AN ABSTRACT OF THE THESIS 0F

Michael T. Bak for the degree of Master of Science in Radiation Health Physics presented on March 18, 2003.

Title: RESEARCH TO DETERMINE SOURCE EFFICIENCIES (ε_S) FOR SCABBLED AND ROUGH CONCRETE SURFACES

Abstract approved:

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The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) requires that Final Status Surveys be performed on materials and surfaces that vary in surface smoothness and/or uniformity. To obtain accurate survey data, it may be necessary to adjust detector response for these surface variations. NUREG-1507 refers to such surface efficiency adjustment factors as ε_s, the source efficiency. This parameter is meant to be a detector-independent, yet surface and nuclide-dependent parameter that can be used to adjust observed count rate to provide a true measure of the degree of contamination present. Key measurements in the calculation of (ε_s) are the energy of the radionuclide contaminant and the average height of the detector above the contaminated surface. During the last year, Oregon State University, Department of Nuclear Engineering and Radiation Health Physics provided technical support for a Final Status Survey of a commercial nuclear plant. OSU NE/RHP has conducted research and experimentation to determine site-specific source efficiency (ε_s) values for concrete surfaces which had undergone simulated decommissioning activities, such as surface scabbling. Source efficiency (ε_s) values were determined for seven separate scabbled concrete surfaces which had been prepared using 5 tool types. Fourteen concrete cores were intentionally contaminated with known amounts of two beta emitting radionuclides: ^{204}Tl and ^{99}Tc. The ε_s values were examined as a function of the type of scabbled surface as well as the contaminating nuclide.

RESEARCH TO DETERMINE SOURCE EFFICIENCIES (ε_S) FOR SCABBLED AND ROUGH CONCRETE SURFACES

by

Michael T. Bak

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APPROVED:

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Major Professor representing Radiation Health Physics

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Head of the Department of Nuclear Engineering and Radiation Health Physics

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Dean of the Graduate School

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Michael T. Bak, Author

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CONTRIBUTION OF AUTHORS

Dr. Higley and Mr. Rocha from PGE assisted with data collection and interpretation of the data. Dr. Higley was also involved with the design and writing of the paper.

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RESEARCH TO DETERMINE SOURCE EFFICIENCIES (ε_S) FOR SCABBLED AND ROUGH CONCRETE SURFACES

ABSTRACT

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) requires that Final Status Surveys be performed on materials and surfaces that vary in surface smoothness and/or uniformity. To obtain accurate survey data, it may be necessary to adjust detector response for these surface variations. NUREG-1507 refers to such surface efficiency adjustment factors as ε_s, the source efficiency. This parameter is meant to be a detector-independent, yet surface and nuclide-dependent parameter that can be used to adjust observed count rate to provide a true measure of the degree of contamination present. Key measurements in the calculation of (ε_s) are the energy of the radionuclide contaminant and the average height of the detector above the contaminated surface. During the last year, Oregon State University, Department of Nuclear Engineering and Radiation Health Physics provided technical support for a Final Status Survey of a commercial nuclear plant. OSU NE/RHP has conducted research and experimentation to determine site-specific source efficiency (ε_s) values for concrete surfaces which had undergone simulated decommissioning activities, such as surface scabbling. Source efficiency (ε_s) values were determined for seven separate scabbled concrete surfaces which had been prepared using 5 tool types. Fourteen concrete cores were intentionally contaminated with known amounts of two beta emitting radionuclides: ^{204}Tl and ^{99}Tc. The ε_s values were examined as a function of the type of scabbled surface as well as the contaminating nuclide.

INTRODUCTION

In 1992 the Trojan Nuclear Plant (TNP)[1] shut down their reactor for the last time. Since then, Portland General Electric Company (PGE) has been decommissioning the plant. Under U.S. Nuclear Regulatory Commission (NRC) regulations all methods in the decommissioning process must have NRC approval. As of now the TNP staff have removed all the internal structures of the containment building including the core, cleaned and removed many structures and items in the auxiliary buildings and in the process of moving the fuel into dry cask storage. TNP staff are ready to do the final survey on all but the fuel pool building.

At this point in the decommissioning phase many buildings are ready for their final radiological release survey. Final status surveys are performed to ensure remaining residual radioactivity meet the release criteria as specified in 10CFR20 subpart E (2002). These surveys are performed on materials and surfaces that vary in surface roughness and/or uniformity. For beta-emitting contaminants distance to the detector is a critical factor in detector count rate. Surfaces that are widely varying in "roughness" may show different count rates compared to the same beta-activity deposited on a flat surface. Many of the surfaces are rough or scabbled due to the removal of layers of specialized paint which had been applied to prevent leaching of activity into the concrete. The paint was removed by special scabbling tools (mentioned later in the paper). To provide accurate estimates of residual activity, it was necessary to adjust detector responses for these surface variations. These surface variation adjustment factors are expressed as the source efficiency (ε_s). This is the surface geometry factor evaluated in this study.

This report describes the research and experimentation performed by Oregon State University (OSU), Department of Nuclear Engineering and Radiation Health

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[1] Owned by Portland General Electric Company, Trojan operated for nearly 17 years. It is located on U.S. highway 30, approximately 12 miles north of St. Helens in Columbia County, OR.

Physics, for the Trojan Nuclear Plant, to determine average height variations and specific ε_s values for several scabbled concrete surfaces. The purpose of this project was to find the source efficiency values for seven different scabbled[2] surfaces that are representative of surfaces to be surveyed during the final status survey project. These results will be used to show that the residual radioactivity satisfies the NRC regulation, 10CFR20.1402 (2002).

When determining ε_s, the detector efficiency (ε_i) needs to be known. The detector efficiency is the ratio of the count rate observed by the detector to the surface emission rate of a source for a specified geometry[3]. The distance of the detector to the source influences the detector efficiency (NUREG-1507, 1998). The source efficiency (ε_s) is the ratio of the number of particles emerging from the surface of a source to the number of particles of the same type created or released within that source per unit time (ISO 7503-1, 1988). This variable takes into account loss of counts by self absorption and/or increase of counts caused by backscatter. Source efficiency is affected by type of radiation, source uniformity, surface roughness and coverings, and surface composition (NUREG-1507, 1998).

The tracers used in this experiment were ^{99}Tc and ^{204}Tl. The tracer ^{99}Tc was used because the beta energy was similar to that of TNP contaminated surfaces. The ^{204}Tl was used to examine the effect of higher energy on ε_s and to bracket energies between the ^{99}Tc and ^{204}Tl (to allow others to find the ε_s for their energy). According to ISO 7503-1 (1988), the "rule of thumb" values for ε_s for these tracers should be 0.25 for ^{99}Tc and 0.5 for ^{204}Tl on flat surfaces.

