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16. Abstract

The Texas Department of Transportation has initiated a two-year field test of seventeen types of retroreflective raised pavement markers (RRPMs). The RRPMs were installed at four freeway facilities in District 15 (San Antonio) in August 1992. A sample of RRPMs is removed from the sites periodically to assess reflectivity retention of each type of marker. In addition, a portable retroreflectometer is being tested at each site to estimate RRPM reflectivity while still installed on the pavement.

This report summarizes the results of field studies to document traffic conditions at each site. Total volumes, truck volumes, and lane-changing frequencies were all examined in the field studies. The report also documents the RRPM reflectivity measurements at each site when RRPMs are new and after approximately two and four weeks exposure.

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RETROREFLECTIVE RAISED PAVEMENT MARKER FIELD TESTING: INITIAL INTERIM REPORT

by

Gerald L. Ullman

Research Report 1946-1
Research Study 2-18-92-1946

Sponsored by

Division of Maintenance and Operations,
Texas Department of Transportation

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University System
College Station, TX 77843

REVISED December 1992

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

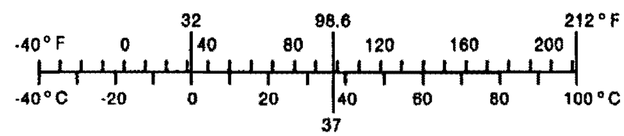
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ABSTRACT

The Texas Department of Transportation has initiated a two-year field test of seventeen types of retroreflective raised pavement markers (RRPMs). The RRPMs were installed at four freeway facilities in District 15 (San Antonio) in August 1992. A sample of RRPMs is removed from the sites periodically to assess reflectivity retention of each type of marker. In addition, a portable retroreflectometer is being tested at each site to estimate RRPM reflectivity while still installed on the pavement.

This report summarizes the results of field studies to document traffic conditions at each site. Total volumes, truck volumes, and lane-changing frequencies were all examined in the field studies. The report also documents the RRPM reflectivity measurements at each site when RRPMs are new and after approximately two and four weeks exposure.

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This study was designed and is being managed by Mr. Lewis Rhodes, P.E. (Division of Maintenance and Operations) and Mr. Arthur Barrow, P.E. (Division of Materials and Tests) of the Texas Department of Transportation (TxDOT). The Texas Transportation Institute has been contracted by TxDOT to monitor traffic conditions at each site throughout the evaluation and to provide study documentation as needed. This study was made possible by the participation of the product suppliers of six different retroreflective pavement marker manufacturers, namely; Apex, Batterson, Empco, Ray-O-Lite, Stimsonite, and Swareflex. The Maintenance section of District 15 in San Antonio assisted in the installation of the markers at the four test sites, and is providing continuing traffic control support for the subsequent return visits to each site for reflectivity measurements. Their help with this study is gratefully acknowledged.

DISCLAIMER

The contents of this report do not necessarily reflect the official views of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation, and is not intended for construction, bidding, or permit purposes. The report was prepared by Mr. Gerald L. Ullman, Texas P.E. registration #66786.

SUMMARY

Seventeen different types of retroreflective raised pavement markers (RRPMs) were installed between travel lanes at four freeway locations in and around San Antonio, Texas in August 1992. Based on the traffic data collected at each site, the RRPMs are being exposed to total traffic volumes (on each side of the RRPMs) varying between 3,300 and 32,700 vehicles per day (vpd); truck volumes varying between 500 and 1,650 vpd; and lane-changing frequencies varying between 235 and 985 changes per mile per day.

Reflectivity measurements of each type of RRPM were taken when new, using both TxDOT laboratory equipment and a portable retroreflectometer designed to estimate the reflectivity of RRPMs installed on the pavement. Laboratory and field measurements are then obtained periodically after installation to assess how the RRPMs reflectivity is degrading over time, and how the different traffic conditions at each site are affecting this degradation.

After the first month of exposure, several RRPMs showed significant losses in reflectivity, especially at the higher volume sites. On the average, the RRPMs at each site displayed only 35 to 65 percent of their original reflectivity at the end of that first month, based on laboratory measurements. Field measurements using the portable retroreflectometer indicate that the reflectivity retention was only between 25 and 55 percent after one month. A substantial amount of this loss in reflectivity was due to dirt and road grime accumulation on the reflective faces of the RRPMs. After washing this grime from the markers, average reflectivity values increased to between 60 and 75 percent of their original levels.

Early comparison of average RRPM reflectivity degradation versus traffic exposure levels suggest that degradation may be most strongly related to the total truck traffic exposure, and to a lesser degree, to total vehicular exposure and lane-changing frequency. As more data become available, these trends will be tested more rigorously using statistical methods.

Correlation analysis performed between reflectivity values recorded in the field using the portable retroreflectometer and those recorded in the laboratory indicate good agreement between the two measurement methods. However, the portable unit may tend to slightly underestimate the reflectivity of the very bright RRPMs, relative to laboratory measurements.

IMPLEMENTATION STATEMENT

The contents of this report should be immediately useful to the Department in its attempt to assess the reflectivity degradation over time of several types of available RRPMs. The study offers a means of directly comparing these RRPMs over a wide range of traffic conditions. However, the findings reported herein are preliminary, based on slightly less than one month exposure of the RRPMs at each site. As this two-year study continues, the additional data collected will solidify the findings presented in this report regarding RRPM reflectivity degradation over time.

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1. INTRODUCTION

Retroreflective raised pavement markers (RRPMs) are used extensively throughout Texas for delineating lanes and intersections in both rural and urban areas. Research has shown them to offer several advantages over paint and thermoplastic markings. These advantages include (1):

- providing increased reflectivity under wet-weather conditions,
- providing better durability than paint or thermoplastic markings, and
- providing a tactile and auditory warning to vehicles crossing the markers.

Early on, significant numbers of RRPMs were lost due to failures of the adhesive binder or the pavement to which the marker was attached. Fortunately, a change to a bitumen adhesive has reduced the magnitude of this problem drastically in recent years (2). However, although RRPMs are now being retained on the roadway over longer periods of time, they must be replaced periodically because they eventually lose their reflective properties.

The Texas Department of Transportation (TxDOT) has been concerned about RRPM reflectivity degradation for many years. TxDOT has sponsored a number of studies to assess how quickly RRPMs lose their reflectivity, as well as to identify what factors influence the rate of reflectivity loss (3,4). The results of this research indicates that sunlight, dirt accumulation and tire abrasions on the reflective face all contribute to the loss of reflectivity in RRPMs. Unfortunately, the interaction among these effects makes them extremely difficult to quantify. Also, differences in RRPM designs may influence the rate of dirt accumulation and abrasion. Further complicating matters is the fact that different roadway types and geographical areas produce different types of dirt and grit which themselves differ in terms of their abrasive properties. As a result, TxDOT cannot reasonably predict which RRPMs will remain most their reflective over time, nor does the Department know how quickly the different types of commercially available RRPMs lose reflectivity and require replacement.

In response to the need for better data regarding the loss rate of RRPM reflectivity, TxDOT initiated a two-year field test in August 1992 of seventeen different RRPMs. RRPMs were installed at four different interstate locations near San Antonio, Texas. The objective of the test is to monitor the degree to which the reflectivity of these RRPMs degrade over time, and to assess how losses in RRPM reflectivity are related to the roadway volumes, amount of truck traffic, and lane-changing frequency at each site.

The reflectivity of each type of RRPM submitted by the manufacturers was sampled in TxDOT's materials and testing laboratory. Periodically, TxDOT personnel return to the installation sites and remove samples of each type of RRPM for follow-up measurements. In conjunction with these laboratory measurements, a state-of-the-art portable retroreflectometer was used to measure RRPM reflectivity as they were installed. The portable unit is also used to estimate reflectivity in the field each time additional RRPM samples are removed from the sites. As a second objective of this study, these field measurements are being correlated with the laboratory measurements to assess the accuracy and precision of measurements taken via the portable retroreflectometer.

Description of RRPMs Under Evaluation

In June 1992, TxDOT contacted a large number of RRPM manufacturers to solicit participation in the field test. Each manufacturer was allowed to submit up to six different types of markers for testing. A total of 6 manufacturers responded, furnishing 17 different markers. A summary of the general characteristics of each marker (manufacturer, model number, marker dimensions, type of reflective surface, and specific intensity) is provided in Table 1. Photographs of each marker are provided in Appendix A.

The majority of the markers are a 4-inch square design made of molded plastic, with either a single clear reflective face or opposing clear/red faces. The exceptions to this design include the models 807 and 817 made by Apex, which are constructed of ceramic; round reflective buttons manufactured by Batterson and Empco; the Ray-O-Lite models 2002 and 2003, which are rectangular low-profile prototype designs; and the Stimsonite models 948 and 953, which are also low-profile designs. All but two of the markers rely on acrylic prismatic cube-corner lenses for reflectivity. Reflectivity of the Batterson marker is achieved by a strip of microprism high-intensity sheeting glued to a portion of the button which is milled perpendicular to its top. Meanwhile, the Swareflex marker is unique in that three rows of small (⅛ inch) glass beads embedded in the face of the marker provide its retroreflectivity (see corresponding photograph in appendix A). The Stimsonite models 911 and 948 have a small layer of glass attached over the acrylic lens to improve the durability of the reflective face. TxDOT has prequalified several of these markers for use on Texas highways. These are noted by an asterisks (*) in Table 1.

The final column in Table 1 summarizes the initial laboratory reflectivity test results on each type of RRPM. These values represent the average specific intensity (SI) of five of each type of RRPM, drawn randomly from those submitted by the manufacturers for installation at the test sites. Measurements were conducted using an entrance angle of 4^{o} and observation angle of 0.2^{o}. The average specific intensities range from a low of 1.0 candles of reflected light per foot-candle of illumination (c/ft-c) for the Apex model 817, to a high of 9.2 c/ft-c for the Stimsonite model 911.

