu on Materials

Tables 6.1.1 through 6.1.7 show sample results for each iteration of the materials tested with ^{154}Eu. Figure 6.1 and Figure 6.2 show the mean percentage removed in the gel and from the material.

Table 6.1.1 Data for Analysis of Single Porcelain Tiles with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	4410	2.32%	3830	2.04%	n.d.	-
# 2	5410	2.03%	5240	2.00%	n.d.	-
# 3	5600	1.96%	5160	2.03%	n.d.	-
# 4	6640	1.74%	6030	1.49%	n.d.	-
# 5	5510	1.97%	5070	2.04%	n.d.	-
# 6	6310	1.79%	5130	0.87%	n.d.	-
# 7	6250	1.81%	5770	1.89%	n.d.	-
# 8	5740	1.93%	5050	2.09%	n.d.	-
# 9	6130	1.87%	5470	1.96%	n.d.	-

n.d.: not detectable

Table 6.1.1 Data from Analysis of Single Porcelain Tiles (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
#1	87%	100%	13%	N/A	N/A	87%	100%
#2	97%	100%	3%	N/A	N/A	97%	100%
#3	92%	100%	8%	N/A	N/A	92%	100%
#4	91%	100%	9%	N/A	N/A	91%	100%
#5	92%	100%	8%	N/A	N/A	92%	100%
#6	81%	100%	19%	N/A	N/A	81%	100%
#7	92%	100%	8%	N/A	N/A	92%	100%
#8	88%	100%	12%	N/A	N/A	88%	100%
#9	89%	100%	11%	N/A	N/A	89%	100%
Mean	90%	100%				90%	100%
Std Dev	4%	0%				4%	0%

N/A: Non Applicable
n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.1.2 Data from Analysis of Vinyl Composite Tiles with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	6260	1.83%	6270	1.80%	n.d.	-
# 2	6360	1.75%	6280	1.77%	35.6	171.74%
# 3 †	2680	23.21%	6010	1.85%	n.d.	-
# 4	6960	1.69%	6110	1.49%	156	32.19%
# 5	7080	1.60%	6220	1.73%	n.d.	-
# 6	7070	1.64%	6270	1.76%	n.d.	-
# 7	7480	1.57%	5730	1.93%	n.d.	-
# 8	6870	1.69%	5950	1.84%	n.d.	-
# 9	6760	1.69%	5840	1.87%	n.d.	-

Table 6.1.2 Data from Analysis of Vinyl Composite Tiles (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	100%	100%	0%	N/A	N/A	100%	100%
# 2	99%	99%	1%	N/A	N/A	99%	99%
# 3 †	224%	100%	-124%	N/A	N/A	-	-
# 4	88%	98%	10%	N/A	N/A	88%	98%
# 5	88%	100%	12%	N/A	N/A	88%	100%
# 6	89%	100%	11%	N/A	N/A	89%	100%
# 7	77%	100%	23%	N/A	N/A	77%	100%
# 8	87%	100%	13%	N/A	N/A	87%	100%
# 9	86%	100%	14%	N/A	N/A	86%	100%
Mean	89%	100%				89%	100%
Std Dev	46%	1%				7%	1%

† # 3 was not included in the mean or results, as there was an error in the initial counts.
N/A: Non Applicable
n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.1.3 Data from Analysis of Porcelain Tiles with Grout with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	1230	5.74%	992	6.87%	272	21.43%
# 2	2660	3.27%	768	8.52%	1030	3.73%
# 3	1900	4.24%	508	12.58%	658	9.93%
# 4	3280	2.80%	2450	3.34%	13.1	79.08%
# 5	3920	2.48%	3460	2.71%	445	13.15%
# 6	2790	3.12%	1360	5.56%	395	15.31%
# 7	3600	2.54%	1510	5.13%	305	13.81%
# 8	2090	3.99%	530	4.00%	1070	6.62%
# 9	2960	3.01%	1080	6.38%	715	9.04%

Table 6.1.3 Data from Analysis of Porcelain Tiles with Grout (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	81%	78%	-3%	n.d.	581	81%	47%
# 2	29%	61%	32%	n.d.	1590	29%	60%
# 3	27%	65%	39%	267	n.d.	41%	100%
# 4	75%	100%	25%	n.d.	n.d.	75%	100%
# 5	88%	89%	0%	n.d.	n.d.	88%	100%
# 6	49%	86%	37%	n.d.	791	49%	28%
# 7	42%	92%	50%	n.d.	797	42%	22%
# 8	25%	49%	23%	n.d.	517	25%	25%
# 9	36%	76%	39%	n.d.	948	36%	32%
Mean	50%	77%				52%	57%
Std Dev	25%	16%				23%	34%

N/A: Non Applicable
n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.1.4 Data from Analysis of Granite Tiles with Grout with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
#1 SGT	1870	4.23%	1290	5.52%	n.d.	-
#2 SGT	3180	2.82%	2980	2.85%	n.d.	-
#3 SGT	2190	3.53%	2000	3.93%	n.d.	-
#4 SGT	3060	2.93%	1830	4.37%	605	9.44%
#5 LGT	4790	2.16%	3420	2.56%	501	10.93%
#6 LGT	4460	1.26%	3900	2.38%	225	23.95%
#7 LGT	3440	2.86%	788	8.20%	2470	3.44%
#8 LGT	‡		3030	2.88%	303	19.17%
#9 LGT	3950	2.44%	2340	3.54%	498	13.44%

Table 6.1.4 Data from Analysis of Granite Tiles with Grout (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
#1 SGT	69%	100%	31%	N/A	N/A	69%	100%
#2 SGT	94%	100%	6%	N/A	N/A	94%	100%
#3 SGT	91%	100%	9%	N/A	N/A	91%	100%
#4 SGT	60%	98%	20%	N/A	N/A	60%	98%
#5 LGT	71%	90%	18%	N/A	N/A	71%	90%
#6 LGT	87%	95%	8%	N/A	N/A	87%	95%
#7 LGT	23%	28%	5%	N/A	N/A	23%	28%
#8 LGT			-	N/A	N/A	-	-
#9 LGT	59%	87%	28%	N/A	N/A	59%	87%
Mean	69%	87%				69%	87%
Std Dev	23%	24%				23%	24%

‡ # 8 LGT was not included in the results, as there was an error in the initial counts. The software showed a negative count.
SGT: Small Granite Tile 1in. x in. tiles
LGT: Large Granite Tile 2 in. x 2in. tiles
N/A: Non Applicable
n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.1.5 Data from Analysis of Painted Concrete with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	8990	1.50%	6080	1.79%	n.d.	-
# 2	10400	1.08%	6330	1.75%	n.d.	-
# 3	9300	1.48%	6450	1.73%	n.d.	-
# 4	10200	1.35%	5330	1.96%	525	11.98%
# 5	10600	1.28%	2580	3.27%	648	9.63%
# 6	9950	1.44%	5350	1.60%	133	39.02%
# 7	14400	1.11%	5820	1.88%	n.d.	-
# 8	12900	1.18%	6970	1.68%	244	22.97%
# 9	13900	1.13%	8520	1.39%	n.d.	-

Table 6.1.5 Data from Analysis of Painted Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	68%	100%	32%	N/A	N/A	68%	100%
# 2	61%	100%	39%	N/A	N/A	61%	100%
# 3	69%	100%	31%	N/A	N/A	69%	100%
# 4	52%	95%	43%	n.d.	302	52%	97%
# 5	24%	94%	70%	n.d.	294	24%	97%
# 6	54%	99%	45%	n.d.	n.d.	54%	100%
# 7	40%	100%	60%	N/A	N/A	40%	100%
# 8	54%	98%	44%	n.d.	n.d.	54%	100%
# 9	61%	100%	39%	N/A	N/A	61%	100%
Mean	54%	98%				54%	99%
Std Dev	14%	2%				14%	1%

N/A: Non Applicable
n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.1.6 Data from Analysis of New Concrete with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	7620	1.64%	1160	2.52%	3040	2.83%
# 2	7660	1.63%	1710	4.29%	2290	2.43%
# 3	8590	1.54%	944	7.59%	3310	2.72%
# 4	7060	1.72%	997	2.96%	2220	3.80%
# 5	8070	1.57%	1770	3.68%	2870	2.18%
# 6	6560	1.81%	1080	6.29%	2480	3.31%
# 7	8110	1.29%	1670	4.75%	3700	2.41%
# 8	7550	1.68%	1920	4.06%	2920	2.52%
# 9	8030	1.61%	1110	6.52%	3540	2.51%