METHODS AND PROCEDURES

Fourteen clean concrete core samples were provided to OSU by staff from the Trojan Nuclear Plant (Fig. 1). These cores were obtained from a concrete floor slab

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[2] Scabbling refers to the technique of removing surface material by pounding, grinding, or chipping.
[3] ε_i can be calculated as net/total 4π emissions or net/total 2π emission. This paper uses the 2π emission rate to calculate ε_i.

of similar age and composition as the concrete structures of the Auxiliary and Fuel buildings which are currently being decommissioned. The surfaces were scabbled prior to coring. They were pulled from the floor using a 25.5 cm diameter coring bit. The cores ranged from 15.25 cm to approximately 30.5 cm in thickness. Surfaces were prepared using five different scabbbling tools. Two cores were prepared using each method. The tools used in this process were: spade bit (Fig. 2a), bush head (Fig. 2b), fingered jack (Fig. 2c), needle gun (Fig. 2d), and floor scabbler (Fig. 2e). These tools are routinely used by staff at TNP in the decommissioning process. The floor scabbler (Fig. 2e) was used to create three different surfaces for analysis, using one, two, and multiple passes (Fig, 3). A qualitative assessment of the relative degree with which a specific tool scabbled a surface is provided in Table 1.

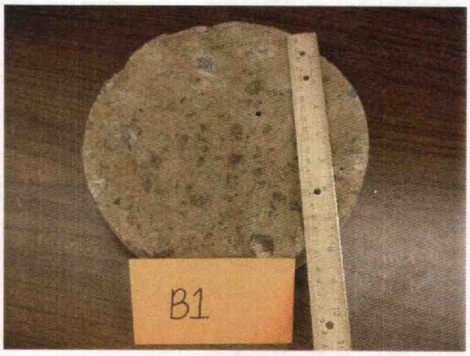

Fig. 1. Example of a scabbled concrete core from Trojan Nuclear Plant

Fig. 2a. Spade Bit

Fig. 2b. Bush Head

Fig. 2c. One Fingered Jack

Fig. 2d. Needle Gun

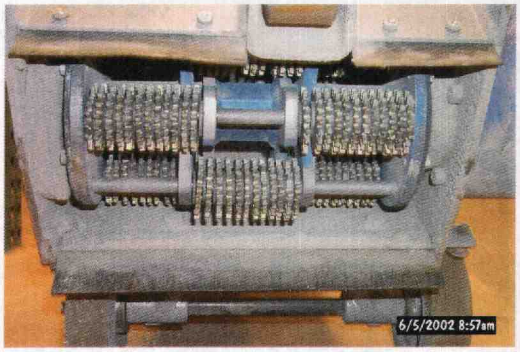

Fig. 2e. Floor Scabbler

Table 1. Comparison of surface roughness versus specific tool and application.

Sample	Degree of "roughness"
Spade Bit	High
Bush Head	↑
1-Finger Jack	↑
Needle Gun	Medium
Floor Scabbler	↑
Two Passes	↑
Multiple Passes	↑
One Pass	Low

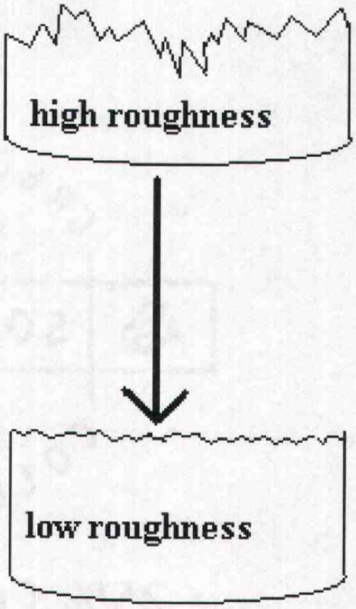

Fig. 3. Illustration of qualitative description high roughness to low roughness

EFFECTIVE SURFACE HEIGHT

Surfaces with obvious "roughness" may display different count rates than surfaces with a relative flat surface when the same activity has been deposited on them. To address this, the average surface height for each of the scabbled surface types was determined. Because the author could not find a standard method for determining effective height, one was constructed. Volume measurements were related to the average height of the surface. First the samples were sealed using a method mentioned later in this paper. Then they were leveled, as shown in Figure 4, by ensuring that the two highest points on the surface touched a level transit line that bisected the core surface. Once leveled, sealant strips[4] with plumbers putty were placed around the circumference of each core to form a two inch wall above the surface. A known volume of water was measured and poured onto the core until the

[4] Magic Bathtub Sealer Trim. Magic American Corporation. Cleveland, Ohio 44122-5955.

surface was completely submerged (Fig. 5). The average height of the surface was calculated using the formula:

$$h = \frac{v}{\pi r^2}$$

Where h is the effective height (cm) of the sample surface, r is the radius of the core (cm), and v is the volume of water required to completely submerge the surface under the water (cm^3). The average value of the two sample cores (made by the individual tool) was used to calculate the effective height for each set of cores (Table 2).

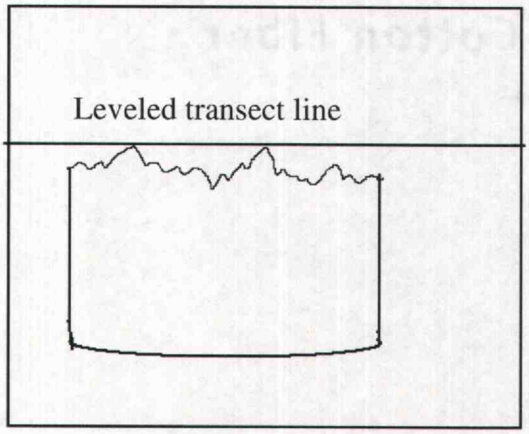

Fig. 4. Cross section of a cement core showing the leveling process

Fig. 5. Cement core with sealer trim around the top to keep the water in place while conducting the volumetric approach of finding the effective height

Table 2. Average effective heights for each tool.