TABLE 1. RRPM CHARACTERISTICS

Manufacturer	Model	Dimensions	Reflective Surface	SI, c/ft-c
Apex	921	3.8" x 4" x 0.7"	acrylic cube-corner	3.5
Apex*	918	4" x 4" x 0.7"	acrylic cube-corner	4.2
Apex	928	4" x 4" x 0.7"	acrylic cube-corner	2.9
Apex	807	4" x 4" x 0.9"	acrylic cube-corner	2.4
Apex	817	4" x 4.8" x 0.9"	acrylic cube-corner	1.0
Batterson	Reflective Button	4" diameter x 0.8"	microprism high-intensity sheeting	5.2
Empco	901	4" diameter x 0.8"	acrylic cube-corner	1.8
Ray-O-Lite	8704 (S)[a]	4" x 4" x 0.7"	acrylic cube-corner	5.3
Ray-O-Lite	8704 (R)[b]	4" x 4" x 0.7"	acrylic cube-corner	5.3
Ray-O-Lite*	9704	4" x 4" x 0.7"	acrylic cube-corner	6.4
Ray-O-Lite	2002	2.4" x 4.8" x 0.5"	acrylic cube-corner	6.3
Ray-O-Lite	2003	2" x 5.8" x 0.4"	acrylic cube-corner	6.9
Stimsonite*	88	4" x 4" x 0.7"	acrylic cube-corner	7.4
Stimsonite*	911	4" x 4" x 0.7"	glass layer over acrylic cube-corner	9.2
Stimsonite*	948	2.3" x 4.7" x 0.5"	glass layer over acrylic cube-corner	8.0
Stimsonite	953	2.8" x 4.5" x 0.6"	acrylic cube-corner	8.7
Swareflex	---	4" x 4" x 0.7"	⅛" glass beads	5.5

* RRPM prequalified by TxDOT
[a] (S) = square-shouldered marker
[b] (R) = round-shouldered marker
SI = Specific Intensity, candles per foot-candle of illumination

Study Design Overview

The manufacturers participating in the field tests provided a minimum of 180 markers per model to be evaluated. These were divided into four lots of 45 markers each to be installed at four interstate locations (four-lane and six-lane facilities) near San Antonio, TX. The sequence of markers was randomized at each site. Markers were installed at 20-ft spacings on a lane line at all sites. At four-lane facilities, the RRPMs separated the inside and outside travel lanes. On six-lane facilities, the RRPMs were installed only on the lane line separating the inside and middle travel lanes. This would then minimize the amount of lane-changing activity that would occur across the RRPMs. The markers were installed using bitumen adhesive using standard TxDOT procedures. Data collection personnel then return to each site according to the following schedule:

- two weeks after installation,
- four weeks,
- six weeks,
- eight weeks,
- twelve weeks,
- twenty weeks,
- twenty-eight weeks,
- thirty-six weeks,
- one year,
- one and one-half years, and
- two years.

During each of these return visits, an attempt is made to sample three markers of each type of RRPM on the roadway at each site using portable retroreflectometer equipment. Following the field measurements, one of each type of RRPM is then removed and taken to the laboratory. Reflectivity measurements are taken of each of these markers in a dry, unwashed state (as removed from each site), and then repeated after washing the road grime from the reflective face of the RRPM.

The remainder of this report documents the roadway and traffic characteristics of the study locations. In addition, the results of the two-week and four-week reflectivity measurements are documented and compared to the original reflectivity values of each type of RRPM to assess the degradation of reflectivity over the initial four-week period.

2. STUDY SITE CHARACTERISTICS

Site Locations and Geometrics

Four controlled-access, interstate-type facilities were selected as study sites for this field test. All sites were located within District 15 of TxDOT, which contains the San Antonio metropolitan area and surrounding suburban and rural region. The sites were selected so as to evaluate the RRPMs over a range of estimated average daily traffic (ADT) volumes. The following sites were selected:

- Site 1 -- 60,000 < ADT < 120,000 -- I-410 northbound @ Marsbach Road
- Site 2 -- 30,000 < ADT < 60,000 -- US-281 northbound @ I-410
- Site 3 -- 10,000 < ADT <30,000 -- I-10 westbound @ Leon Springs
- Site 4 -- ADT < 10,000 -- I-10 westbound @ Kerrville

The specific locations of the sites are shown in Figure 1. A brief description of each is presented below.

Site 1: I-410 northbound @ Marsbach Road

The first site, located on the western side of San Antonio in the northbound direction of Interstate Loop I-410, begins at the Marsbach Road overpass and continues north about 3 miles. The facility consists of three 12-ft travel lanes, with full 12-ft shoulders on the inside and outside edge of the roadway. A concrete median barrier separates opposing mainlane traffic. Within this section of freeway, ramps are spaced approximately one mile apart (entrance to entrance). One-way, three-lane continuous frontage roads parallel the freeway, providing access to a limited number of strip commercial shopping areas and several collector streets serving nearby residential areas.

The general vertical alignment of the freeway is made up of crest and sag curves occurring wherever the freeway passes over major cross-street arterials every mile or so and then returns to grade. In addition, the site contains one major horizontal curve to the right.

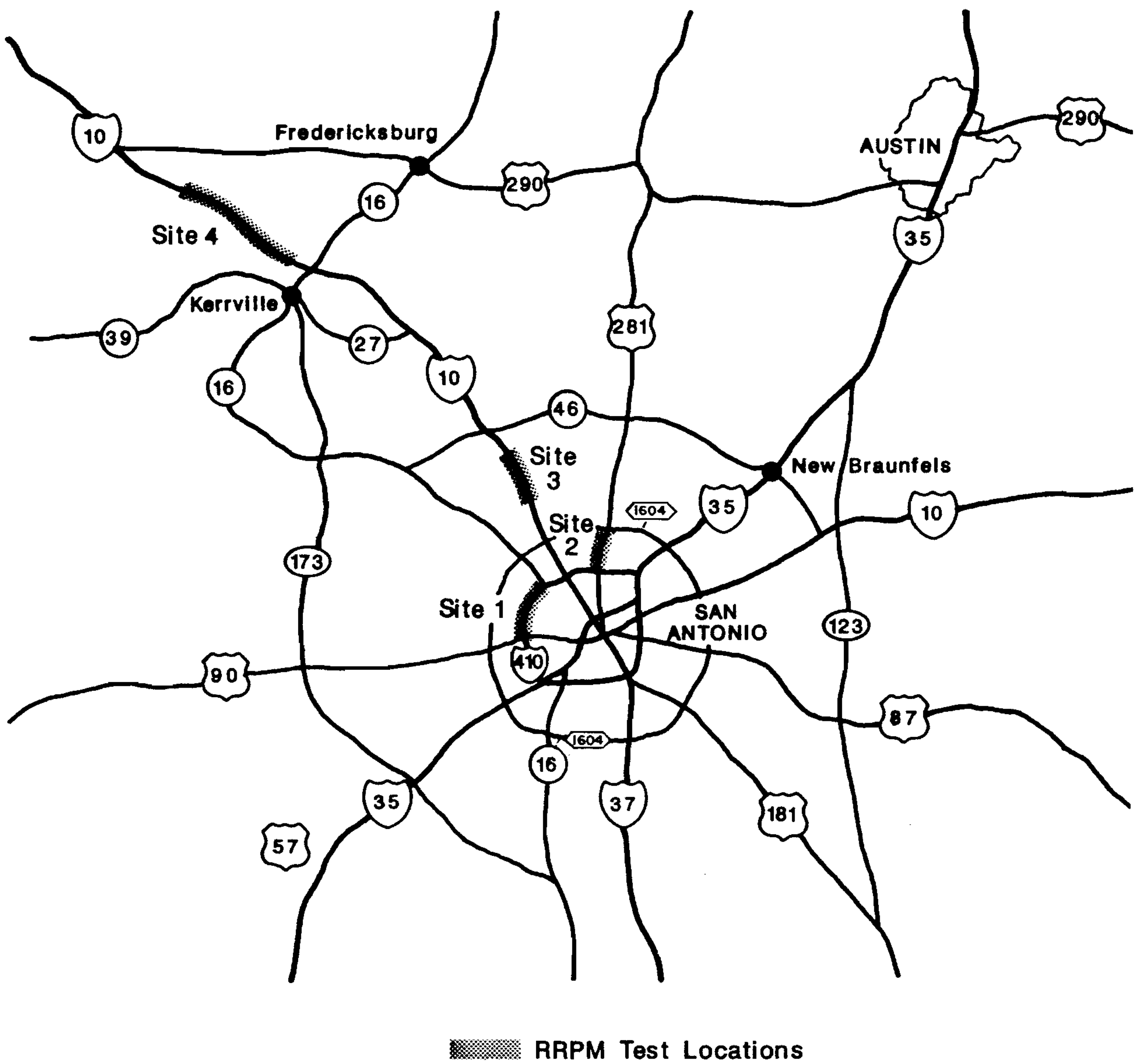

Figure 1. Study Site Locations

Site 2: US-281 northbound @ I-410

The second site is located in the northbound direction of US-281, beginning at the I-410 Loop and extending north to Bitters Road. The roadway passes immediately to the west of the San Antonio International Airport. In general, the roadway is three lanes wide per direction. However, there are a few sections with auxiliary lanes which increase the total width to five lanes per direction for short distances. Full 12-ft shoulders are present on both sides of the travel lane. Also, the opposite directions of travel are separated by a concrete median barrier. One-way, two-lane frontage roads again parallel the freeway, and are fronted by numerous commercial activity centers (banks, restaurants, businesses, etc.).

Unlike site 1, though, the arterial cross-streets pass over the freeway, occasionally creating a canyon-like appearance on the freeway mainlanes. This results in very little vertical curvature. There are more exit ramps than entrance ramps within and just north of the study site, accommodating the highly directional traffic flows of nearby residents returning to their homes during the evening peak period. Entrance ramps are located about 1.3 miles apart (on the average), whereas the exit ramps are more closely spaced (averaging 0.7 miles apart). A series of gentle horizontal curves are present within the site.

Site 3: I-10 westbound @ Leon Springs

The I-10 site at Leon Springs is a four-lane interstate located approximately 5 miles from the outskirts of San Antonio. The study section begins just to the west of FM 3351 and continues west 2.8 miles. The terrain is relatively level, with only a few slight horizontal curves within the study section. A 12-ft right shoulder and 6-ft left shoulder are provided for refuge, and a grass median separates opposing mainlane traffic. Two cross-streets pass over the freeway in the vicinity of the study site. Only one set of ramps are actually located within the study section, which are utilized on an occasional basis by local traffic. Conditions at site 3 are predominantly rural, although a few convenience stores and other small commercial centers are situated along the two-lane, two-way frontage roads on each side of the interstate.