Table 6.1.6 Data from Analysis of New Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	15%	60%	45%	765	3600	25%	53%
# 2	22%	70%	48%	n.d.	2320	22%	70%
# 3	11%	61%	50%	327	3000	15%	65%
# 4	14%	69%	54%	n.d.	2040	14%	71%
# 5	22%	64%	43%	574	4180	29%	48%
# 6	16%	62%	46%	454	2960	23%	55%
# 7	21%	54%	34%	764	4130	30%	49%
# 8	25%	61%	36%	1470	3490	45%	54%
# 9	14%	56%	42%	951	3070	26%	62%
Mean	18%	62%				26%	58%
Std Dev	5%	5%				9%	9%

n.d.: not detectable

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.1.7 Data from Analysis of Old Concrete with 600 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	6970	1.70%	3360	2.69%	2030	3.76%
# 2 ‡	1820	38.58%	2460	3.39%	1900	4.40%
# 3	5710	1.58%	1450	5.16%	1410	5.44%
# 4	8160	1.57%	3480	2.58%	2310	3.50%
# 5	6350	1.82%	1650	3.92%	2320	3.56%
# 6	7970	1.59%	2330	1.51%	1820	1.23%
# 7	5880	1.92%	2310	3.57%	1890	3.35%
# 8	5570	1.97%	2930	2.91%	1920	4.28%
# 9	5240	2.03%	2600	3.23%	1420	4.99%

Table 6.1.7 Data from Analysis of Old Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	48%	71%	23%	364	458	53%	93%
# 2 ‡			-140%	326	1590	153%	13%
# 3	25%	75%	50%	537	1710	35%	70%
# 4	43%	72%	29%	388	2180	47%	73%
# 5	26%	63%	37%	494	849	34%	87%
# 6	29%	77%	48%	442	1250	35%	84%
# 7	39%	68%	29%	n.d.	1780	39%	70%
# 8	53%	66%	13%	659	1700	64%	69%
# 9	50%	73%	23%	183	763	53%	85%
Mean	39%	71%				57%	72%
Std Dev	11%	5%				37%	24%

‡ # 2 was not included in the results, as there was an error in the initial counts.
n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

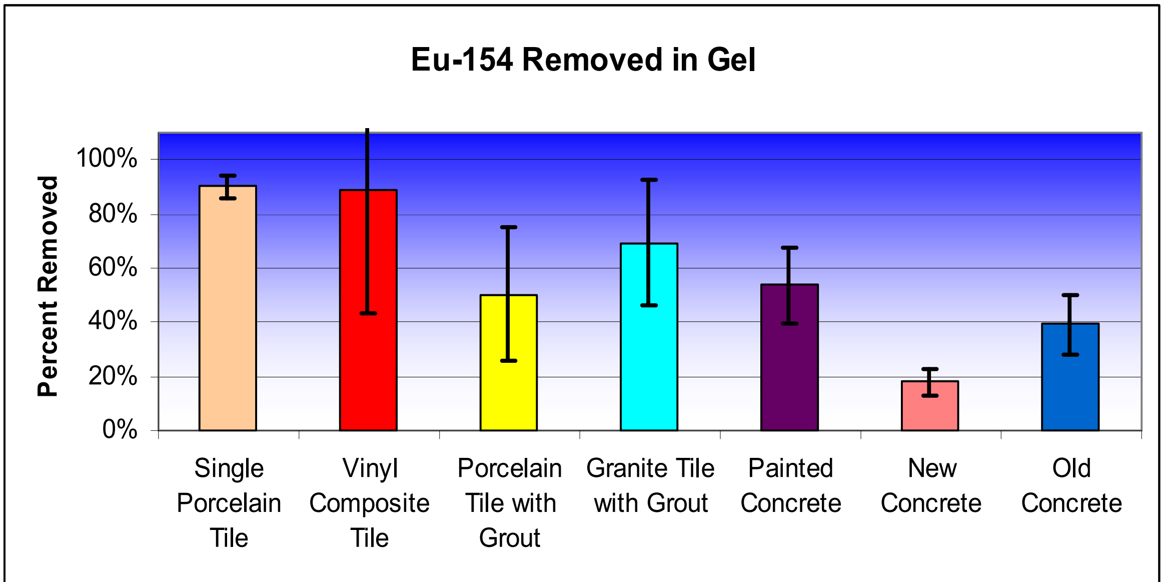

Figure 6.1 Mean Percent Removal of ^{154}Eu Contained in Gel

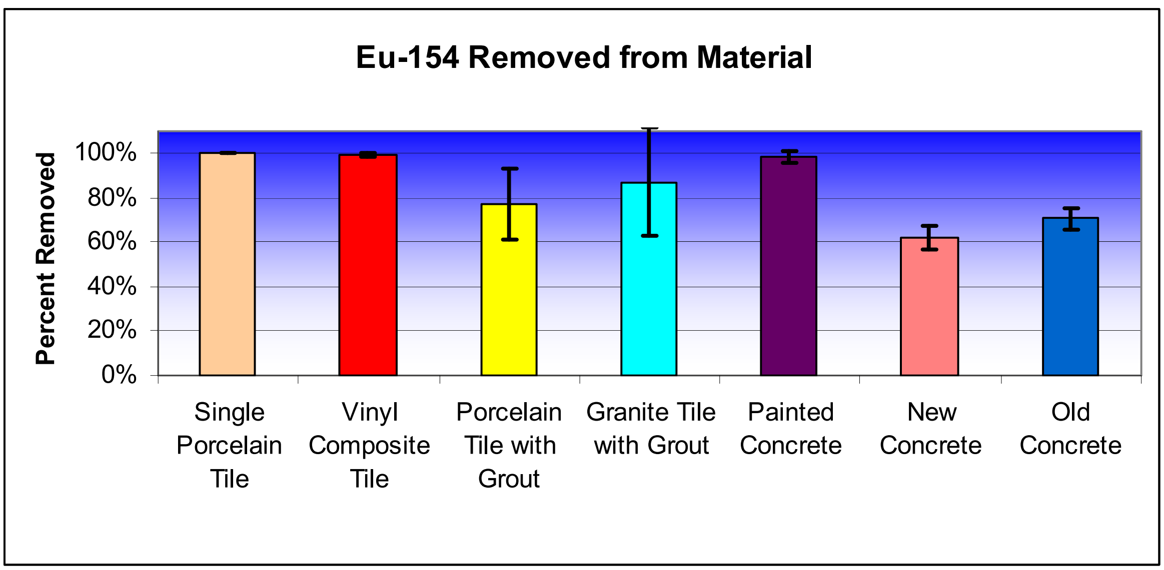

Figure 6.2 Mean Percent Removal of ^{154}Eu from the Test Materials

6.2 Evaluation of Decon Gel 1101 with ^{137}Cs on Materials

Tables 6.2.1 through 6.2.7 show sample results for each iteration of the materials tested with ^{137}Cs. Figure 6.3 and Figure 6.4 show the mean percentage removed in the gel and from the material.

Table 6.2.1 Data from Analysis of Single Porcelain Tiles with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	105000	0.31%	86900	0.36%	2450	3.25%
# 2	103000	0.32%	88700	0.35%	2340	2.03%
# 3	106000	0.31%	80900	0.37%	3070	2.83%
# 4	104000	0.32%	90900	0.35%	3000	1.04%
# 5	107000	0.31%	89300	0.35%	1880	4.40%
# 6	102000	0.32%	84300	0.36%	2450	0.64%
# 7	108000	0.31%	90300	0.35%	2560	2.49%
# 8	104000	0.32%	86100	0.36%	2730	1.36%
# 9	103000	0.32%	80100	0.37%	1930	0.48%

Table 6.2.1 Data from Analysis of Single Porcelain Tiles (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	83%	98%	15%	1390	1330	84%	99%
# 2	86%	98%	12%	1140	1240	87%	99%
# 3	76%	97%	21%	2460	1550	79%	99%
# 4	87%	97%	10%	1730	1300	89%	99%
# 5	83%	98%	15%	988	765	84%	99%
# 6	83%	98%	15%	1290	1210	84%	99%
# 7	84%	98%	14%	1500	1090	85%	99%
# 8	83%	97%	15%	1100	1990	84%	98%
# 9	78%	98%	20%	1660	1280	79%	99%
Mean	83%	98%				84%	99%
Std Dev	4%	0%				3%	0%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.2.2 Data from Analysis of Vinyl Composite Tiles with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	102000	0.32%	82000	0.37%	6650	1.52%
# 2	96900	0.33%	77100	0.38%	5350	1.77%
# 3	97100	0.33%	78200	0.38%	9220	1.25%
# 4	91900	0.34%	70200	0.40%	10600	1.14%
# 5	99400	0.32%	82600	0.37%	7230	1.42%
# 6	101000	0.32%	81200	0.37%	8040	0.15%
# 7	99400	0.32%	84900	0.36%	6440	1.57%
# 8	103000	0.32%	84700	0.36%	4840	1.95%
# 9	104000	0.04%	81400	0.37%	9490	1.25%