Effective Height Results	
Sample	Average Height (cm)
Spade Bit	1.093
Bush Head	0.453
1-Finger Jack	0.516
Needle Gun	0.310
Floor Scabbler	
One Pass	0.369
Two Passes	0.343
Multiple Passes	0.335

PREPARATION OF CONTAMINANT SOLUTIONS

Two radioactive solutions of beta-emitters were purchased from Isotope Products[5]. One, a ^{99}Tc source was made from NH_4TcO_4 in H_20, with a total activity of 3763 kBq on 15 May 2002 in 9.989398 g (density of 0.9982 g ml^{-1}) and a specified radionuclide concentration of 380.4 kBq g^{-1}. The second solution was a ^{204}Tl source, made from TlCl in 1 M HCl, with a total activity of 3796 kBq on 15 May 2002 in 9.88820 g (density of 1.0171 g ml^{-1}) and a specified radionuclide concentration of 384.1 kBq g^{-1}.

[5] Isotope Products Laboratories, 24937 Avenute Tibbitts, Valencia, CA 91355

Secondary solutions were prepared from the commercially purchased solutions. The secondary solution of ^{204}Tl was made by pouring 100 ml of distilled water into a volumetric flask then adding 20 ml of HCl acid. This was followed by 600 μl of the primary ^{204}Tl into the solution. The solution was topped off to 200 ml with distilled water, and 4 drops of food coloring were added into the mixture to ensure visibility of the contaminant following application on the concrete surface. The activity concentration of the ^{204}Tl solution was 1518.48 Bq ml^{-1}.

The ^{99}Tc solution was made using a 600 μl aliquot of the ^{99}Tc standard solution and diluting it with 100ml of distilled water, adding 4 drops of another food coloring, and topping off with distilled water to 200 ml total volume. The activity concentration of the secondary ^{99}Tc solution was calculated at 1505.16 Bq m^{-1}.

DETECTION EQUIPMENT AND PRELIMINARY CALIBRATION

A Ludlum[6] model 43-68 gas-proportional detector was used in the determination of detector efficiency (Fig. 6 a and b). Although the measurement of ε_s is meant to be instrument independent, this is the same detector type as used by the Trojan surveying team. In this experiment the measurement height was kept at 1 cm (the same height Trojan surveyors used to keep the detector from the surface when surveying). This was done by means of an aluminum frame with 1 cm high leg attached to each corner (Fig. 7 a and b). The detector was attached to a Ludlum 2200 scalar ratemeter. Counting gas was used (P-10[7]), with the detector purged for approximately fifteen minutes with a flow rate of 15 to 50 cm^3 min^{-1}. During measurements the counting gas was set at a continuous flow rate of 5 cm^3 min^{-1} to keep condensation from developing on the probe face. The aluminum frame which supported the detector also contained a bubbler unit to indicate gas flow through the

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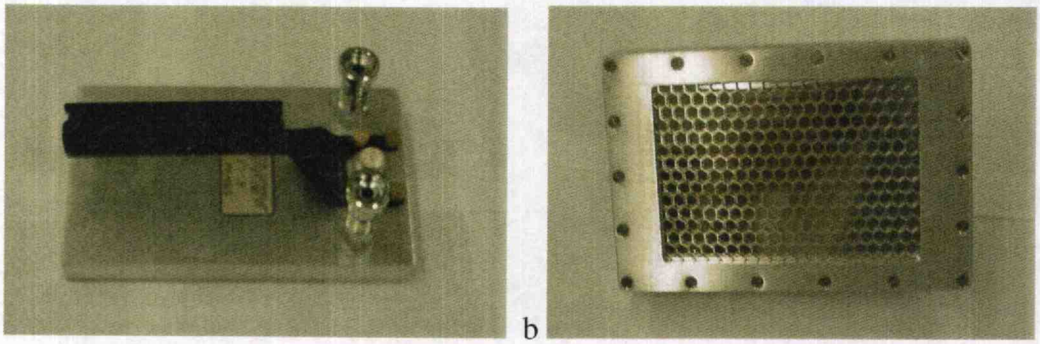
[6] Ludlum Measurements, Inc. P.O.Box 810/501 Oak Street, Sweetwater, Texas 79556

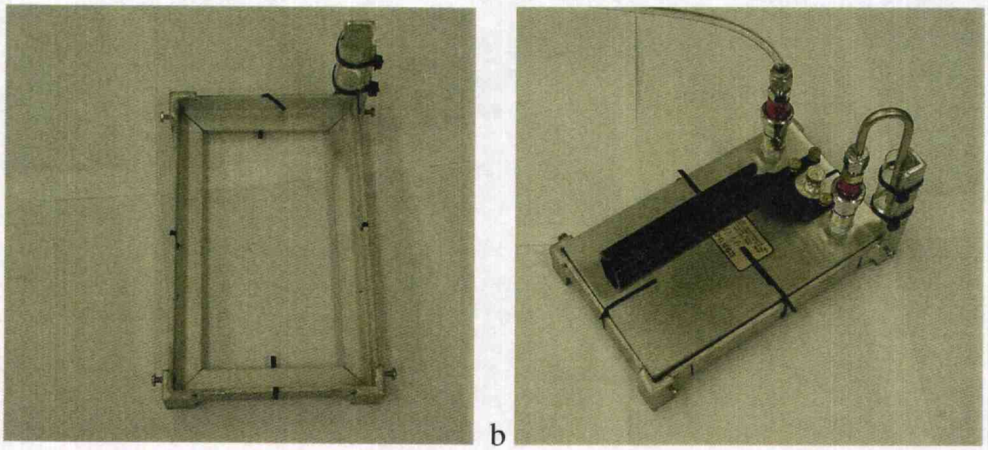
[7] P-10 gas mixture of 90% argon and 10% methane

detector. For this experiment the counting equipment was placed in a safety hood, and absorbent lab paper was used to cover the work area to prevent contamination.



a b

Fig 6. The Ludlum model 43-68 gas-proportional detector was used in the determination of surface efficiency. Picture a is the top view of the detector and picture b is the bottom of the probe face

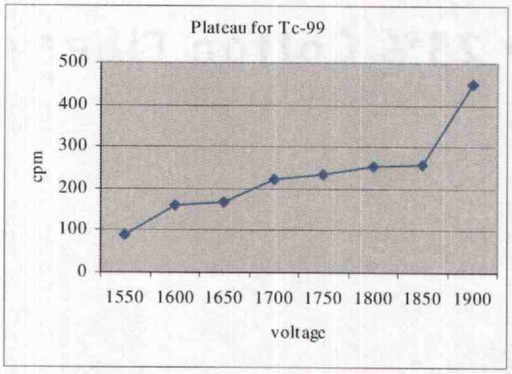


a b

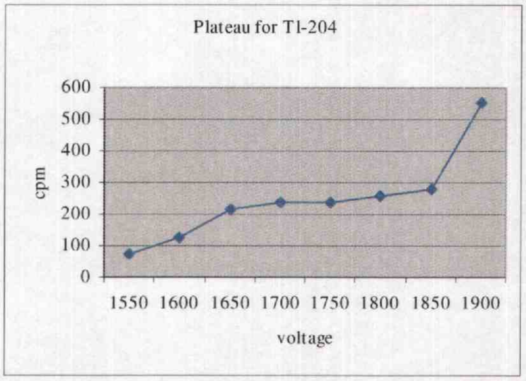
Fig. 7. Trojan surveyors keep the detector 1 cm from the surface when surveying. This was done in the experiment by means of an aluminum frame with 1 cm high leg attached to each corner. A bubbler in the front right corner of the detector was to indicate a constant air flow. Picture a is the frame and picture b is the detector place in the frame, which is the position of the detector during counting.