The pavement at this site received an asphalt overlay at the end of July 1992, a few weeks prior to the installation of the RRPMs. Although normal TxDOT procedure is to allow the asphalt overlay material to cure a few months before installing RRPMs, the study markers were installed sooner to keep the study on schedule. An earlier installation, however, may affect reflectivity if oil and tar residue from the new pavement coat the markers. In addition, the marrkers may sink into the new pavement slightly until it has fully cured, futher reducing their effective reflectivity.

Site 4: I-10 westbound near Kerrville

The fourth and final site is also located on I-10 approximately 60 miles to the west of San Antonio. The site begins just prior to the interchange with FM 783. This site is located in the heart of the Texas Hill Country, and contains fairly significant vertical grades as well as numerous horizontal curves. The basic interstate cross-section consists of two 12-ft travel lanes, a 12-ft right shoulder, and a 6-ft left shoulder. Because of its rural locale, there are no frontage roads at this site. Likewise, entrance and exit ramps are few and far between, existing only at the FM 783 overpass in the vicinity of the study section.

Traffic Characteristics

As stated previously, the sites were selected in order to subject the RRPMs to a wide range of traffic conditions. To document these conditions, traffic studies were performed at each site in August 1992, one week following the installation of the RRPMs at each location. The studies consisted of 24-hour volume counts across all lanes of traffic (measured with mechanical counters connected to pneumatic tubes placed across the roadway) supplemented with manual vehicle classification, lane distribution, and lane-changing counts sampled throughout the day.

Three days of traffic volume data were recorded at each site (Tuesday through Thursday) and averaged to determine the total daily roadway volumes. Counts were taken at both ends of sites 1 and 2, as it was anticipated that volumes varied dramatically from one end of the site to the other. Sites 3 and 4, on the other hand, were expected to experience more uniform volumes throughout and, therefore, required only one count to be made. At site 2, unfortunately, data collection personnel had difficulty keeping the pneumatic tubes across the roadway. Hence, the data from this site represents the average of what data was available during the three-day recording period.

Table 2 summarizes the average daily volumes in the direction of interest at each site, whereas a graph of the hourly volumes throughout the day is presented in Figure 2 (hourly volumes from sites 1 and 2 represent the average of the two counts taken at those sites). Site 1, located on I-410, is the most heavily utilized site, with daily volumes ranging from 36,700 vehicles per day (vpd) on the southern end to 58,900 vpd at the northern end. Since these values are for the northbound direction only, the total ADT for the entire freeway does indeed fall within the 60,000 to 120,000 vpd range defined previously. Both morning and evening peak hour volumes are quite high, between 4,000 and 4,750 vehicles per hour (vph).

TABLE 2. TRAFFIC VOLUMES

Site	Vehicles Per Day	Vehicles Per Peak Hour	Ratio of Pk Hour Volume to Daily Volume
Site 1: South North	36,700 58,900	3,980 4,750	0.108 0.081
Site 2: South North	21,200 21,400	3,030 3,040	0.143 0.142
3	18,600	1,950	0.105
4	3,300	250	0.076

Site 2, in comparison, is a radial freeway facility serving outbound commuters, and traffic volumes display a single peak during the afternoon period (see Figure 2). Peak-hour volumes recorded at this site were slightly higher than 3,000 vph. Meanwhile, the total daily volume northbound at site 2 is much less than that of site 1, ranging between 21,200 vpd and 21,400 vpd on the southern and northern ends of the study section, respectively.

Even though it is located several miles outside of San Antonio, volumes at site 3 are also quite high, averaging 18,600 vpd in the westbound direction. Based on these counts, it appears that the ADT at site 3 may be slightly greater than the 10,000 to 30,000 vpd range for which this site was selected originally. This section of interstate apparently serves a sizeable driving population commuting to and from San Antonio. As Figure 2 illustrates, a distinctive peak hour (approaching 2,000 vph) is evident in the afternoon.

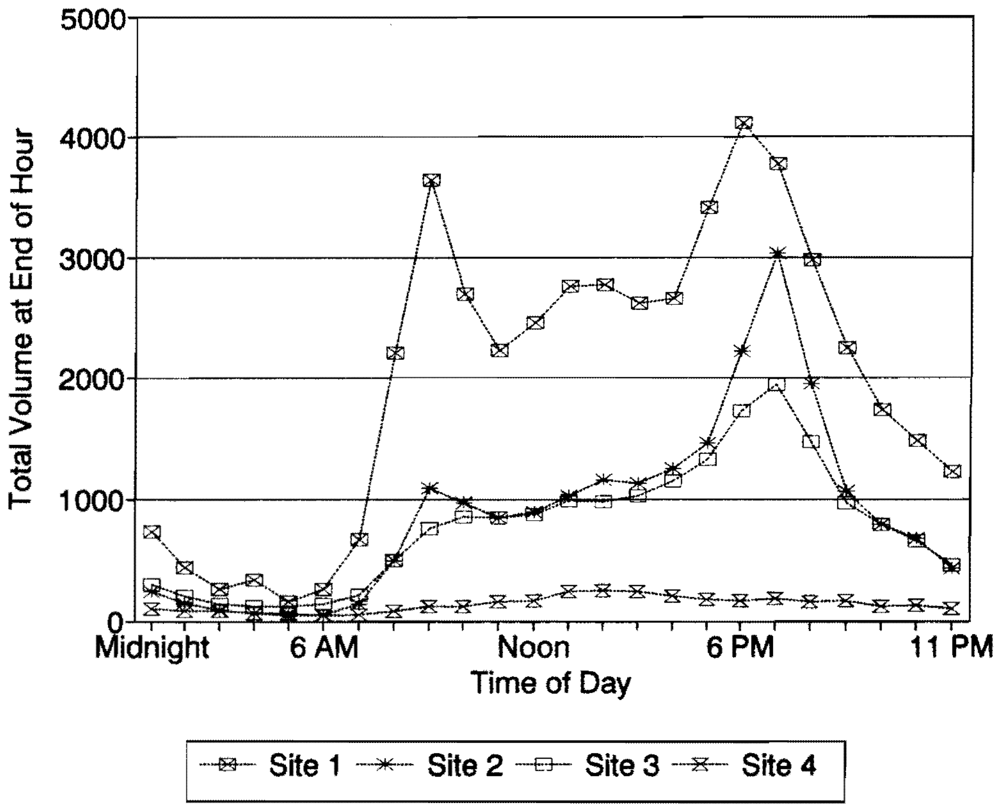

Figure 2. Hourly Traffic Volumes by Site.

Finally, site 4 is characterized by very low volumes, near 3,300 vpd in the westbound direction. In addition, there is essentially no peaking during morning or evening rush hours (see Figure 2). The maximum hourly volume at this site is only 250 vph.

Table 3 documents the results of the manual counts performed to determine the percent of heavy trucks (defined as those vehicles with 4 or more axles) in the traffic stream, the distribution of traffic using each lane, and the frequency of lane-changing maneuvers observed at each site. Data collection occurred during daylight off-peak periods as well as during the PM peak period. Data on the general traffic utilization of the inside and middle lanes at sites 1 and 2 are important from the standpoint that it is that traffic which is assumed to have the most direct influence on RRPM reflectivity loss rates. The data from both sites indicate that approximately two-thirds of the total traffic volumes on these roadways travel in the lanes adjacent to the test RRPMs.

As would be expected, there is a gradual increase in the percentage of trucks as one proceeds from site 1 (the highest volume and most urban site), to site 4 (the lowest volume and most rural site). Trucks are generally underrepresented in the inside travel lane at sites 1 and 2. Whereas approximately 33 percent of all traffic at site 1 and 27 percent of traffic at site 2 use the inside lane, only 10 percent and 13 percent of trucks utilize that lane at those respective sites. Meanwhile, trucks are also underrepresented in the inside lane at site 3, but overrepresented in the inside lane at site 4.

TABLE 3. SUMMARY OF MANUAL TRAFFIC COUNTS AT EACH SITE

	Site 1	Site 2	Site 3	Site 4
Lane Distribution:				
inside lane	32.6%	27.4%	32.7%	16.8%
middle lane	35.9%	37.9%	-.-	-.-
outside lane	31.5%	34.7%	67.3%	83.2%
Truck Percentages:				
total off-peak	5.6%	8.4%	10.1%	15.4%
total peak	2.7%	3.1%	6.0%	10.6%
inside lane	9.9%	12.8%	1.0%	26.0%
middle lane	44.3%	55.1%	-.-	-.-
outside lane	45.8%	32.1%	87.0%	74.0%
Lane-Changing Rate: (per 1000 vehicles[a] per mile)	24.4	44.9	27.7	71.9

-.- No middle lane present at this site

[a] lane-changing rate is based on number of vehicles in lanes adjacent to RRPMs. At sites 1 and 2, this represents vehicles in the inside and middle lanes only, whereas it represents all vehicles at sites 3 and 4.

Table 3 also documents the rate at which lane-changing was observed between the lanes which the RRPMs are separating. This value was determined by recording the number of lane changes made within each site over a viewing distance of 1600 to 3600 ft at each site (depending on the visual perspective that was attainable), and dividing by the volumes in those lanes during a set period of time. The viewing sections were selected so as to be as representative of each site as possible. As shown in the table, rates are higher for sites 2 and 4 than they are for sites 1 and 3. The fairly large rate at site 4 (71.9 lane changes per 1000 vehicles per mile) is due to a combination of very low volumes and the rather significant grades present at that location. Trucks at this location tended to move to the inside lane on the steep downgrades as they increased speed and passed automobiles travelling in the shoulder lane, but then moved to the shoulder lane as they transferred to the upgrade and began to lose speed.

The data as presented in Tables 2 and 3 provide a relative comparison of the general traffic characteristics at each site. However, it must be remembered that sites 1 and 2 are very different than sites 3 and 4 in terms of the amount of traffic directly adjacent to the test RRPMs. Using the data documented in Tables 2 and 3, it is possible to develop normalized measures of traffic volumes, truck volumes, and lane changing rates being experienced at the four sites on a per day basis. Table 4 presents a summary of the daily exposure rates for each site.