Table 6.2.2 Data from Analysis of Vinyl Composite Tiles (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	80%	93%	13%	3110	2880	83%	97%
# 2	80%	94%	15%	3140	1970	83%	98%
# 3	81%	91%	10%	5050	4720	86%	95%
# 4	76%	88%	12%	5120	4760	82%	95%
# 5	83%	93%	10%	3580	3430	87%	97%
# 6	80%	92%	12%	4120	2900	84%	97%
# 7	85%	94%	8%	3920	3000	89%	97%
# 8	82%	95%	13%	3380	2360	86%	98%
# 9	78%	91%	13%	5020	5220	83%	95%
Mean	81%	92%				85%	96%
Std Dev	3%	2%				2%	1%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.2.3 Data from Analysis of Porcelain Tiles with Grout with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	102000	0.33%	49600	0.48%	47800	0.49%
# 2	96000	0.34%	41500	0.51%	52800	0.46%
# 3	102000	0.33%	43800	0.51%	45700	0.50%
# 4	90000	0.35%	11800	1.08%	80900	0.37%
# 5	98800	0.34%	29200	0.64%	67800	0.41%
# 6	99600	0.33%	52500	0.46%	43500	0.51%
# 7	99300	0.34%	22100	0.74%	79100	0.38%
# 8	99100	0.34%	32400	0.60%	63900	0.42%
# 9	97000	0.34%	25500	0.68%	68200	0.41%

Table 6.2.3 Data from Analysis of Porcelain Tiles with Grout (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	49%	53%	5%	7220	43400	56%	57%
# 2	43%	45%	2%	11100	40200	55%	58%
# 3	43%	55%	12%	5260	38700	48%	62%
# 4	13%	10%	-3%	3440	71200	17%	21%
# 5	30%	31%	2%	8290	54000	38%	45%
# 6	53%	56%	4%	6170	33900	59%	66%
# 7	22%	20%	-2%	7180	65700	29%	34%
# 8	33%	36%	3%	10400	49400	43%	50%
# 9	26%	30%	3%	4440	61100	31%	37%
Mean	35%	37%				42%	48%
Std Dev	13%	16%				13%	14%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.2.4 Data from Analysis of Granite Tiles with Grout with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
#1 SGT	106000	0.31%	30900	0.62%	67800	0.41%
#2 SGT	102000	0.32%	11500	0.88%	88100	0.37%
#3 SGT	94100	0.34%	37900	0.62%	59000	0.41%
#4 SGT	106000	0.31%	30600	0.52%	65900	0.05%
#5 LGT	98100	0.34%	30500	0.66%	67300	0.39%
#6 LGT	96400	0.34%	16400	0.62%	84800	0.41%
#7 LGT	98800	0.34%	30700	1.09%	67200	0.36%
#8 LGT	103000	0.33%	42100	0.55%	59400	0.44%
#9 LGT	104000	0.33%	27400	0.62%	73500	0.42%

Table 6.2.4 Data from Analysis of Granite Tiles with Grout (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
#1 SGT	29%	36%	7%	10100	58400	39%	45%
#2 SGT	11%	14%	2%	4910	76720	16%	25%
#3 SGT	40%	37%	-3%	10100	41800	51%	56%
#4 SGT	29%	38%	9%	12600	49200	41%	54%
#5 LGT	31%	31%	0%	11200	52700	43%	46%
#6 LGT	17%	12%	-5%	5600	71900	23%	25%
#7 LGT	31%	32%	1%	9840	52900	41%	46%
#8 LGT	41%	42%	1%	10200	43500	51%	58%
#9 LGT	26%	29%	3%	16000	55100	42%	47%
Mean	28%	30%				38%	45%
Std Dev	10%	11%				12%	12%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.2.5 Data from Analysis of Painted Concrete with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	110000	0.31%	89400	0.35%	5650	1.76%
# 2	113000	0.30%	89800	0.35%	5520	1.79%
# 3	106000	0.31%	83500	0.36%	8610	1.33%
# 4	102000	0.32%	70800	0.40%	13800	0.99%
# 5	104000	0.32%	73800	0.39%	12900	1.03%
# 6	107000	0.31%	81000	0.37%	14100	0.98%
# 7	105000	0.32%	83800	0.36%	6890	1.54%
# 8	114000	0.30%	93700	0.33%	4890	1.99%
# 9	114000	0.30%	92300	0.34%	7540	1.45%

Table 6.2.5 Data from Analysis of Painted Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	81%	95%	14%	3740	2720	85%	98%
# 2	79%	95%	16%	2880	1990	82%	98%
# 3	79%	92%	13%	4280	3140	83%	97%
# 4	69%	86%	17%	3010	11100	72%	89%
# 5	71%	88%	17%	4260	7630	75%	93%
# 6	76%	87%	11%	2470	10800	78%	90%
# 7	80%	93%	14%	2440	4550	82%	96%
# 8	82%	96%	14%	3380	2130	85%	98%
# 9	81%	93%	12%	2830	3690	83%	97%
Mean	78%	92%				81%	95%
Std Dev	5%	4%				4%	4%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.2.6 Data from Analysis of New Concrete with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	89400	0.34%	22400	0.74%	63800	0.43%
# 2	94600	0.33%	26100	0.68%	73300	0.39%
# 3	98100	0.33%	25200	0.69%	68700	0.41%
# 4	97100	0.33%	24800	0.69%	77700	0.37%
# 5	105000	0.32%	26200	0.68%	68000	0.41%
# 6	101000	0.32%	26400	0.67%	70800	0.40%
# 7	101000	0.32%	21100	0.76%	80200	0.36%
# 8	105000	0.32%	23500	0.72%	82600	0.36%
# 9	106000	0.31%	28500	0.64%	68200	0.41%

Table 6.2.6 Data from Analysis of New Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	25%	29%	4%	11500	51700	38%	42%
# 2	28%	23%	-5%	14100	59800	42%	37%
# 3	26%	30%	4%	11800	60200	38%	39%
# 4	26%	20%	-6%	13800	57300	40%	41%
# 5	25%	35%	10%	17100	50700	41%	52%
# 6	26%	30%	4%	10400	55300	36%	45%
# 7	21%	21%	0%	10500	62100	31%	39%
# 8	22%	21%	-1%	13400	52000	35%	50%
# 9	27%	36%	9%	10800	54200	37%	49%
Mean	25%	27%				38%	44%
Std Dev	2%	6%				3%	6%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.2.7 Data from Analysis of Old Concrete with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	107000	0.31%	27300	0.66%	78500	0.37%
# 2	109000	0.31%	28300	0.65%	76600	0.38%
# 3	97100	0.33%	27100	0.66%	70000	0.39%
# 4	96900	0.33%	41300	0.06%	57400	0.45%
# 5	98500	0.33%	29900	0.62%	79700	0.04%
# 6	109000	0.31%	32100	0.61%	67800	0.05%
# 7	95200	0.33%	33700	0.59%	65600	0.42%

Table 6.2.7 Data from Analysis of Old Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	26%	27%	1%	13600	53100	38%	50%
# 2	26%	30%	4%	12300	54600	37%	50%
# 3	28%	28%	0%	15000	52400	43%	46%
# 4	43%	41%	-2%	13600	40300	57%	58%
# 5	30%	19%	-11%	13600	54000	44%	45%
# 6	29%	38%	8%	11300	48900	40%	55%
# 7	35%	31%	-4%	11200	46500	47%	51%
Mean	31%	30%				44%	51%
Std Dev	6%	7%				6%	4%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