A beta plateau was performed using "flood" sources of ^{99}Tc and ^{204}Tl purchased from Isotope Products. These plateaus were used to determine where to set the operating voltage of the detector. The results concurred with the factory suggested voltage of 1750 volts (Fig. 8 a and b).

The beta energy of ^{99}Tc is 101keV[8] and ^{204}Tl has an average beta energy of 244 keV (ICRP 38, 1983). The ^{99}Tc and ^{204}Tl were used in a similar experiment that was used to find variables affecting minimum detectable concentrations in the field (NUREG-1507, 1998) and the ^{99}Tc is the energy that TNP is concerned about in their decommissioning efforts.



a



b

Fig. 8. Beta plateaus that were produced during the calibration of the detector. Graph a: ^{99}Tc and graph b: ^{204}T l.

The stock solutions of ^{99}Tc and ^{204}Tl were used to prepare "grid" standards to find the detector efficiencies (ε_i) as well as provide for contamination of the scabbled concrete surfaces in support of the source efficiency determinations (ε_s). Grid source standards were made using a Finn Pipette®[9] multi-channel micropipette and NIST-traceable solutions of radiotracers. Drop patterns consisting of a 7 x 6 series of 30 μl microdrops of the stock (secondary) solutions were placed onto thin plastic surfaces (Fig. 9). These were evaporated to dryness using a heat lamp. The 2π surface emission rates (calculated as 0.5 of the total disintegration rate) were 738 Bq for the ^{204}Tl source and 713 Bq for ^{99}Tc on the plastic surface.

[8] Note that reference values for this isotope range from 84.6keV to 101keV.
[9] Finnpipette Varichannel. Thermo Labsystems Oy. P.O.Box 208, FIN-00811 Helsinki, Finland.

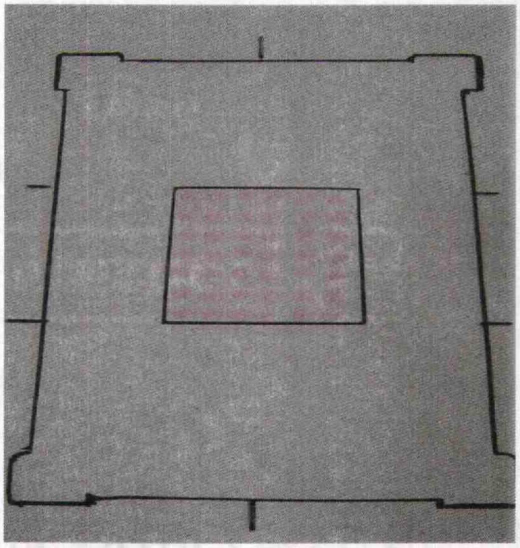


Fig. 9. The stock solutions of ^{99}Tc and ^{204}Tl were used to prepare "grid" standards to find the detector efficiencies (ε_i). The activity was deposited onto an area that corresponded to the center of the detector's face. The lines surrounding the droplets were made to allow the detector to be reproducibly placed in the same location.

Detector efficiencies were measured at 1, 1.1, 1.3, 1.5, 1.8, and 2 cm heights above the "grid" source. Both ^{99}TC and ^{204}T l grid sources were counted with the gas flow proportional counter attached with a 1.9 cm thick Plexiglas shield that is 30.5 cm x 15.25 cm. The shield had a window in the middle that allowed a 6 x 7 drop area to be "viewed" by the detector. Five-minute background counts were taken, and then each grid source was placed under the detector. Without moving the grid source or the detector, three, 3-minute counts were taken at each of the six heights. The cpm of each trial for each individual height with the background subtracted, yielded the net cpm. The detector efficiency was found by the formula:

$$\varepsilon_i = \frac{cpm_{net}}{dpm(2\pi)_{calc}}$$

Where cpm_{net} was the 1 minute net count rate and dpm $(2\pi)_{calc}$ was half the calculated total activity deposited on the plastic sheet.

Once all three detector efficiencies were found, the average of the three was used as the ε_i for a specific source to detector distance. This was done for both the ^{99}Tc and ^{204}Tl grid sources. Results in Table 3 show that (as expected) as the height increases the efficiency decreases.

Table 3. Detector efficiencies at each measured height

^{99}Tc		^{204}Tl	
Height (cm)	ε_i	Height (cm)	ε_i
1	0.412	1	0.429
1.1	0.404	1.1	0.421
1.3	0.391	1.3	0.413
1.5	0.371	1.5	0.395
1.8	0.335	1.8	0.377
2	0.314	2	0.357

SOURCE EFFICIENCY MEASURMENTS – SURFACE SEALING

Since the purpose of this experiment was to determine source efficiency and how surface variation affects the detector response, it was necessary to work with samples that had contamination only on the surface. This was done by developing a technique to keep deposited activity on the concrete surfaces. First the scabbled surfaces were cleaned using a compressed air spray to remove all the dirt and dust. Selected surface sealing compounds were evaluated for their ability to keep the contaminated solutions on the sample surface. A commercial marble tile with an unfinished surface was used to test the sealants. The tile was divided into twelve separate sections. Five sealants: Krylon Clear®[10], Armor All Waterproofing Sealer©[11], Rubber in a Can[12], clear nail polish[13], and PVC cement were applied to the tile (two areas each) a sixth area was left unsealed as a control. The sealants were tested by applying 30 µl of water or a 30 µl drop of 1M of hydrochloric acid (representative of the solution of each of the tracers being used) (Fig. 10). After depositing the drops, the surface was examined to see if bubbling occurred (indicating the sealant did not protect the surface). Krylon Clear® was found to be the best sealant to use because it kept the solution from penetrating into the sample surface. It was also easy to apply by spraying onto the surface. Background counts were taken from the core surfaces before and after spraying. Results indicated that the Krylon Clear® coating had no statistically significant effect on the background count rate of the samples.