TABLE 4. DAILY RRPM TRAFFIC EXPOSURE RATES

Exposure Criteria	Site 1[a]	Site 2[a]	Site 3	Site 4
Total Vehicles Per Day	32,700[b]	14,000[b]	18,600	3,300
Total Trucks Per Day	1,150	950	1,650	500
Lane Changes Per Mile Per Day	985	630	515	235

[a] Considering only vehicles in the inside and middle lanes at this site

[b] Represents the average of the two counts made at each end of the site

Presenting the data in this fashion, it can be seen from the table that RRPMs at site 1 (I-410) are being exposed to the greatest amount of traffic, and are having the greatest number of lane changes per day across them (the latter a result of the urban freeway design of closely-spaced ramps with moderate to high volumes). Meanwhile, the RRPMs at site 3 are being exposed to the greatest number of trucks per day, and the second highest total daily traffic volume. Despite accommodating a slightly higher total daily roadway volume at site 2, the amount of traffic directly influencing the RRPMs at this site is slightly less than for site 3. Finally, the RRPMs at site 4 are being subjected to the least amount of traffic, including trucks, and are enduring much lower lane-changing activity than any of the other three sites (less than one-fourth the rate recorded at site 1).

3. RRPM REFLECTIVITY ANALYSES

This chapter summarizes the results of laboratory and field reflectivity measurements of the RRPM samples from each site during the first month of exposure. The RRPMs were installed over a four-day period the first week of August 1992. On August 16th and again on August 30th, 1992, TxDOT and TTI personnel returned to each of the study sites to obtain field reflectivity measurements of three of each type of RRPM. At the time of the follow-up evaluations, the RRPMs had been in place at each site for the amount of time listed in Table 5.

TABLE 5. DURATION OF RRPM EXPOSURE AT EACH SITE

Site	August 16, 1992 Measurement	August 30, 1992 Measurement
Site 1	12 days	26 days
Site 2	11 days	25 days
Site 3	10 days	24 days
Site 4	9 days	23 days

Each time study personnel returned to the sites, at least one of each type of RRPM was removed from each site for reflectivity measurements at the TxDOT testing laboratory. In an attempt to improve the accuracy of measurements at sites 1 and 2 (where significant losses in reflectivity were anticipated very quickly), three samples of each type of RRPM were removed from site 1 on August 16th, and three from site 2 on August 30th.

This chapter is divided into three additional sections. The results of the laboratory reflectivity measurements are documented in the first section. Measurements were made of each RRPM unwashed (indicative of its condition in the field), and again after being washed. In the second section of the chapter, the results of the field reflectivity measurements are documented. In the third and final section of this chapter, the correlation between laboratory and field-measured reflectivity levels is assessed.

Laboratory-Measured SI Values

SI Values Before Washing

Tables 6 and 7 present the specific intensity values measured in the TxDOT laboratory of each of the unwashed RRPM samples from each site. Table 6 documents the data from August 16th, whereas data from August 30th are found in Table 7. Where more than one sample of each RRPM was taken, the range of SI values obtained are shown encased in brackets. As a means of tracking the performance of each type of RRPM over time and across all sites, these data are presented graphically in Appendix B.

The data presented in Table 6 suggest that several types of RRPMs experienced a substantial loss in reflectivity after less than two weeks exposure to roadway conditions. The losses were most significant at sites 1 and 3, where the RRPMs were exposed to higher traffic volumes, truck volumes, and lane-changing activity. Conversely, reductions in reflectivity were less dramatic at sites 2 and 4. In general, those RRPMs having high SI values initially also had high values at the August 16th evaluation. At site 1, (where multiple readings were obtained), the range in SI values after field exposure were generally less than the range recorded for each type of RRPM when new. The major exceptions to this trend were with the Stimsonite RRPM models 911 and 948 as well as the Ray-O-Lite model 2003, which displayed a greater range of values at the August 16th evaluation. The Stimsonite RRPMs were also the most reflective after exposure, and were also those covered with a thin layer of glass. The Ray-O-Lite marker was also one of the more reflective RRPMs after exposure.

The reflectivity of each type of RRPM from the August 30th data are documented in Table 7. Overall, additional reflectivity degradation is evident in the different types of RRPMs as compared to that shown in Table 6. However, there are instances where the SI value is actually higher on August 30th than on August 16th. This is most likely due to marker-to-marker variability in SI values for a given type of RRPM. The range of SI values recorded at site 2 for each marker again was generally lower than observed for the same markers when new, except for the Stimsonite 911 and 948 RRPMs.

TABLE 6. LABORATORY-MEASURED REFLECTIVITY: BEFORE WASHING
August 16, 1992

RRPM Type	Specific Intensity (c/ft-c)				
	New[a]	Site 1[b]	Site 2[c]	Site 3[c]	Site 4[c]
Apex 921	3.5 [2.7-4.9]	0.8 [0.4-1.3]	2.1	1.3	1.5
Apex 918	4.2 [2.9-7.0]	1.2 [0.6-1.9]	1.8	1.0	1.2
Apex 928	2.9 [1.5-4.8]	1.5 [1.1-2.1]	4.4	0.7	2.5
Apex 807	2.4 [0.9-6.3]	0.7 [0.6-0.8]	1.0	0.4	1.0
Apex 817	1.0 [0.8-1.4]	1.0 [0.8-1.1]	2.2	0.3	0.9
Batterson	5.2 [4.6-5.6]	1.0 [1.0]	1.7	1.4	3.5
Empco 901	1.8 [1.3-2.9]	0.8 [0.5-1.1]	1.1	1.2	1.7
Ray-O-Lite 8704 (S)	5.3 [3.4-7.4]	2.1 [1.8-2.6]	3.8	n.a.	n.a.
Ray-O-Lite 8704 (R)	5.3 [5.2-5.4]	1.5 [1.5-1.6]	n.a.	1.8	3.0
Ray-O-Lite 9704	6.4 [4.9-8.0]	2.8 [2.6-3.3]	4.8	1.2	5.0
Ray-O-Lite 2002	6.3 [5.1-7.8]	4.1 [3.3-5.0]	3.1	2.7	3.6
Ray-O-Lite 2003	6.9 [4.9-8.1]	4.6 [1.8-9.5]	4.7	2.9	6.5
Stimsonite 88	7.4 [6.3-8.1]	2.4 [2.1-2.7]	1.0	3.0	4.8
Stimsonite 911	9.2 [8.3-10.4]	6.0 [3.2-8.7]	6.8	5.3	9.7
Stimsonite 948	8.0 [7.5-8.6]	7.0 [4.6-10.7]	4.1	2.3	11.4
Stimsonite 953	8.7 [7.6-11.0]	4.7 [4.3-5.4]	5.8	4.5	5.3
Swareflex	5.5 [5.1-5.7]	2.8 [2.6-2.9]	3.6	1.5	4.3

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n.a. = data not available
a Average of five markers.
b Average at three markers.
c Data from a single marker.
[ ] Numbers in brackets are the range of readings recorded.

TABLE 7. LABORATORY-MEASURED REFLECTIVITY: BEFORE WASHING
August 30, 1992

RRPM Type	Specific Intensity (c/ft-c)				
	New[a]	Site 1[c]	Site 2[b]	Site 3[c]	Site 4[c]
Apex 921	3.5 [2.7-4.9]	1.7	1.5 [1.0-1.9]	0.9	2.5
Apex 918	4.2 [2.9-7.0]	1.2	1.2 [1.2]	0.8	1.9
Apex 928	2.9 [1.5-4.8]	1.0	1.0 [0.7-1.3]	2.0	1.2
Apex 807	2.4 [0.9-6.3]	0.5	0.7 [0.6-0.9]	1.0	0.9
Apex 817	1.0 [0.8-1.4]	0.9	0.4 [0.0-0.6]	0.7	1.5
Batterson	5.2 [4.6-5.6]	0.4	0.5 [0.4-0.5]	0.4	2.3
Empco 901	1.8 [1.3-2.9]	0.5	0.6 [0.4-0.7]	n.a	1.0
Ray-O-Lite 8704 (S)	5.3 [3.4-7.4]	2.3	1.9 [1.7-2.9]	n.a.	n.a.
Ray-O-Lite 8704 (R)	5.3 [5.2-5.4]	2.2	n.a.	1.8	2.7
Ray-O-Lite 9704	6.4 [4.9-8.0]	2.9	3.1 [2.8-3.5]	2.7	3.5
Ray-O-Lite 2002	6.3 [5.1-7.8]	3.7	3.8 [2.4-4.5]	0.8	4.2
Ray-O-Lite 2003	6.9 [4.9-8.1]	2.5	3.8 [3.1-4.2]	1.3	5.5
Stimsonite 88	7.4 [6.3-8.1]	2.7	2.5 [1.7-3.0]	2.4	5.7
Stimsonite 911	9.2 [8.3-10.4]	4.9	7.3 [4.5-10.3]	4.7	13.4
Stimsonite 948	8.0 [7.5-8.6]	5.7	5.3 [4.6-6.1]	2.8	9.4
Stimsonite 953	8.7 [7.6-11.0]	2.9	5.3 [4.9-5.8]	1.9	5.4
Swareflex	5.5 [5.1-5.7]	2.3	3.6 [0.9-2.3]	1.0	3.1

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n.a. = data not available
[a] Average of five markers.
[b] Average at three markers.
[c] Data from a single marker.
[ ] Numbers in brackets are the range of readings recorded.

SI Values After Washing

SI readings for the RRPMs taken from each site after they had been cleaned are presented in Tables 8 and 9 (representing the data from August 16th and August 30th, respectively). The SI values in the tables (as well as in the graphs presented in Appendix B) show a wide range in the amount of permanent reflectivity loss incurred by the various RRPMs. For both the August 16th and August 30th data, the SI values of several RRPMs (particularly sites 2 and 4) exceed the average value for new markers. For the most part, then, the data suggest that the permanent losses in reflectivity in the majority of the RRPMs were relatively small at all the sites during the first month of exposure.

The range of SI values recorded at sites 1 and 2 (where multiple readings were taken) were generally less than the range of values for each when new. Again, the Stimsonite models 911 and 948 did not follow this trend. The range in SI values for the Swareflex RRPM and Ray-O-Lite model 2003 was also greater after field exposure.