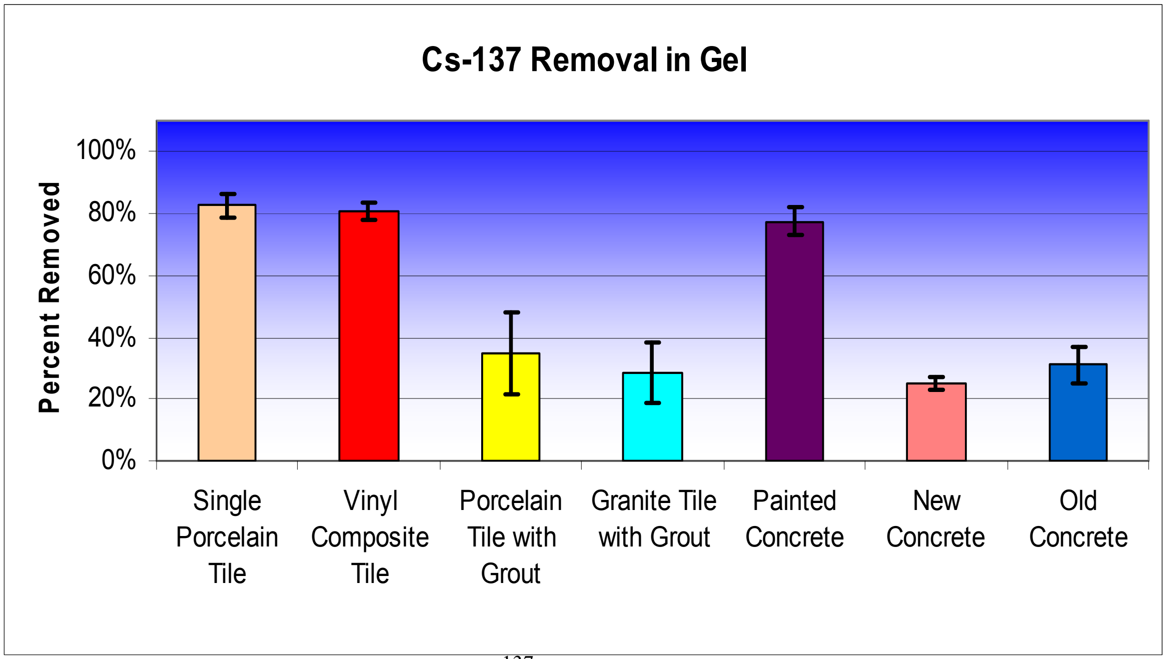

Figure 6.3 Mean Percent Removal of ^{137}Cs Contained in Gel

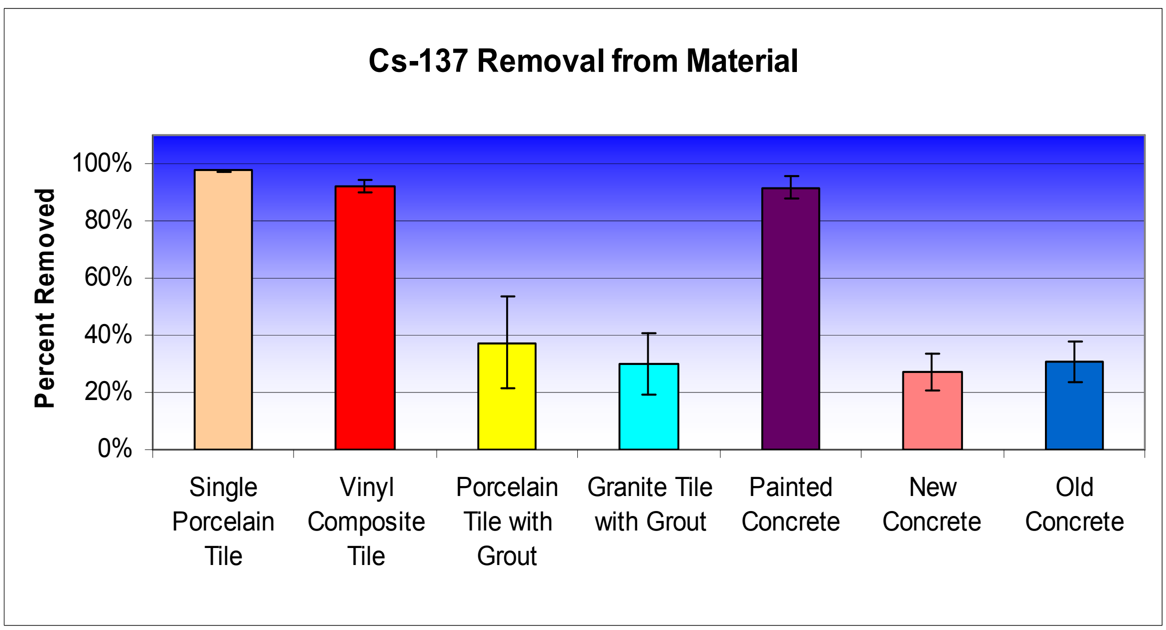

Figure 6.4 Mean Percent Removal of ^{137}Cs from the Test Materials

6.3 Evaluation of Decon Gel 1101 with ^{60}Co on Materials

Tables 6.3.1 through 6.3.7 show sample results for each iteration of the materials tested with ^{137}Cs. Figure 6.5 and Figure 6.6 show the mean percentage removed in the gel and from the material.

Table 6.3.1 Data from Analysis of Single Porcelain Tiles with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	31400	0.78%	28500	0.83%	198	38.94%
# 2	29700	0.80%	27100	0.86%	245	36.49%
# 3	29800	0.82%	27400	0.86%	n.d.	N/A
# 4	31900	0.77%	27100	0.86%	190	43.99%
# 5	31900	0.75%	27700	0.85%	417	25.51%
# 6	30600	0.80%	27500	0.85%	231	37.55%
# 7	29700	0.81%	28900	0.81%	450	24.20%
# 8	31100	0.78%	28400	0.83%	542	23.74%
# 9	30000	0.79%	28500	0.83%	75	101.59%

Table 6.3.1 Data from Analysis of Single Porcelain Tiles (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	91%	99%	9%	n.d.	n.d.	91%	100%
# 2	91%	99%	8%	n.d.	n.d.	91%	100%
# 3	92%	100%	8%	n.d.	n.d.	92%	100%
# 4	85%	99%	14%	236	n.d.	86%	100%
# 5	87%	99%	12%	227	n.d.	88%	100%
# 6	90%	99%	9%	158	n.d.	90%	100%
# 7	97%	98%	1%	n.d.	n.d.	97%	100%
# 8	91%	98%	7%	225	n.d.	92%	100%
# 9	95%	100%	5%	n.d.	n.d.	95%	100%
Mean	91%	99%				91%	100%
Std Dev	4%	1%				3%	0%

N/A: Non Applicable, n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.3.2 Data from Analysis of Vinyl Composite Tiles with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	33700	0.71%	26400	0.87%	1700	4.24%
# 2	33400	0.71%	27900	0.83%	1220	13.93%
# 3	26700	0.87%	23900	0.11%	1740	4.19%
# 4	33600	0.72%	27300	0.86%	484	22.04%
# 5	32300	0.74%	26700	0.87%	176	55.04%
# 6	30100	0.79%	27600	0.84%	1250	14.51%
# 7	32200	0.75%	27700	0.85%	1590	4.43%
# 8	30400	0.79%	27900	0.84%	910	6.59%
# 9	29600	0.80%	26300	0.87%	1490	4.76%

Table 6.3.2 Data from Analysis of Vinyl Composite Tiles (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	78%	95%	17%	n.d.	n.d.	78%	100%
# 2	84%	96%	13%	n.d.	n.d.	84%	100%
# 3	90%	93%	10%	459	n.d.	91%	100%
# 4	81%	99%	15%	n.d.	n.d.	81%	100%
# 5	83%	99%	17%	672	n.d.	85%	100%
# 6	92%	96%	4%	1220	n.d.	96%	100%
# 7	86%	95%	9%	797	n.d.	89%	100%
# 8	92%	97%	5%	n.d.	n.d.	92%	100%
# 9	89%	95%	6%	333	n.d.	90%	100%
Mean	86%	96%				87%	100%
Std Dev	5%	2%				6%	0%

n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.3.3 Data from Analysis of Porcelain Tiles with Grout with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	25800	0.89%	9470	1.48%	18500	1.06%
# 2	28500	0.84%	15100	1.17%	14200	1.20%
# 3	28300	0.84%	12200	1.31%	16400	1.10%
# 4	29800	0.81%	8070	1.66%	22300	0.93%
# 5	28500	0.83%	17200	1.10%	9180	1.56%
# 6	28500	0.83%	5580	2.07%	23300	0.92%
# 7	29300	0.83%	13400	1.22%	17600	1.07%
# 8	31200	0.78%	22700	0.95%	6490	1.86%
# 9	31400	0.77%	21300	1.03%	3170	3.08%