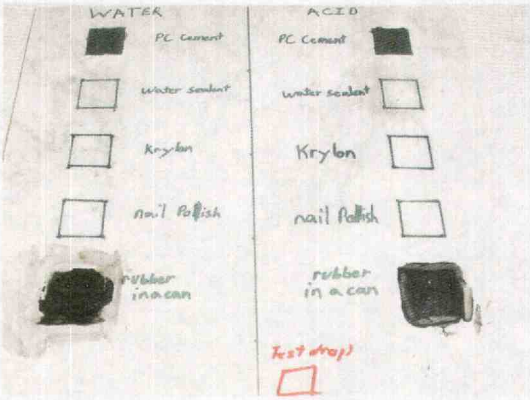


Fig. 10. The tile was treated with 5 sealants. Mock contaminant solutions of 30µl drops of water and 1M solution of HCl were pipetted onto the sealants to check for penetration into the marble tile. If bubbling was observed the sealant failed.

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[10] Manufactured by: Krylon Products group. The specialty division. Division of the Sherman-Williams Company. Solon, Oh 44139.
[11] W.M. Barr & Company. Memphis, TN 38101-1879.
[12] Share Corp. P.O. Box 245013, Milwaukee, WI 53224.
[13] AM Products, Inc., Dist. North Arlington, N.J. 07031.

SOURCE EFFICIENCY MEASUREMENTS – SAMPLE CONTAMINATION

In determining the source efficiency for scabbled concrete several surfaces were contaminated with known amounts of ^{99}Tc and ^{204}Tl. The researchers chose to lay down a grid pattern on each surface using a multi-channel micropipette and NIST-traceable solutions of radiotracers. A trial was used to determine the appropriate volume and number of drops to be pippetted onto the surface. Colorant was added to the tracer solution. A positioning grid devised from a pipette rack ensured consistent and reproducible positioning of the contaminated solutions. Thumbtacks with sticky tack were placed into each corner of the grid. These provided "legs" for consistent vertical positioning as well as a means to prevent the grid from moving when applying the contaminated solution. An area on top of the grid was masked open to present a series of holes, 6 x 16 (5 x 14 cm) in arrangement (Fig. 11). This ensured a consistent, reproducible spacing of solution when pipetted onto the scabbled surface. A Finn Pipette® multichannel pipette using 8 tips was used to deliver the solution to the surface of the core. Multiple trials with this method indicated that 30μL per pipette tip provided a uniform, non-spreading series of droplets.

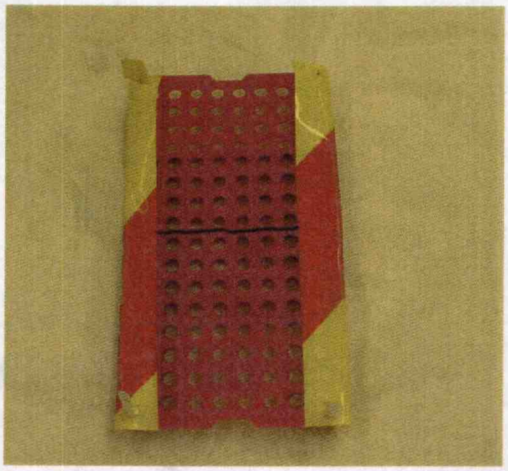

Fig. 11. The grid used to apply the tracer onto the concrete surface in a consistently reproducible way. An area on top of the grid was masked open to present a series of holes, 16 X 6 in arrangement

The fourteen cores were divided into two groups of seven. Group A was contaminated with ^{99}Tc and group B with ^{204}Tl. On each of the concrete samples guide lines were applied using a stencil which allowed two arrays of the 6 x 16 grid pattern to be dropped. The guide lines also allowed for the detector to be reproducibly placed while counting as shown in Figs. 12 and 13.

Fig. 12. On each of the concrete samples guide lines were applied using tape which allowed two arrays of the 16 x 6 grid pattern to be dropped. These also provided guide lines for the detector to be reproducibly placed while counting.

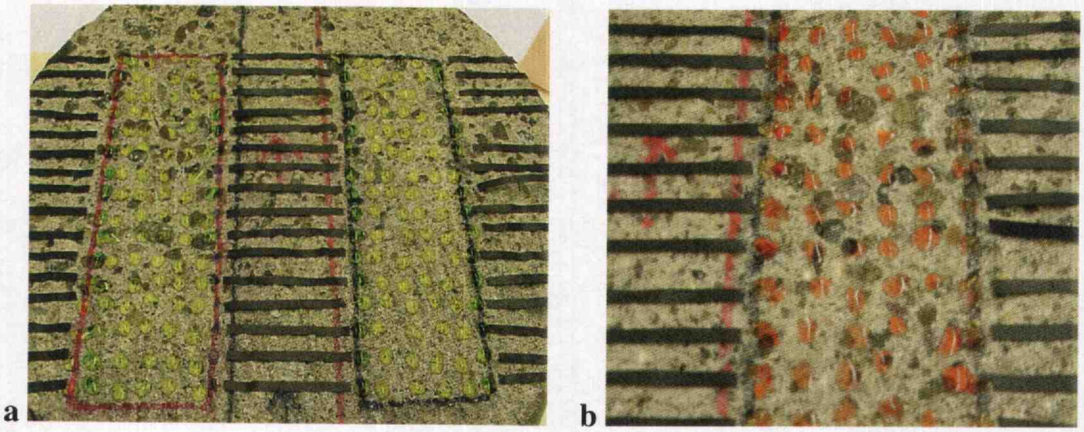

Fig. 13. The 6 x 16 grid pattern was placed twice on each sample surface. Picture a shows ^{99}Tc with green colorant with its two arrays of 6 x 16 pattern and b shows a close up ^{204}Tl with red colorant which makes it easer to locate the drops when dried.

QUALITY ASSURANCE / QUALITY CONTROL

Prior to contaminating the core surfaces, quality control and reproducibility tests were performed. The digital and multi-channel micropipettes were checked for accuracy and reproducibility by weight[14] using a calibrated microbeam scale in a closed room at constant temperature (Fig. 14 and Table 4).