Relationship between Reflectivity Degradation and Traffic Conditions at Each Site

Because of the small number of RRPMs being evaluated in the laboratory and the small period of time over which data has been collected, it is difficult to assess the effects of the different traffic conditions at each site upon every type of RRPM being evaluated. However, some insight into the relationship between RRPM reflectivity degradation and traffic characteristics can be gained by examining the combined remaining reflectivity of all types of RRPMs at each site. Table 10 summarizes these averages. Averages are presented for both the unwashed and washed RRPMs. Those RRPMs which had higher SI values after being in the field than the estimated SI value of that type of RRPM when new were said to have 100 percent reflectivity remaining. In reality, these markers probably had extremely high SI values to begin with, and did experience some loss of reflectivity over time. Nevertheless, the averages do provide an overall picture of how well RRPM reflectivity was sustained at each of the sites during the first month of exposure.

TABLE 8. LABORATORY-MEASURED REFLECTIVITY: AFTER WASHING
August 16, 1992

RRPM Type	Specific Intensity (c/ft-c)				
	New[a]	Site 1[b]	Site 2[c]	Site 3[c]	Site 4[c]
Apex 921	3.5 [2.7-4.9]	1.4 [0.9-2.2]	1.9	3.0	2.4
Apex 918	4.2 [2.9-7.0]	1.9 [1.2-2.5]	2.3	3.3	1.9
Apex 928	2.9 [1.5-4.8]	2.1 [1.2-3.4]	4.7	1.2	3.7
Apex 807	2.4 [0.9-6.3]	1.0 [0.9-1.1]	1.5	0.7	1.2
Apex 817	1.0 [0.8-1.4]	1.2 [1.0-1.4]	1.9	0.6	1.3
Batterson	5.2	4.2 [4.0-4.6]	3.8	5.1	4.6
Empco 901	1.8 [1.3-2.9]	1.1 [0.7-1.3]	1.3	1.5	1.7
Ray-O-Lite 8704 (S)	5.3 [3.4-7.4]	4.1 [3.8-4.4]	6.4	n.a.	n.a.
Ray-O-Lite 8704 (R)	5.3 [5.2-5.4]	3.6 [4.6-7.3]	n.a.	3.2	3.9
Ray-O-Lite 9704	6.4 [4.9-8.0]	5.8 [5.3-6.3]	5.4	3.0	5.8
Ray-O-Lite 2002	6.3 [5.1-7.8]	4.9 [4.3-5.5]	5.9	5.9	5.6
Ray-O-Lite 2003	6.9 [4.9-8.1]	6.1 [3.0-12.3]	4.5	5.1	6.1
Stimsonite 88	7.4 [6.3-8.1]	5.7 [4.6-7.3]	7.9	5.2	5.0
Stimsonite 911	9.2 [8.3-10.4]	10.1 [7.3-13.4]	8.8	12.4	13.3
Stimsonite 948	8.0 [7.5-8.6]	8.5 [7.6-9.0]	4.5	4.8	12.7
Stimsonite 953	8.7 [7.6-11.0]	6.4 [6.2-6.5]	6.6	6.6	6.3
Swareflex	5.5 [5.1-5.7]	4.8 [3.9-5.8]	5.3	4.9	5.8

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n.a. = data not available
[a] Average of five markers.
[b] Average at three markers.
[c] Data from a single marker.
[ ] Numbers in brackets are the range of readings recorded.

TABLE 9. LABORATORY-MEASURED REFLECTIVITY: AFTER WASHING
August 30, 1992

RRPM Type	Specific Intensity (c/ft-c)				
	New[a]	Site 1[c]	Site 2[b]	Site 3[c]	Site 4[c]
Apex 921	3.5 [2.7-4.9]	2.1	1.8 [1.5-2.4]	1.9	3.1
Apex 918	4.2 [2.9-7.0]	1.7	1.8 [1.5-1.9]	1.5	2.5
Apex 928	2.9 [1.5-4.8]	1.2	1.4 [1.2-1.5]	3.5	1.5
Apex 807	2.4 [0.9-6.3]	0.6	0.7 [0.5-0.9]	1.4	0.9
Apex 817	1.0 [0.8-1.4]	1.3	0.7 [0.1-1.0]	0.9	1.4
Batterson	5.2 [4.6-5.6]	2.6	2.2 [1.6-2.9]	3.7	4.8
Empco 901	1.8 [1.3-2.9]	0.7	0.9 [0.7-1.1]	n.a.	0.9
Ray-O-Lite 8704 (S)	5.3 [3.4-7.4]	2.9	2.8 [2.1-3.8]	n.a.	n.a.
Ray-O-Lite 8704 (R)	5.3 [5.2-5.4]	2.4	n.a.	3.6	3.7
Ray-O-Lite 9704	6.4 [4.9-8.0]	3.4	3.7 [2.3-5.2]	5.7	3.8
Ray-O-Lite 2002	6.3 [5.1-7.8]	7.0	5.9 [5.0-7.0]	2.9	6.1
Ray-O-Lite 2003	6.9 [4.9-8.1]	3.3	7.0 [5.0-8.8]	6.3	6.7
Stimsonite 88	7.4 [6.3-8.1]	3.0	3.2 [3.0-3.4]	4.1	6.8
Stimsonite 911	9.2 [8.3-10.4]	5.8	9.5 [7.8-11.4]	8.7	13.9
Stimsonite 948	8.0 [7.5-8.6]	7.5	7.5 [6.5-9.5]	5.7	10.8
Stimsonite 953	8.7 [7.6-11.0]	5.7	6.8 [6.2-7.5]	6.4	6.3
Swareflex	5.5 [5.1-5.7]	5.8	5.2 [4.4-5.6]	3.1	5.8

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n.a. = data not available
[a] Average of five markers.
[b] Average at three markers.
[c] Data from a single marker.
[ ] Numbers in brackets are the range of readings recorded.

TABLE 10. AVERAGE PERCENT REMAINING RRPM REFLECTIVITY BY SITE

Evaluation Date	Average Percent of Original SI Values			
	Site 1	Site 2	Site 3	Site 4
August 16th, 1992:				
Unwashed	48.8	60.9	35.7	71.3
Washed	73.9	80.3	71.7	83.0
August 30th, 1992:				
Unwashed	42.3	45.1	36.1	63.4
Washed	60.0	65.5	70.3	73.7

From the data presented in Table 10, reflectivity retention percentages of the unwashed RRPMs show much more variability from site to site than do the washed RRPMs, particularly for the August 16th evaluation. In general, it appears that site differences have much less of an effect upon long-term reflectivity loss. Also, the difference between the percentages shown for the unwashed and washed RRPMs are much more significant at site 3 than any of the other sites. As stated in Chapter 2, there was some concern that oil and tar residue from the new asphalt overlay on which the RRPMs at site 3 were placed might degrade RRPM reflectivity more severely at that site. Based on these early estimates of reflectivity retention, it does appear that dirt and road grime accumulation were more of a factor at site 3 than at the remaining sites.

To more directly assess the effects of the traffic conditions at each site upon the average reflectivity retention at each site, the values in Table 10 were plotted against estimates of three different measures of traffic exposure. Again referring back to Chapter 2, traffic studies performed at each site yielded daily rates of the total traffic volumes, truck volumes, and lane-changing frequencies to which the RRPMs were being exposed. These were presented in Table 3. By multiplying that data by the number of exposure days RRPMs at each site (see Table 5), an estimate of the total exposure to date for each traffic measure was computed for each site. These estimates were then plotted together against the average remaining reflectivity percentages, as shown in Figures 3 through 5.

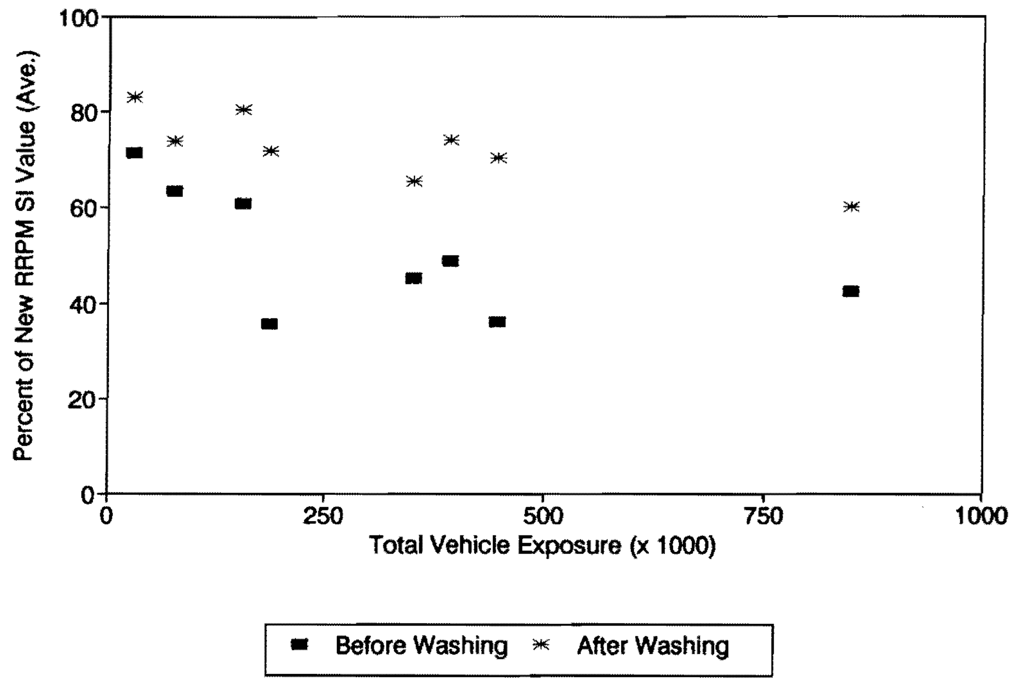

Figure 3. Average Percent of New RRPM Reflectivity versus Amount of Traffic Exposure.