Table 6.3.3 Data from Analysis of Porcelain Tiles with Grout (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	37%	28%	-8%	2130	16100	45%	38%
# 2	53%	50%	-3%	2660	9830	62%	66%
# 3	43%	42%	-1%	1830	13500	50%	52%
# 4	27%	25%	-2%	1490	16500	32%	45%
# 5	60%	68%	7%	2280	7120	68%	75%
# 6	20%	18%	-1%	1120	19700	24%	31%
# 7	46%	40%	-6%	1550	15300	51%	48%
# 8	73%	79%	6%	3970	2830	85%	91%
# 9	68%	90%	22%	2110	1790	75%	94%
Mean	47%	49%				55%	60%
Std Dev	18%	25%				20%	23%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.3.4 Data from Analysis of Granite Tiles with Grout with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
#1 SGT	29100	0.81%	9570	1.54%	16100	1.12%
#2 SGT	31000	0.79%	11100	1.41%	18400	1.05%
#3 SGT	27200	0.86%	19300	1.02%	8050	1.68%
#4 SGT	29700	0.81%	10600	1.38%	17900	1.06%
#5 LGT	28300	0.84%	22500	0.97%	5130	1.37%
#6 LGT	29500	0.81%	22800	0.93%	8260	1.60%
#7 LGT	28600	0.82%	23700	0.92%	4870	2.17%
#8 LGT	32000	0.78%	8420	1.62%	19300	0.12%

Table 6.3.4 Data from Analysis of Granite Tiles with Grout (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
#1 SGT	33%	45%	12%	n.d.	14600	33%	50%
#2 SGT	36%	41%	5%	478	16200	37%	48%
#3 SGT	71%	70%	-1%	2540	5680	80%	79%
#4 SGT	36%	40%	4%	n.d.	5680	36%	81%
#5 LGT	80%	82%	2%	2150	3020	87%	89%
#6 LGT	77%	72%	-5%	2230	4590	85%	84%
#7 LGT	83%	83%	0%	2600	2480	92%	91%
#8 LGT	26%	40%	13%	1240	19500	30%	39%
Mean	55%	59%				60%	70%
Std Dev	24%	20%				28%	21%

n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.3.5 Data from Analysis of Painted Concrete with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	31700	0.75%	28400	0.83%	945	46.34%
# 2	32200	0.75%	26000	0.88%	989	14.54%
# 3	30900	0.79%	27100	0.86%	931	16.01%
# 4	22400	0.93%	21200	0.97%	359	35.06%
# 5	30500	0.79%	25200	0.88%	2570	3.20%
# 6	30000	0.80%	26900	0.87%	2330	3.52%
# 7	29900	0.80%	22320	0.99%	1760	4.22%
# 8	31000	0.78%	24200	0.91%	3610	2.65%
# 9	31000	0.79%	27100	0.86%	533	28.30%

Table 6.3.5 Data from Analysis of Painted Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	90%	97%	7%	n.d.	1170	90%	96%
# 2	81%	97%	16%	61	n.d.	81%	100%
# 3	88%	97%	9%	n.d.	n.d.	88%	100%
# 4	95%	98%	4%	n.d.	358	95%	98%
# 5	83%	92%	9%	n.d.	1920	83%	94%
# 6	90%	92%	3%	n.d.	2110	90%	93%
# 7	75%	94%	19%	484	1380	76%	95%
# 8	78%	88%	10%	53	3160	78%	90%
# 9	87%	98%	11%	n.d.	349	87%	99%
Mean	85%	95%				85%	96%
Std Dev	6%	4%				6%	4%

n.d.: not detectable
* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.3.6 Data from Analysis of New Concrete with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	30300	0.75%	5850	1.97%	22100	0.96%
# 2	31700	0.75%	7380	1.73%	21300	0.97%
# 3	33200	0.72%	10000	1.48%	18600	1.05%
# 4	30700	0.76%	6320	1.89%	21400	0.97%
# 5	29200	0.78%	5050	2.17%	20400	1.00%
# 6	31200	0.75%	7240	1.75%	21600	0.97%
# 7	30700	0.77%	6870	1.81%	22300	0.94%
# 8	32200	0.74%	4870	2.24%	22400	0.95%
# 9	30900	0.76%	6650	1.87%	20000	1.02%

Table 6.3.6 Data from Analysis of New Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	19%	27%	8%	1690	18200	25%	40%
# 2	23%	33%	10%	3240	15800	34%	50%
# 3	30%	44%	14%	3830	13000	42%	61%
# 4	21%	30%	10%	6240	14300	41%	53%
# 5	17%	30%	13%	2040	16700	24%	43%
# 6	23%	31%	8%	2830	18100	32%	42%
# 7	22%	27%	5%	4730	16000	38%	48%
# 8	15%	30%	15%	2860	17000	24%	47%
# 9	22%	35%	14%	3210	16600	32%	46%
Mean	21%	32%				32%	48%
Std Dev	4%	5%				7%	6%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

Table 6.3.7 Data from Analysis of Old Concrete with 300 Second Count Time

Sample Number	Initial Application on Material Net Counts	% Standard Deviation of Initial Net Count	Post Removal Gel Net Counts	% Standard Deviation of Gel Net Count	Post Removal Material Net Counts	% Standard Deviation of Post Net Count
# 1	32400	0.75%	7880	1.64%	19400	0.12%
# 2	31000	0.77%	9690	1.49%	19400	1.01%
# 3	30700	0.77%	7270	1.74%	21500	0.96%
# 4	30400	0.78%	5230	2.18%	20700	0.12%
# 5	31800	0.75%	9020	1.57%	17900	1.08%
# 6	31000	0.77%	8610	1.57%	20600	0.99%
# 7	30700	0.78%	10600	1.40%	19500	1.00%

Table 6.3.7 Data from Analysis of Old Concrete (continued)

Sample Number	% Removed in Gel	% Removed from Material	% Un-accounted *	Gel Net Counts After 2nd Usage	Sample Net Counts After 2nd Usage	Total Percentage Removed in Gel Both Applications	Total Percentage Removed from Material Both Applications
# 1	24%	40%	16%	3710	18000	36%	44%
# 2	31%	37%	6%	4300	13600	45%	56%
# 3	24%	30%	6%	3680	17000	36%	45%
# 4	17%	32%	15%	4270	15200	31%	50%
# 5	28%	44%	15%	4880	13800	44%	57%
# 6	28%	34%	6%	3370	16500	39%	47%
# 7	35%	36%	2%	4300	13100	49%	57%
Mean	27%	36%				40%	51%
Std Dev	6%	5%				6%	6%

* Unaccounted: (Total initial counts - post decontamination total counts (gel + material))/Total initial counts).