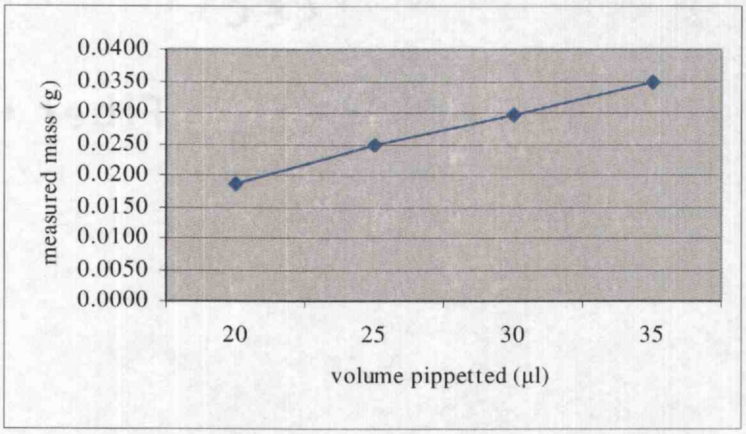

Fig. 14. Graph of the relationship between expected volume dropped by the pipette to the actual mass recorded

Table 4. The average volume deposited by the pipette for each setting tested.

Volume (µl)	Average Weight (n=8) (g)
20	0.0187
25	0.0250
30	0.0296
35	
	0.0347

[14] At 20°C density of water is 1 g cm^{-1}.

The NIST-traceable solutions were checked for purity and accuracy using a digital pipette and a Beckman three-channel liquid scintillation system[15]. Multiple dilutions of the NIST-traceable standards were made, and the results plotted and compared to the predicted count rate. The count rate was in agreement with the stated activity in the tracers and also indicated that the digital pipette worked correctly.

The NIST-traceable solutions were also checked for purity by gamma ray spectrometry on 10ml samples of both ^{99}Tc and ^{204}Tl the prepared stock solutions. Aliquots were pipetted onto filter paper and then counted for one hour each. The results showed no abnormal peaks outside anticipated background. This indicated the tracers had no additional photon emitters.

OPTIMAL COUNTING TIMES

When collecting data, it is necessary to know how long to count to minimize statistical error. The sample and background count times were determined using the optimization method of Cember (1996):

$$\frac{t_g}{t - t_g} = \sqrt{\frac{r_g}{r_b}}$$

Where t is the total count time, r_g is gross count rate, t_g is gross count time and, r_b is the background count rate. Based on a typical gross count rate of 15,000 cpm, background counts of 1 min or less were acceptable.

After all the calibrations were done and the detector efficiencies were determined, the core samples were marked for contamination. This was done by

[15] Beckman LS 6500 multi-purpose scintillation counter; Beckman Instruments, 4300 N. Harbor Blvd., P.O.Box 3100, Fullerton, Ca. 92834-3100.

using the same stencils used for outlining the grid patterns on the flood sources. Two contaminated areas were made per core. Both sides had a 6 x 16 (5 x 14 cm) drop pattern. Of the pair of scabbled cores, one was contaminated with ^{99}Tc and the other with ^{204}Tl. During counting, a piece of Plexiglas was placed over the half of the core not being counted to reduce background. Over the array that was being counted, a shield was placed with a 6 x 7 (6 x 6 cm) window to expose the detector face to the counting area (Fig. 15). One minute counts of rows one through seven were taken. Then the shield was moved to the second row of contamination and rows two through eight were counted. This process was continued down the array, yielding ten counting areas. The detector was consistently positioned by lining up the crosshairs on the shield with the crosshairs on the detector (Fig. 16). This same method was repeated for both arrays on the sample surface, resulting in twenty separate counts of the surface. The source efficiency was calculated for each 6 x 7 array using:

$$\varepsilon_s = \frac{cpm_{net}}{dpm_{calc} \times \varepsilon_i}$$

Where the dpm_{calc} is the 4π value for the 6 x 7 array and ε_i was the pre-determined detector efficiency for this specific surface type. The ε_s values for the contaminated surfaces were calculated as average values by:

$$\varepsilon_s = \frac{\Sigma \varepsilon_{s,array}}{n}$$

Where n equals number of counts of each isotope (20 counts per core) and ε_s, array is the source efficiency for each (n = 20) 6 x 7 array.

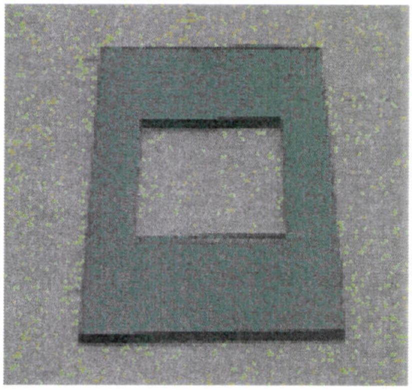

Fig. 15. The beta shield was placed under the detector and the window was wide enough for only a 6 x 7 drop area to be counted.

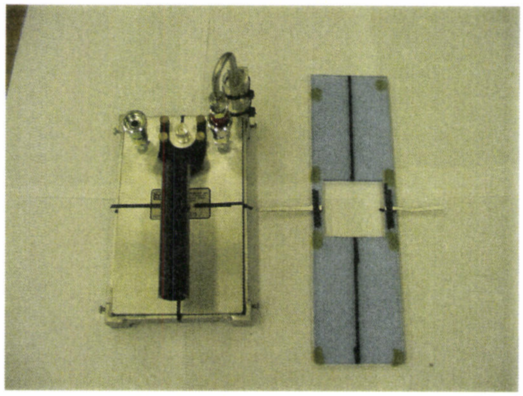

Fig. 16. The detector was consistently positioned by lining up the crosshairs on the shield with the crosshairs on the detector.

The final step in the experiment was to compare the different surfaces and their respective surface efficiencies. Data were grouped according to which tool was used in scabbling the sample surface.

RESULTS AND DISCUSSION

Detector efficiency declines as distance from source to detector increases (Fig. 17). The ^{99}Tc at 1.8 cm distance showed a greater rate of decline most likely due to its weaker energy. The overall ε_i for ^{204}Tl was slightly greater than that of ^{99}Tc, owing to its greater beta energy (Fig. 17). These results were used to adjust the detector efficiency for the different scabbled surfaces as shown in Table 5.