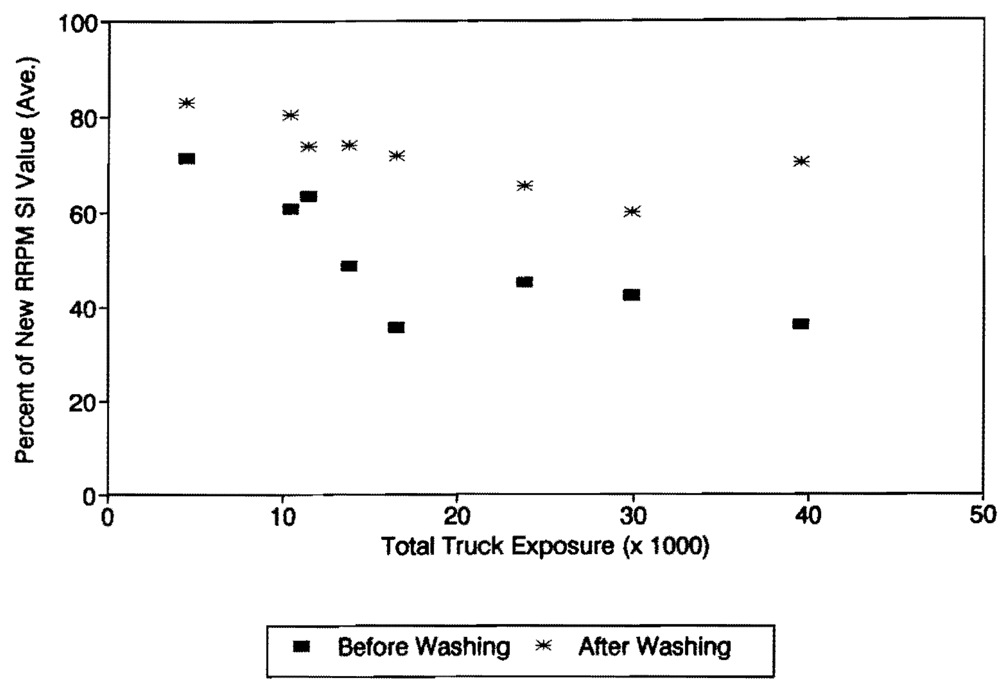

Figure 4. Average Percent of New RRPM Reflectivity versus Amount of Truck Traffic Exposure.

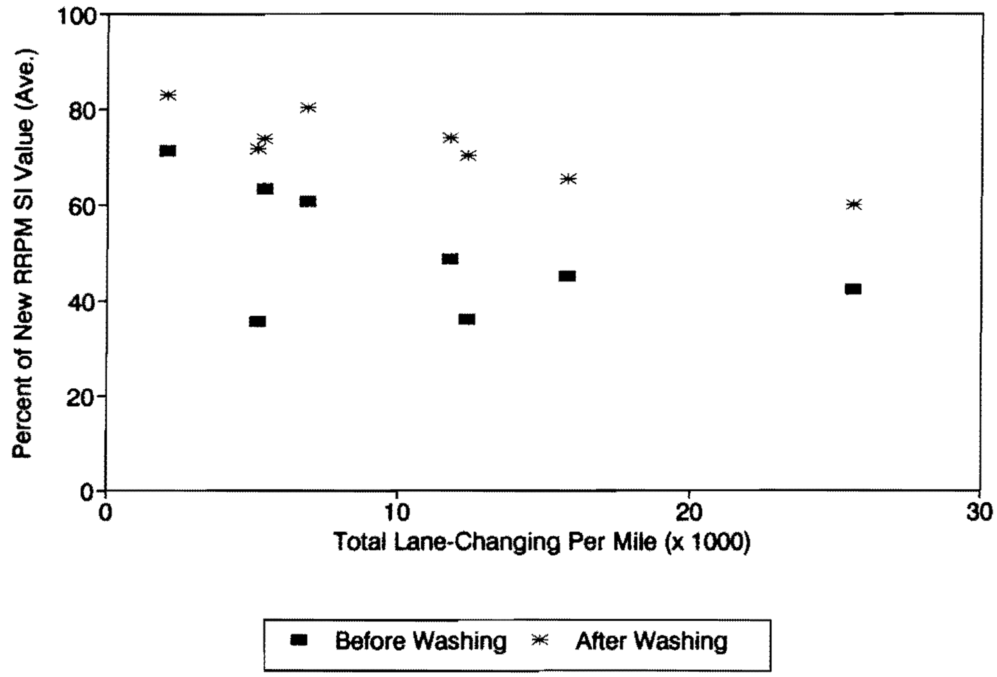

Figure 5. Average Percent of New RRPM Reflectivity versus Amount of Lane-Changing Per Mile.

Comparing the graphs of Figures 3 through 5, it appears that reflectivity degradation is related to all three traffic exposure measures (total traffic, truck traffic, and lane-changing rates). That is as exposure to all three traffic measures increases the average percent of remaining reflectivity decreases. This is expected, since those sites with high total traffic volumes also have high total truck volumes and lane-changing activity. However, it seems that reflectivity degradation of both unwashed and washed RRPMs is most strongly related to total truck exposure (a steeper slope of the data with less scatter). Once additional reflectivity data is collected, the relationship between reflectivity and traffic conditions will be examined more rigorously using statistical methods.

Field-Measured SI Values

Average SI Values of New RRPMs

A prototype portable RRPM retroreflectometer manufactured by Advanced Retro Technology, Inc. (Model 1200C) (5) was used to estimate RRPM SI values at the time of installation, and during the follow-up visits on August 16th and August 30th. The retroreflectometer is a self-contained unit with an internal rechargeable battery, light source, and light detector. Placed over the RRPM, the unit illuminates the measurement area with the calibrated light source and measures the total amount of light reflected back. This is in contrast to laboratory units which rely on a point source of illumination. The portable retroreflectometer simulates standard reflectivity testing geometry (i.e., 0.2° observation angle and a reported entrance angle of less than 2°), assessed over a measurement area that is approximately 1 inch by 5.5 inches. Unfortunately, the Ray-O-Lite model 2003 marker was slightly wider than the measurement area of the portable unit, which kept the unit from properly seating on the pavement during reflectivity measurements of this RRPM. Some stray light may have seeped under the unit when evaluating those markers, yielding values slightly greater than actually provided by the RRPM.

Approximately 90 of each type of RRPM were measured with the portable retroreflectometer at the sites at the time of installation. Table 11 presents a comparison of the average SI values obtained for each RRPM type by the laboratory and by the portable unit. Also presented in Table 11 are the standard deviations of the SI readings for each type of measurement. In general, good agreement exists between the laboratory-measured and field-measured average SI values for most RRPMs. The portable retroreflectometer does appear to be slightly higher in some cases, however, particularly for those RRPMs manufactured by Ray-O-Lite. Likewise, a comparison of the standard deviations of the laboratory- and field-measured SI values show those from the portable unit to be slightly more variable for almost all RRPM types. However, many more observations were taken in the field than in the laboratory, which may partly explain the greater variability in SI values for the portable unit.

TABLE 11. LABORATORY AND FIELD-MEASURED SI VALUES: New RRPMS

RRPM Type	Specific Intensity, c/ft-c			
	Average		Standard Deviation	
	Laboratory	Field	Laboratory	Field
Apex 921	3.5	4.4	0.9	1.9
Apex 918	4.2	3.5	1.9	1.1
Apex 928	2.9	4.0	1.1	1.1
Apex 807	2.4	1.4	2.2	0.8
Apex 817	1.0	1.7	0.3	0.9
Batterson	5.2	5.5	0.4	1.0
Empco	1.8	2.4	0.7	1.0
Ray-O-Lite 8704 (S)	5.3	7.1	1.3	1.5
Ray-O-Lite 8704 (R)	5.3	5.3	0.1	1.3
Ray-O-Lite 9704	6.4	9.1	1.1	2.2
Ray-O-Lite 2002	6.3	9.3	1.0	1.8
Ray-O-Lite 2003	6.9	9.5	1.3	3.3
Stimsonite 88	7.4	7.1	0.7	2.1
Stimsonite 911	9.2	9.1	0.9	2.5
Stimsonite 948	8.0	8.9	0.4	2.4
Stimsonite 953	8.7	7.3	1.3	1.4
Swareflex	5.5	5.4	0.3	1.0

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM

Average SI Values After Field Exposure

During both the August 16th and the August 30th evaluations, three markers of each type of RRPM were measured per site using the portable retroreflectometer. These measurements were then averaged. The averages are reported for both evaluations in Tables 12 and 13, respectively. As was done for the laboratory measurements, field SI values are presented graphically over time and by site for each RRPM individually in Appendix B. Also it was possible to directly compare readings of indicated over time at sites 1 and 2, where readings were taken of all RRPMs when installed. These trend data for individual markers are discussed in Appendix C.

Sampling the reflectivity of three of each type of RRPM per site provided a much more stable picture regarding the degradation of RRPM reflectivity over time at each site. In Table 12, the SI values from the August 16th evaluation indicate that conditions at sites 1 and 3 had the most significant impact upon reflectivity. RRPMs at site 2 were slightly more reflective, and conditions at site 4 were found to have the least effect upon RRPM reflectively. Furthermore, these values are consistent with those obtained by the laboratory SI measurements and reported in Table 6. Field-measured SI values from August 30th are presented in Table 13. From the data in Table 13, it appears that RRPMs at site 2 experienced the most dramatic degradation in reflectivity from the prior (August 16th) evaluation. The SI values from the portable unit also appear to correlate well with the laboratory measurements reported in Table 7.

The range of readings for each RRPM shown in both tables were lower after exposure than the range of readings taken when new. Also, those RRPMs with higher average reflectivity values after field exposure tended to show a greater range in values than those having lower SI values. It should be noted that the study personnel had no experience with the retroreflectometer when they began taking SI readings of the new RRPMs in the field. Much of the variability in SI values for each RRPM when new could be due to inexperience with calibrating and operating the retroreflectometer.