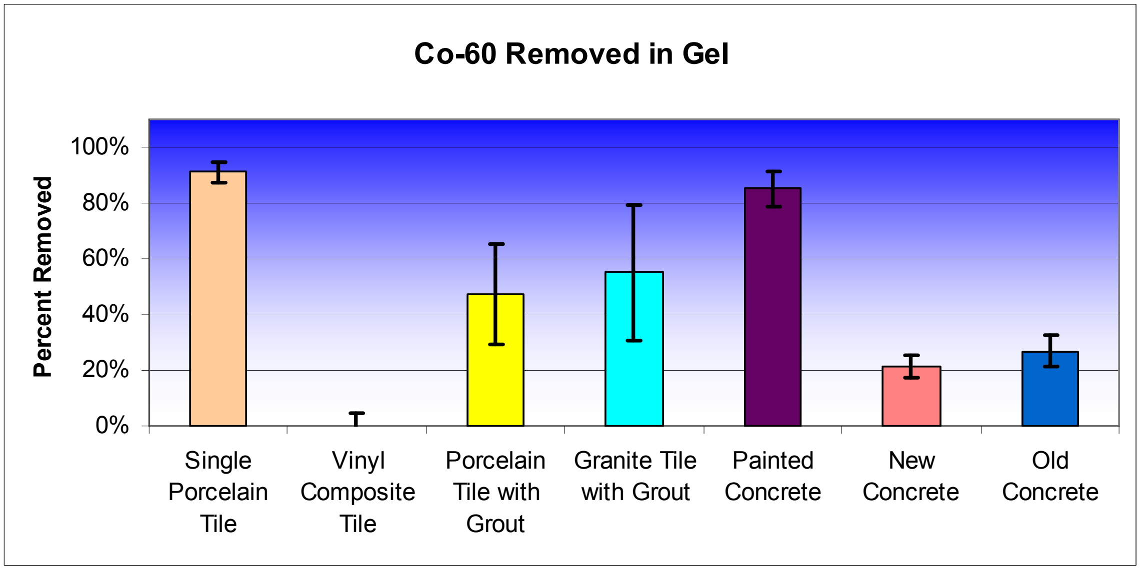

Figure 6.5 Mean Percent Removal ^{60}Co Contained in Gel

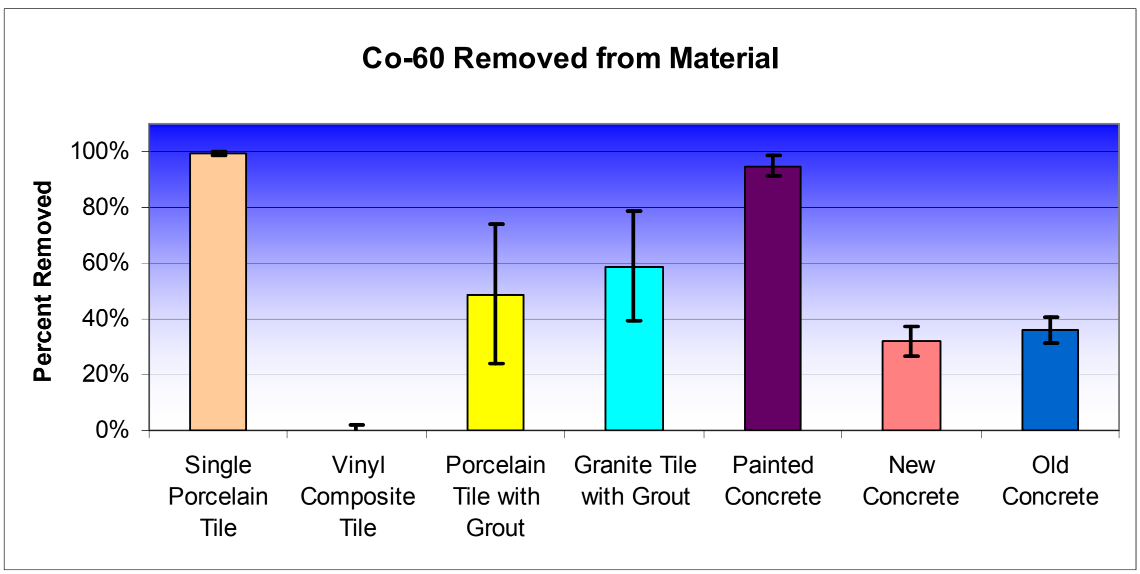

Figure 6.6 Mean Percent Removal of ^{60}Co from the Test Materials

7. Discussion

7.1 Differences in Calculation Methods

The two different percent decontamination calculation methods, discussed in Chapter 5, present a different perspective on the removal process. The percentage in the gel shows how effective the gel is at encapsulating and binding to isolate the radionuclides. The percentage removed from the material shows how effective the gel is at decontamination. Since the manufacturer touts the gel as viable for forensic analysis, knowing the difference between these two percentages could be critical. While both methods will be presented and addressed, for the purposes of comparison and discussion, the focus will be on removal from the material.

7.2 Use of the Decontamination Gel

The gel application process was uncomplicated and odorless. Although the manufacturer provided a trowel and paint brush, the trowel was the more user friendly. For applications on a smaller scale a plastic roller would be beneficial.

The peelable gel removal was quick and uncomplicated on all but the unsealed concrete surfaces. Some of the 24 hour and most of the 48 hour drying time gels required the use of tweezers on the unsealed concretes for complete removal.

Overall Removal Properties

The percentage removed varied greatly with the type of material as seen in Figures 7.1 and 7.2. The radionuclides were removed with ease from the ungrouted porcelain tile, showing a greater than 95% removal from the material with each nuclide and greater than 80% bond to gel for each nuclide. This discrepancy is discussed further in section 7.6.

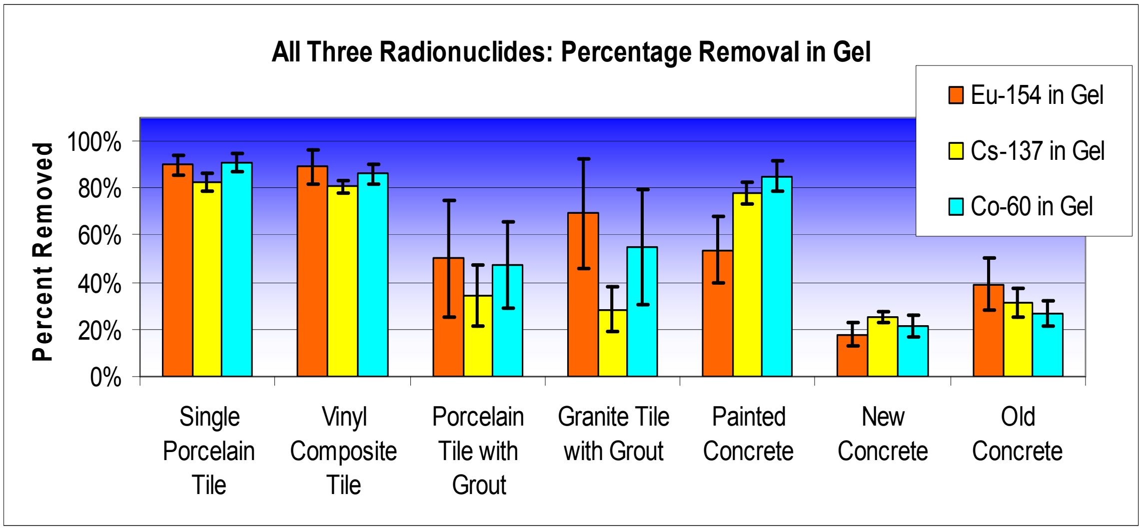

Figure 7.1 Comparison of First Application Percentage Removed into the Gel with All Three Nuclides

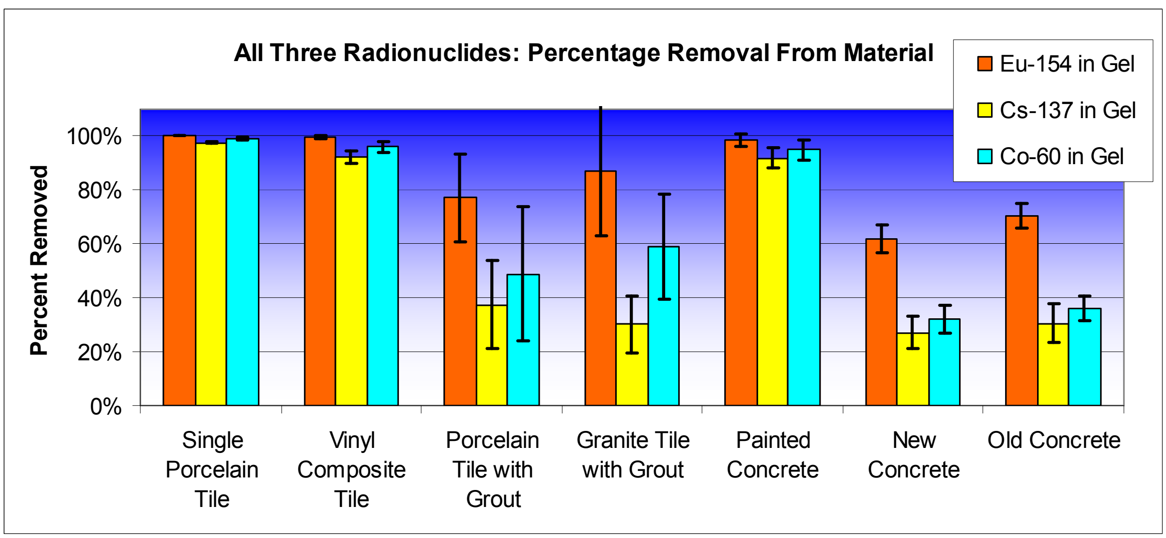

Figure 7.2 Comparison of First Application Percentage Removed From the Material with All Three Nuclides

The grouted granite and porcelain showed between 25% and 85% removal from the material and had the largest standard deviations of any of the materials. When comparing the ungrouted porcelain tile to the grouted, it is clear that the decontaminating gel has difficulty penetrating the grout.

The gel demonstrates great efficiency at removal from the painted concrete surfaces, greater than 95%. Since neither the old concrete nor the new concrete was sealed, this seems to be a defining factor in the removal efficiency.

Figure 7.3 Initial Application Gel, Post Removal

Additionally, the unsealed concrete presented a challenge in removal, since the gel penetrated each crevice. The age of the concrete seems to have little impact as shown in Figure 7.2. During the initial round of tests, the post removal gel slowly began to shrivel and harden. This presented geometric detection issues, as seen in Figure 7.3. This was rectified by placing the gel between fitted Petri dishes immediately following removal as seen is Figure 7.4. The Petri dish on the right contain the initial testing gel (allowed to dry without flattening) and the one on the left contain the gel using the second method. Nesting the gel in between the two Petri dishes allowed the gel to maintain a flat surface for more a consistent counting geometry.