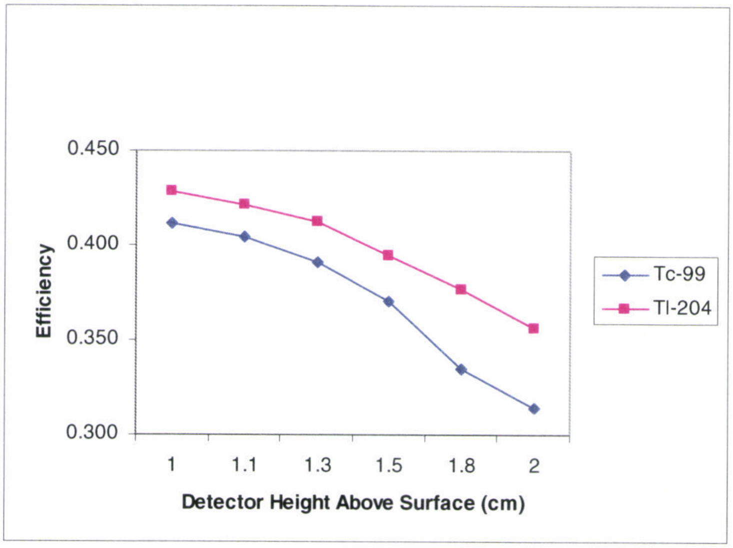

Fig. 17. 2-π efficiency of the gas-flow proportional detector as a function of height above grid source.

Table 5. The ε_i values determined as a function of distance from surfaces

Sample	Detector to Surface Height (cm)	^{99}Tc ε_i	^{204}Tl ε_i
Plastic	1	0.412	0.429
Control	1	0.412	0.429
Spade Bit	2	0.314	0.357
Bush Head	1.5	0.371	0.395
1-Finger Jack	1.5	0.371	0.395
Needle Gun	1.3	0.391	0.413
Floor Scabbler	1.3		
One Pass	1.3	0.391	0.413
Two Passes	1.3	0.391	0.413
Multiple Passes	1.3	0.391	0.413

For the ^{99}Tc contaminated surfaces, the measured count rates decreased as surface roughness increased (Table 6, column 2). The data were also normalized to that observed on a flat surface (a plastic sheet) (Table 6, column 4). Results from this comparison show as surface roughness increases the observed activity decreases. The principle objective of this study was to determine the effect of surface roughness on source efficiency (ε_s). As a check on the techniques used, ε_s was calculated for each surface in two different ways. The results are shown in Table 6, columns 5-6 and discussed in the following paragraphs.

Taking the values normalized to the plastic (column 4) the source efficiency was found by:

$$\varepsilon_{s_A} = (normalized\,ratio)(0.500)$$

This is a straight forward method to estimate ε_s because the detector will count 2-π of a source on a perfectly level surface and with the same activity deposited on all surfaces, variations in observed count rate are directly related to ε_s. The results are shown on Table 6 in column 5. The results once again show that as the surface scabbling increases, the source efficiency decreases.

The second method used to calculate ε_s ($\varepsilon_{s,B}$ column 6 Table 6) utilized the observed cpm, the known dpm and a detector ε_i of 0.412 (the value found by the grid source at 1 cm height). The calculated dpm was 85596 dpm. Once again it is shown that as the surface is more scabbled, the source efficiency is reduced. Also note the relatively good agreement between the data in columns 5 and 6.

The final evaluation of the ^{99}Tc data was completed using ε_i as a function of the height from each surface. The height (and surface) specific values for ε_i are found in Table 5 and the results of the comparison are presented in Table 6, column 7. Column 7 is found by dividing the net cpm by ε_i (height correction value) and multiplying by the calculated dpm. Results show that the extent of roughness does not affect the source efficiency, but distance from the detector to the source does. The results show that, with the ε_i height correction, the ratio is 50% ± 3%. On a flat surface the value should be 50%, and with the height correction all other roughness, per se, values are in that range. This suggests that height variation, not scabbled surface is the predominant geometry factor for source efficiency. In Fig. 18, the graph supports the theory by comparing the total distance to detector (effective surface height plus detector "cradle" height) versus cpm for the average net cpm of each sample. Qualitative responses are almost identical, illustrated by the trendlines being almost overlapping. This indicates that the detector distance is the primary factor in source efficiency, not surface roughness.

Table 6. Data used in finding source efficiency for ^{99}Tc. See text for an explanation of methods used to calculate ε_s.

^{99}Tc Contaminated Samples						
Sample	Average Net CPM[a]	Std Dev	Count Rate Normalized To Flat (Plastic) Surface	$\varepsilon_{s,A}$	$\varepsilon_{s,B}$	Height Analysis
Plastic	18206	135	1.000	0.500	0.516	0.516
Control	18130	135	0.996	0.498	0.514	0.514
Spade Bit	13582	117	0.746	0.373	0.385	0.505
Bush Head	15100	123	0.829	0.415	0.428	0.475
1-Finger Jack	15188	123	0.834	0.417	0.431	0.478
Needle Gun	16846	130	0.925	0.463	0.478	0.503
Floor Scabbler						
One Pass	17044	131	0.936	0.468	0.483	0.509
Two Passes	16300	128	0.895	0.448	0.462	0.487
Multiple Passes	16430	128	0.902	0.451	0.466	0.491