TABLE 12. FIELD-MEASURED REFLECTIVITY
August 16, 1992

RRPM Type	Average Specific Intensity (c/ft-c)				
	New[a]	Site 1[b]	Site 2[b]	Site 3[b]	Site 4[b]
Apex 921	4.4 [0.7-11.0]	0.9 [0.4-1.8]	1.3 [1.1-1.5]	0.7 [0.3-1.1]	3.3 [2.1-5.1]
Apex 918	3.5 [0.6-8.0]	1.0 [0.6-1.5]	1.7 [1.4-2.3]	0.9 [0.6-1.2]	2.0 [1.4-2.8]
Apex 928	4.0 [1.6-7.6]	1.5 [1.4-1.5]	2.5 [2.2-2.8]	1.0 [0.6-1.7]	2.0 [1.5-2.5]
Apex 807	1.4 [0.3-6.1]	0.5 [0.4-0.6]	0.8 [0.3-1.0]	0.3 [0.1-0.6]	0.6 [0.1-0.9]
Apex 817	1.7 [0.2-5.4]	0.7 [0.5-0.8]	0.8 [0.0-1.3]	0.5 [0.2-0.8]	1.0 [0.6-1.6]
Batterson	5.5 [3.0-8.9]	0.6 [0.3-0.7]	1.4 [1.4-1.5]	1.0 [0.8-1.3]	2.6 [1.9-3.5]
Empco 901	2.4 [1.0-5.6]	0.6 [0.5-0.7]	1.0 [0.9-1.0]	0.8 [0.5-1.2]	1.0 [0.8-1.3]
Ray-O-Lite 8704 (S)	7.1 [3.8-13.3]	2.4 [1.9-2.6]	2.9 [1.6-4.0]	n.a.	n.a.
Ray-O-Lite 8704 (R)	5.3 [2.0-9.7]	1.2 [1.1-1.3]	n.a.	1.1 [0.8-1.5]	3.3 [3.1-3.6]
Ray-O-Lite 9704	9.1 [2.2-15.6]	2.5 [2.0-3.4]	5.1 [4.3-5.9]	1.6 [0.8-2.0]	6.2 [5.9-6.5]
Ray-O-Lite 2002	9.3 [4.5-14.5]	4.0 [3.4-4.5]	5.0 [4.1-6.1]	1.6 [0.5-2.7]	6.4 [5.0-7.8]
Ray-O-Lite 2003	9.5 [2.3-16.7]	3.8 [1.6-7.8]	3.5 [1.9-5.0]	2.1 [1.5-3.1]	7.2 [6.2-7.9]
Stimsonite 88	8.1 [4.5-16.2]	2.7 [2.0-3.1]	3.7 [2.7-4.6]	2.3 [1.6-3.8]	5.4 [3.5-7.8]
Stimsonite 911	9.1 [1.8-15.7]	4.8 [2.8-6.0]	7.7 [6.4-10.0]	4.5 [2.5-5.7]	10.5 [9.3-12.5]
Stimsonite 948	8.9 [5.0-15.2]	3.5 [2.4-4.4]	5.1 [3.2-8.2]	2.1 [1.4-2.8]	8.9 [7.4-11.8]
Stimsonite 953	7.3 [4.2-11.1]	4.2 [2.9-5.6]	6.1 [1.8-6.9]	4.2 [2.1-6.3]	7.9 [7.7-8.3]
Swareflex	5.4 [2.8-9.9]	1.8 [1.1-2.5]	3.1 [2.4-4.0]	1.6 [2.2-5.7]	4.1 [2.2-5.7]

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n.a. = data not available
[a] Average of 87 to 95 measurements at time of installation.
[b] Average of 3 measurements.
[ ] Numbers in brackets are the range of readings recorded.

TABLE 13. FIELD-MEASURED REFLECTIVITY
August 30, 1992

RRPM Type	Average Specific Intensity (c/ft-c)				
	New[a]	Site 1[b]	Site 2[b]	Site 3[b]	Site 4[b]
Apex 921	4.4 [0.7-11.0]	1.3 [1.1-1.5]	0.6 [0.2-0.9]	0.7 [0.7-0.8]	3.1 [1.9-3.7]
Apex 918	3.5 [0.6-8.0]	1.2 [1.0-1.4]	1.0 [0.9-1.2]	0.6 [0.5-0.8]	1.7 [1.1-2.3]
Apex 928	4.0 [1.6-7.6]	1.0 [1.0-1.1]	1.3 [0.8-1.6]	1.6 [1.1-2.3]	1.9 [1.2-2.9]
Apex 807	1.4 [0.3-6.1]	0.4 [0.3-0.6]	0.4 [0.2-0.8]	0.4 [0.2-0.7]	0.5 [0.3-0.6]
Apex 817	1.7 [0.2-5.4]	0.6 [0.5-0.8]	0.4 [0.0-0.7]	0.4 [0.4-0.5]	0.6 [0.4-0.7]
Batterson	5.5 [3.0-8.9]	0.3 [0.2-0.4]	0.4 [0.4-0.5]	0.5 [0.3-0.6]	1.6 [1.4-1.8]
Empco 901	2.4 [1.0-5.6]	0.4 [0.3-0.5]	0.5 [0.4-0.7]	0.9 [0.9]	1.2 [0.6-2.1]
Ray-O-Lite 8704 (S)	7.1 [3.8-13.3]	1.9 [1.7-2.1]	1.7 [1.3-2.1]	n.a.	n.a.
Ray-O-Lite 8704 (R)	5.3 [2.0-9.7]	1.0 [0.9-1.3]	n.a.	1.5 [1.4-1.6]	2.6 [2.1-3.1]
Ray-O-Lite 9704	9.1 [2.2-15.6]	2.0 [1.7-2.4]	2.7 [1.6-3.7]	2.4 [2.0-2.9]	4.7 [4.0-5.5]
Ray-O-Lite 2002	9.3 [4.5-14.5]	4.4 [4.3-4.6]	3.9 [3.4-4.7]	1.6 [1.2-2.3]	6.4 [3.4-9.9]
Ray-O-Lite 2003	9.5 [2.3-16.7]	2.9 [1.8-5.0]	3.6 [3.2-4.0]	1.9 [1.0-2.5]	5.7 [5.3-6.0]
Stimsonite 88	8.1 [4.5-16.2]	2.1 [1.7-2.9]	2.0 [1.4-2.4]	1.9 [1.0-2.5]	3.7 [2.1-5.8]
Stimsonite 911	9.1 [1.8-15.7]	5.3 [4.5-6.4]	6.3 [3.8-8.2]	3.2 [2.1-4.2]	7.9 [5.5-9.7]
Stimsonite 948	8.9 [5.0-15.2]	4.6 [3.8-5.8]	5.6 [3.6-7.0]	2.1 [1.6-2.5]	6.9 [6.0-8.3]
Stimsonite 953	7.3 [4.2-11.1]	4.8 [4.6-4.9]	5.2 [0.2-7.0]	2.8 [2.1-3.5]	6.6 [5.7-7.1]
Swareflex	5.4 [2.8-9.9]	1.3 [1.2-1.5]	1.2 [0.8-1.4]	0.7 [0.5-0.8]	2.8 [2.1-3.3]

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n.a. = data not available
[a] Average of 87 to 95 measurements at time of installation.
[b] Average of 3 measurements.
[ ] Numbers in brackets are the range of readings recorded.

Table 14 summarizes the average percentage of remaining reflectivity by site, as was computed earlier for the laboratory reflectivity measurements. In general, the percentages in Table 14 are consistently lower than shown in Table 10 (laboratory-measured reflectivity) for the unwashed RRPMs. It was noted in Table 11 that the portable unit tended to provide higher SI values for those RRPMs which were more reflective initially. If an initial value is artificially high, subsequent measurements compared to that value would tend to yield lower percentages. Although the values in Table 14 are lower than those of Table 10, there is generally good agreement between the two measurement approaches with respect to the site-to-site variability in degradation, and in the small amount of additional reduction in reflectivity from the August 16th to the August 30th evaluations.

TABLE 14. AVERAGE PERCENT RRPM REFLECTIVITY RETENTION BY SITE: Field Measured Reflectivity

Evaluation Date	Average Percent of Original SI Values			
	Site 1	Site 2	Site 3	Site 4
August 16th, 1992	34.3	51.9	27.2	68.2
August 30th, 1992	32.2	33.8	24.8	56.3

Figures 6 through 8 illustrate the relationship that exists between the average percent of remaining reflectivity and the traffic exposure measures calculated in the previous section. As before, the most consistent relationship appears to be between reflectivity degradation and total truck exposure at each site. The relationship appears to be less significant between retention and total traffic exposure, and least dependent upon lane-changing exposure rates.

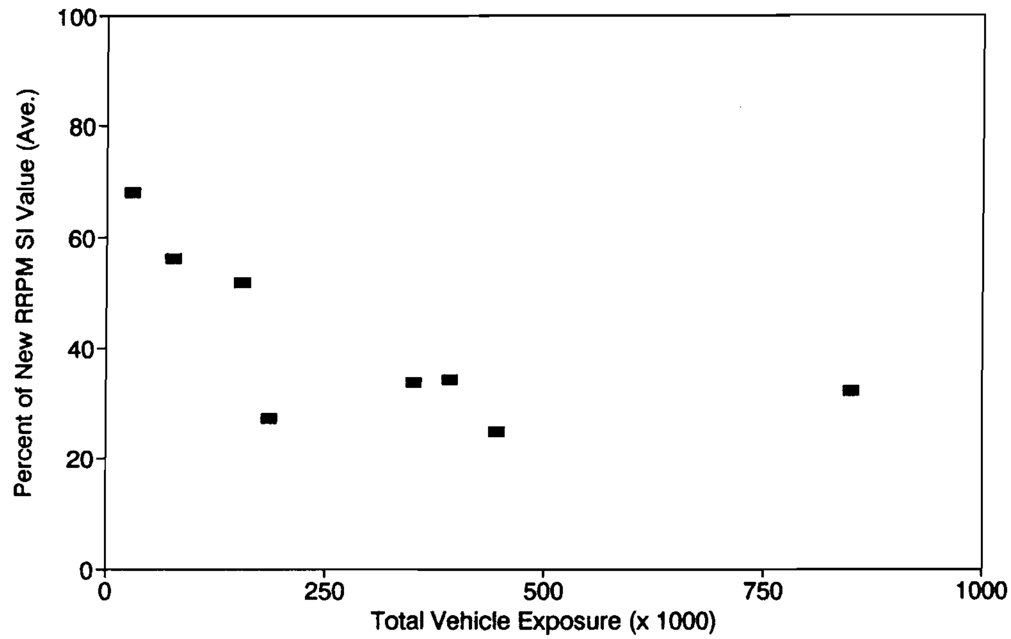

Figure 6. Average Percent of Field-Measured New RRPM Reflectivity Retention versus Amount of Traffic Exposure.