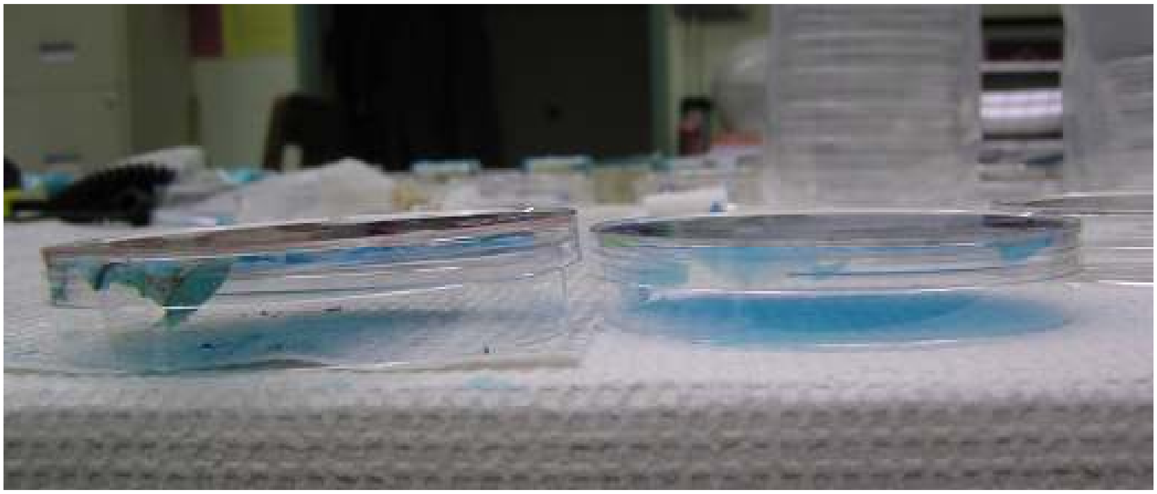

Figure 7.4 Differences in Geometry for First and Second Drying Methods

7.3 ^{154} Eu Removal

The initial round of tests was conducted with ^{154}Eu. The radionuclide was dissolved in a solution with a pH of <1; no visible reactions with the materials were noted.

Figure 7.5 shows background of uncontaminated VCT as compared to contaminated VCT with ^{154}Eu. The spectrum shows clarity of the peak of interest as compared to the background peaks.

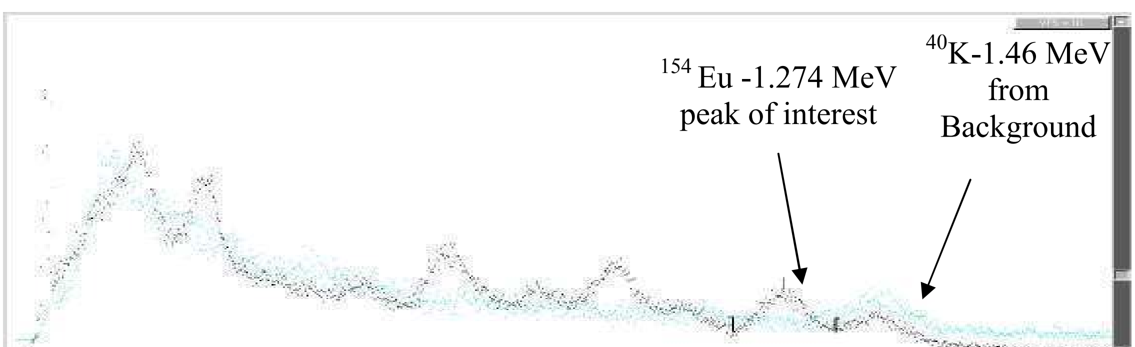

Figure 7.5 Spectra of ^{154}Eu (in Black) and Background of VCT (in Teal)

7.4 ^{137}Cs Removal

The second set of test was conducted with ^{137}Cs in a solution with a slightly higher pH ≈ 1. There was visible reaction in vinyl composite tile and both unsealed concretes. The reaction involved fizzing and bubbling, indicating possible damage to the surface of the material. This chemical reaction could be imbedding the nuclide deeper into the surface of the material. This could cause the decreased removal rate, consistently seen with this nuclide in Figure 7.2. Research has shown that the higher the pH, the greater the interaction with the materials (Bangesh, 1991; Adeleye, 1994).

Figure 7.6 shows a comparison between uncontaminated VCT and VCT contaminated with ^{137}Cs. The scale of the background is slightly greater to show the 1.46 MeV peak. The peak of interest is clearly discernable.

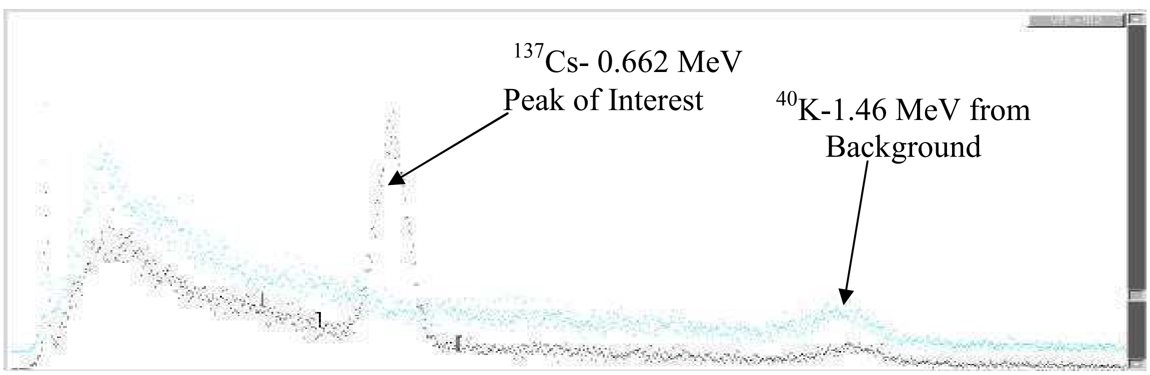

Figure 7.6 Spectra of ^{137}Cs (in Black) and Background of VCT (in Teal)

7.5 ^{60}Co Removal

The third set of tests conducted with ^{60}Co resulted in no visible interactions. Although the pH was also ≈ 1, a different chemical solution was used.

Figure 7.7 shows a comparison between uncontaminated VCT and VCT contaminated with ^{60}Co. Since the 1.173 MeV peak was determined to have greater efficiency than the 1.332 MeV peak, the 1.173 MeV peak was used as the peak of interest. Additionally, it was more clearly discernable, at lower activities, from the 1.46 MeV ^{40}K background peak.

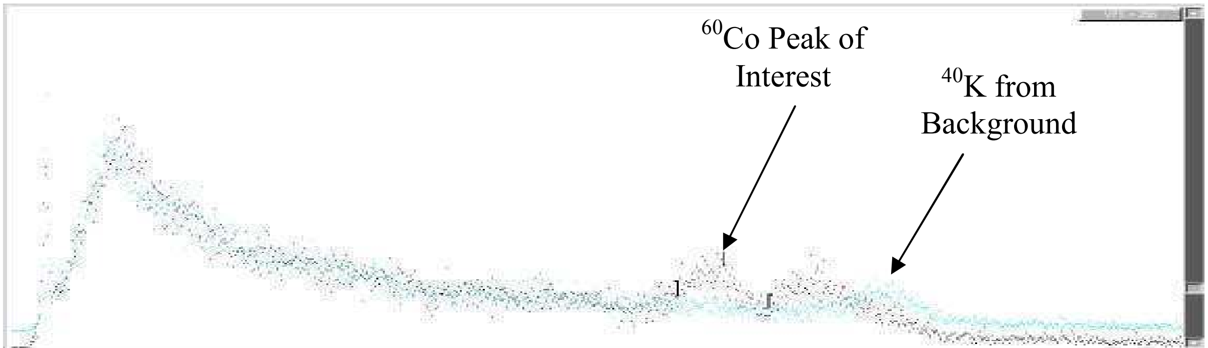

Figure 7.7 Spectra of ^{60}Co (in Black) and Background of VCT (in Teal)

7.6 "Unaccounted" Radioactivity in Experiment

In the tables in Chapter 6, the unaccounted column presents the percentage of radionuclide that was either "lost" or "found" after all counts were completed. This error is most likely due to the inconsistency of counting or due to loss of particle material during the removal process although post decontamination surveys found no spreadable contamination after gel removal. The ^{154}Eu data show the greatest amount of "loss" most likely due the geometry error introduced by the gel drying. The unaccounted number drops considerably in the second and third nuclide tests.