a. Based on a deposition of 2378 Bq cm^{-2}

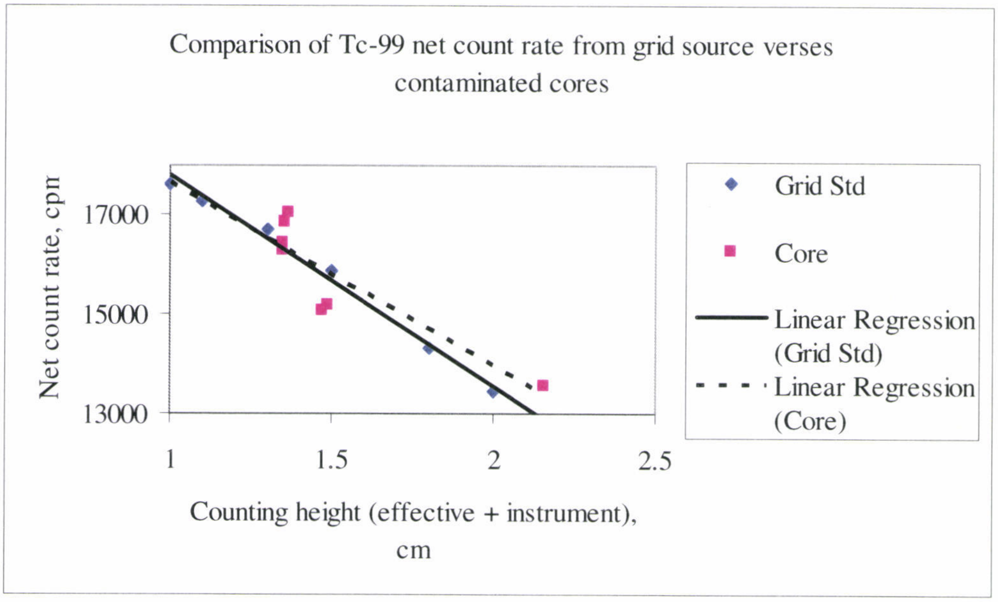

Fig. 18. Comparison of ^{99}Tc net count rate source versus contaminated cores

The ^{204}Tl data was compared using the same method described above for ^{99}Tc. The results for ^{204}Tl are shown in Table 7. For the ^{204}Tl, different values for ε_i were used (0.429 based on measured data values). The calculated value for columns 5 and 6 also changed due to the difference in activity deposited (88536 dpm) per area. The results were similar to those observed for ^{99}Tc. However, the data in column 7 indicate a possible problem with the ^{204}Tl results. If source – to – detector distance is the only factor impacting ε_s, then the values in column 7 should be clustered around 0.5. Because these values were lower it was speculated that the loss was caused by some of the activity leaching into the concrete. Similar activity was deposited for ^{99}Tc and ^{204}Tl, it was expected that ^{204}Tl would have a higher count rate because it has a more energetic beta. It is believed that the acid solution of the ^{204}Tl slowly ate through the Krylon Clear® sealant as it dried. Because all the ^{204}Tl contaminated cores exhibit similar patterns, the leaching hypothesis is considered the most probable. In Fig. 19, a graph was made for ^{204}Tl, comparing the net count rate to height. The graph shows the same trend as the ^{99}Tc. Unlike the ^{99}Tc data, the trendlines are not overlapping for ^{204}Tl because of the presumed loss of activity from the surface during the experiment.

Table 7. Data used in finding source efficiency for ^{204}Tl. See text for explanation

^{204}Tl Contaminated Samples						
Sample	Average Net CPM[b]	Std Dev	Count Rate Normalized To Flat (Plastic) Surface	$\varepsilon_{s,A}$	$\varepsilon_{s,B}$	Height Analysis
Plastic	19107	138	1.000	0.500	0.503	0.503
Control	18824	137	0.985	0.493	0.496	0.496
Spade Bit	10911	105	0.571	0.286	0.287	0.345
Bush Head	13267	115	0.694	0.347	0.349	0.379
1-Finger Jack	13662	117	0.715	0.358	0.360	0.391
Needle Gun	14324	120	0.750	0.375	0.377	0.392
Floor Scabbler						
One Pass	15826	126	0.828	0.414	0.417	0.433
Two Passes	15802	126	0.827	0.414	0.416	0.432
Multiple Passes	16359	16359	0.856	0.428	0.431	0.447

b. Based on a deposition of 2459 Bq cm^{-2}

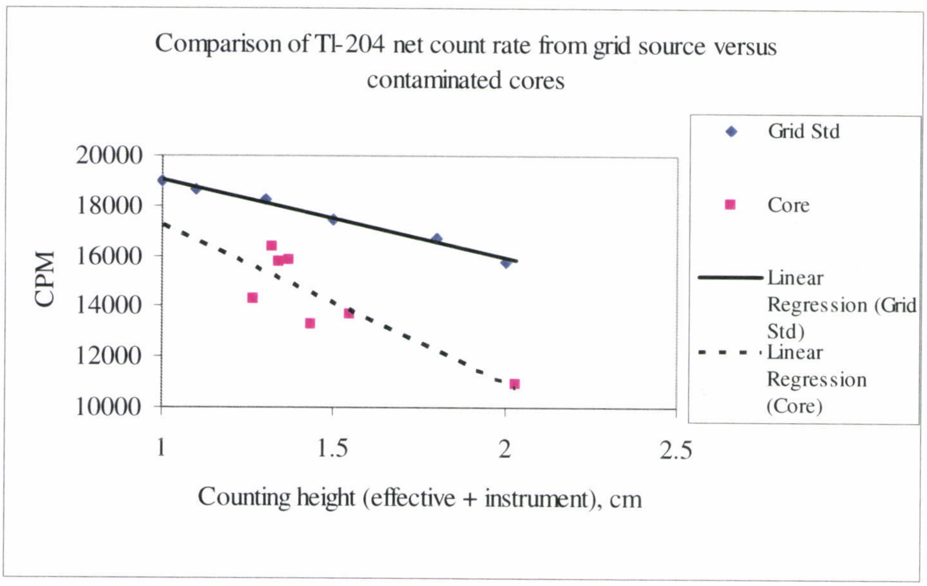

Fig. 19. Comparison of ^{204}Tl net count rate of grid source verses contaminated cores.

In the ISO 7503-1 Evaluation of Surface Contamination (1988), it suggests that value of ε_s (source efficiency) on a level surface for a beta-emitter with energies between 0.15 MeV and .4 MeV should be approximately 0.25. This energy range includes ^{99}Tc (beta max value about 0.303 MeV). From the results in Table 5, the flat plastic sheet has a calculated source efficiency of 0.516, and the flat control concrete sample has a source efficiency of .514. Thus, ISO 7503-1 underestimates the source efficiency for ^{99}Tc and the value should be 0.5 as shown from this experiment. The observed results are greater than 0.5 most likely due to backscattering .

CONCLUSION

This experiment shows that the change in effective surface height of the sample influences the source efficiency. The standard ISO 7503-1 (1988) was shown to underestimate the source efficiency for ^{99}Tc. ISO 7503-1 recommended a source efficiency for ^{99}Tc of 0.25, whereas the results from the flat concrete surface and flat plastic sheet show the source efficiency should be nearer to 0.5.

Even though the ^{204}Tl presumably had activity leach below the surface, it still showed the same trend as ^{99}Tc, which helps support the conclusion that source efficiency is affected by surface height, not roughness. Future studies will be done using ^{204}Tl to test this hypothesis. This will be done by repeating the experiment but neutralizing the acidic solution of the ^{204}Tl, and using a more acid resistant sealant.

It is recommended that further efforts be made to create a more efficient means to determine effective heights. The volumetric approach done in this experiment proved to be an effective way of getting acceptable results but is very labor intensive. It is possible that a specialized height test machine called Atomic Force Microscope might give better results. This would yield more precise results for source efficiency. Another study that will be conducted will be to find another way to deposit the ^{204}Tl onto the surface without it leaching into the concrete. This can be done by neutralizing the acidic solution or finding an acid proof sealant.

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