7.7 Comparison with other studies

The Sandia National Laboratories' (SNL) study of Decon Gel 1101 allows for a direct comparison with our ^{137}Cs on newly poured concrete. The same solution, pH, and drying time were used in both the Sandia testing and this research. Additionally, there were no indications of sealant being applied to the SNL concrete. Tables 7.1 and 7.2 were taken directly from the official correspondence between the manufacturer and SNL.

Table 7.1 Sandia National Laboratories Data for ^{137}Cs

Cs-137 data on Concrete

			1st Coating			2nd Coating			
Sample #	Initial Area	Initial Activity (μCi)	Final Area (1st coating)	Final Activity (μCi)	% decon	Final Area (2nd coating)	Final Activity (μCi)	% decon	Diff btwn 1st and 2nd coating
CCs-1	2.46E+4	1.0062	2.04E+4	0.8344	17.07%	1.80E+4	0.7371	26.75%	9.7%
CCs-2	2.38E+4	0.9735	2.01E+4	0.8221	15.55%	1.78E+4	0.7453	23.44%	7.9%

As seen in Table 7.1, the percentage removed from the material is ≈16% for the initial application and ≈25% for the second application in the SNL study, as compared to 27% removed on the first application and 43% on the second application for this study. Variations in the results could be due to differences in the application methods, drying times or content of concrete.

Table 7.2 Sandia National Laboratories Data ^{241}Am

Am-241 data on Concrete

Sample #	Initial Area	Initial Activity (μCi)	Counts after 1st coating	Activity after 1st decon (μCi)	% decon (1st)	Counts after 2nd coating	Activity after 2nd decon (μCi)	% decon (2nd)	Diff btwn 1st and 2nd coating
CAm-3	351	0.9799	60.4	0.1686	82.79%	21.7	0.0632	93.55%	10.76%
CAm-4	318	0.8878	53.4	0.1491	83.21%	17.14	0.0499	94.38%	11.17%

The overall trend indicates that the gel works better with the trivalent ^{154}Eu on unsealed new concrete than the ^{137}Cs. This is in agreement with the data presented by SNL in Table 7.2. Europium-154 can be compared to the ^{241}Am due to the similar adsorptive properties discussed in Chapter 4. Europium-154 has 59% removal for the initial application on the new concrete as compared to 83% for ^{241}Am. This is greater than the ^{137}Cs removal percentage in the SNL study (shown in sample numbers 1 and 2 in Table 7.1) and in this thesis research.

<u>7.8 Overall Second Application</u>

A second application of Decon Gel 1101 was applied to each surface that had any detectable residual radionuclide following the first decontamination. This test was allowed to dry for 48 hours, resulting in the greatest removal in the materials with the least percentage removal in the first application (see Figures 7.8 and 7.9. This is most likely due to a greater residual activity from the first application allowing for a greater percentage removed or it could be due to need for a longer drying period of grouted and unsealed concrete materials.

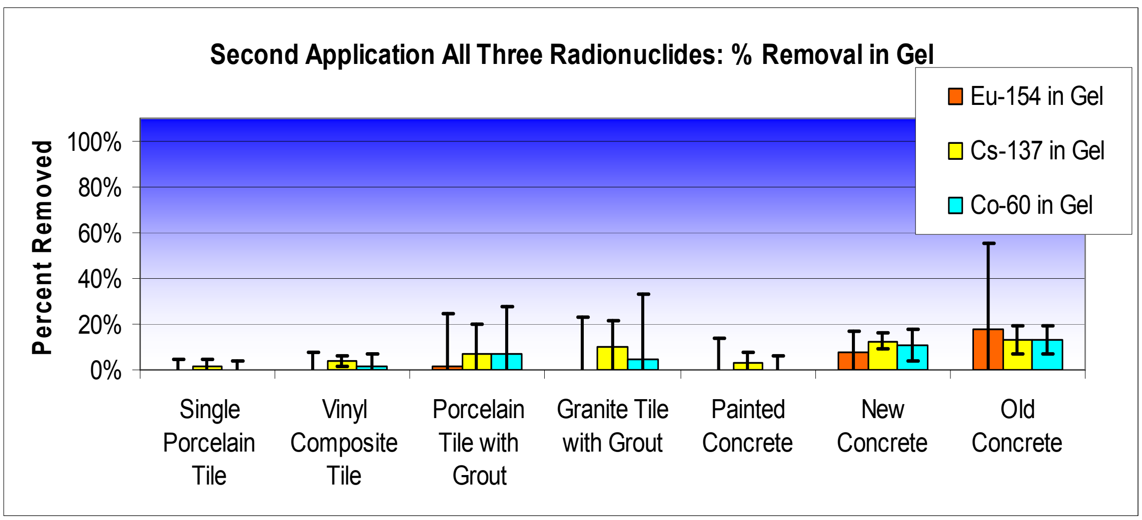

Figure 7.8 Second Application Comparison of First Application Percentage Removed with All Three Nuclides in Gel

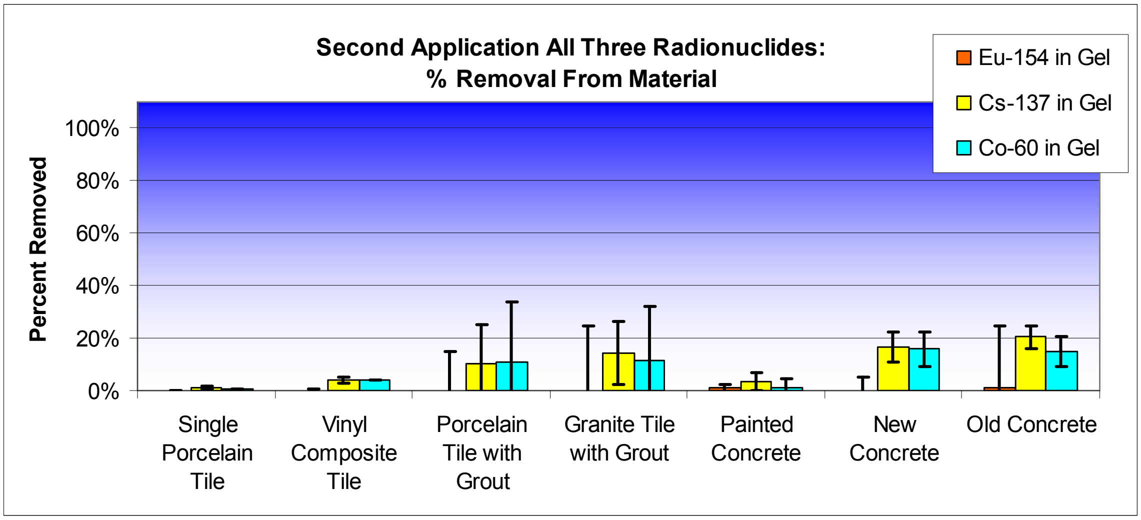

Figure 7.9 Second Application Comparison of First Application Percentage Removed with All Three Nuclides from Material

8. Conclusion

Decon Gel 1101 was determined to be a user friendly, low odor, peelable decontamination gel. It allowed for single or multiple material applications to the contaminated surfaces. While the rehydratable polymer does allow for any necessary recovery or qualitative analysis of the contaminant, a small amount of loss in radionuclide recovery in the gel should be taken into consideration for quantitative analysis.

For application in radiological consequence management, with additional research Decon Gel 1101 could prove to be a reliable decontamination method with select materials. Grouted materials and unsealed concrete did present challenges, which may require repeated applications or a different decontamination method. Since most laboratory environments would not have unsealed concrete or grout, this is less of an issue for general decontamination.

Decon Gel 1101 has many potential future applications. Each of the DOE "Nine Isotopes of Interest" should be tested for removal efficiencies. Variations in the drying time should be tested to determine the optimum and minimal drying time for each material for use in emergency situations. Questions that still need answered include: how does the decontamination gel work on fabric and polyvinyl chloride, and what role does the pH of the solution play in the adsorption process or absorption into the contaminated materials?

While Decon Gel 1101 does not completely remove all nuclides from every surface, it should be seen as a valuable tool in the tool box of decontamination methods.

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Appendices

Appendix A

Raw Data Spreadsheet

Raw Data File is included in the cd-rom found on the back cover of this document.

Appendix B

Sodium Iodide Spectroscopy Reports

Select reports are included in the cd-rom found on the back cover of this document.

Appendix C

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