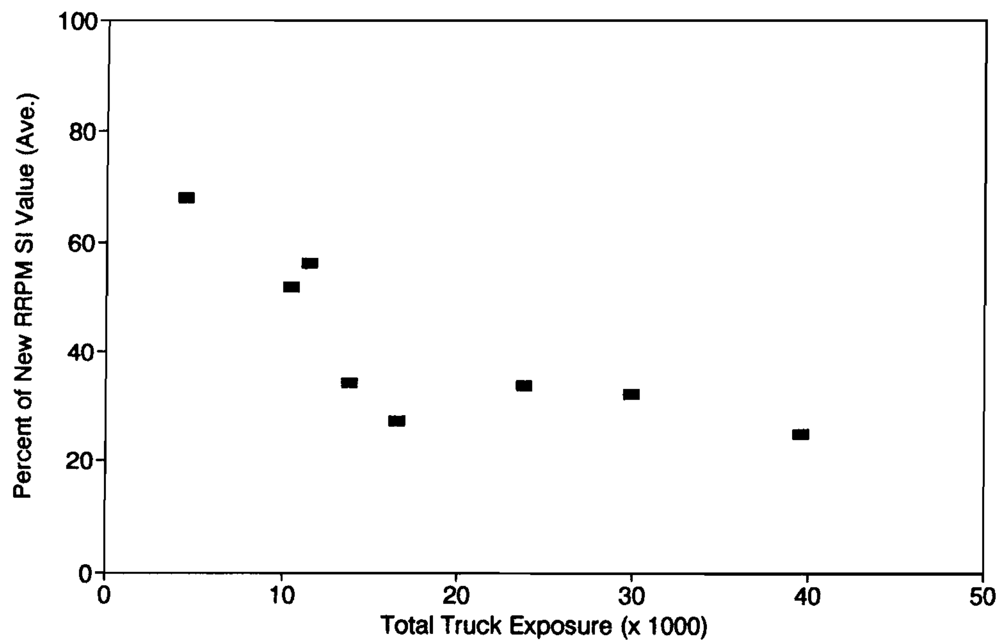

Figure 7. Average Percent of Field-Measured New RRPM Reflectivity Retention versus Amount of Truck Traffic Exposure.

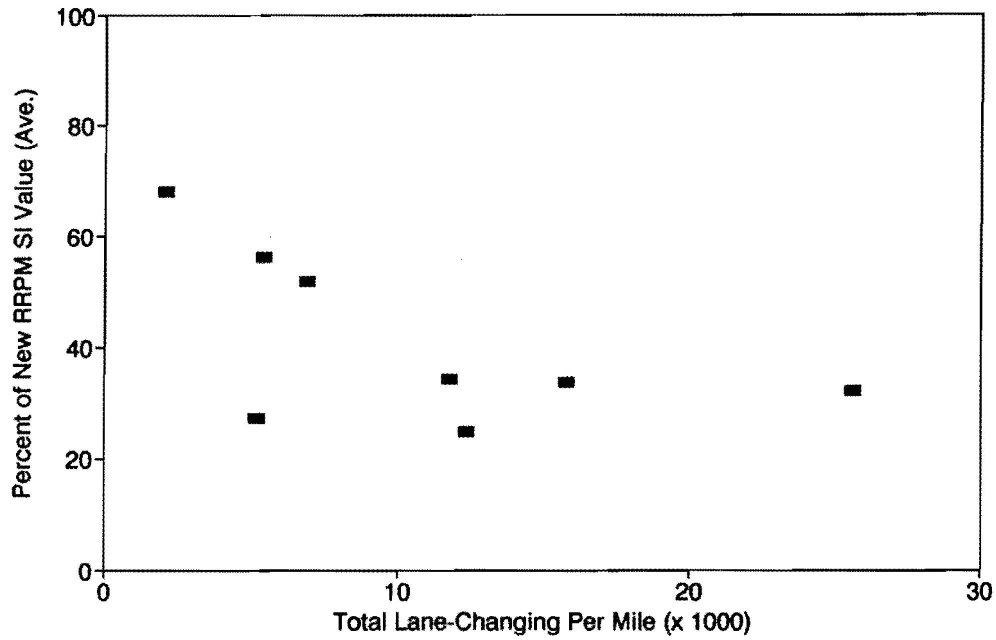

Figure 8. Average Percent of Field-Measured New RRPM Reflectivity Retention versus Amount of Lane-Changing Per Mile.

Correlation Between Field and Laboratory SI Values

An important sidelight to this field testing of the various RRPMs is the performance of the portable retroreflectometer. If it was determined that the portable unit could reasonably estimate RRPM SI values that would be measured in the laboratory, it would dramatically reduce the need to remove RRPMs from the roadway when assessing the amount of reflectivity being provided by the markers. Overall, a comparison of the SI values from the lab before washing to those recorded using the portable retroreflectometer suggests fairly good agreement between the two measurements. Figure 9 presents a graph of field-measured SI values versus laboratory-measured SI values for all RRPMs removed from all sites during the August 16th and August 30th evaluations. As the figure illustrates, relatively good agreement exists between the two methods of measurement, although slightly larger discrepancies are evident at higher SI values.

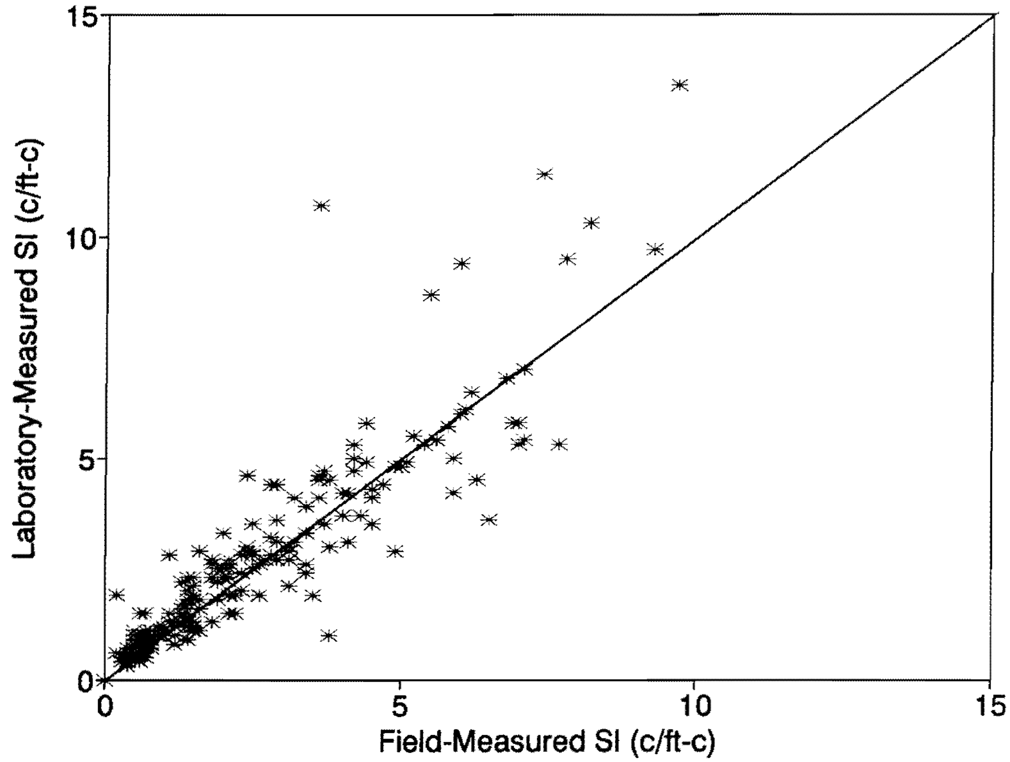

Figure 9. Field-Measured versus Laboratory-Measured SI Values.

Correlation coefficients were computed between the two types of measurement to provide a more quantitative assessment of their comparability. Two variables which are perfectly correlated with each other will result in a coefficient of either +1 or -1 (depending on whether they are positively or negatively correlated). A coefficient of 0 indicates that the two variables are not correlated at all. In statistical terms, the correlation coefficient is simply the square root of the r^2 value (coefficient of determination) resulting from fitting a linear regression line through the data.

Correlation coefficients were computed for the entire dataset, and then recomputed by study (August 16th and 30th), by site, and then by individual RRPM type. The coefficients are documented in Table 15. Overall correlation between the portable retroreflectometer and laboratory measurements was 0.90. Furthermore, the correlation was fairly consistent for each follow-up study, being only slightly higher for the second evaluation on August 30th. Similar consistency was noted when the data was evaluated

TABLE 15. CORRELATION BETWEEN FIELD AND LABORATORY-MEASURED SI VALUES

	Correlation Coefficient
Overall (n=200)	0.90
By Evaluation Study:	
August 16th (n=101)	0.86
August 30th (n=99)	0.93
By Site:	
Site 1 (n=68)	0.86
Site 2 (n=67)	0.93
Site 3 (n=33)	0.94
Site 4 (n=32)	0.88
By RRPM Type:	
Apex 921 (n=12)	0.54
Apex 918 (n=12)	0.84
Apex 928 (n=12)	0.88
Apex 807 (n=12)	0.85
Apex 817 (n=12)	0.81
Batterson (n=12)	0.98
Empco (n=12)	0.89
Ray-O-Lite 8704 (S) (n=11)	0.90
Ray-O-Lite 8704 (R) (n=9)	0.86
Ray-O-Lite 9704 (n=12)	0.84
Ray-O-Lite 2002 (n=12)	0.68
Ray-O-Lite 2003 (n=12)	0.98
Stimsonite 88 (n=12)	0.71
Stimsonite 911 (n=12)	0.91
Stimsonite 948 (n=12)	0.61
Stimsonite 953 (n=12)	0.60
Swareflex (n=12)	0.81

(S) = Square-shouldered RRPM
(R) = Round-shouldered RRPM
n = sample size

on a per-site basis. The correlation between measurement methods on RRPMs ranged from a low of 0.86 at site 1 to a high of 0.94 at site 3. Somewhat more variability in the coefficients was evident when the RRPMs were evaluated separately. The Apex model 921, the Stimsonite 948 and Stimsonite 953 displayed lower correlation coefficients than the remaining RRPM models.

Summary

Field and laboratory SI measurements of each type of RRPM after slightly less than two weeks and four weeks exposure at each site were collected and analyzed. The results if the analyses are as follows:

1. Laboratory SI values of both unwashed and washed RRPM samples removed from each site on August 16th and August 30th demonstrate considerable variation in terms of the amount of reflectivity degradation by each RRPM type. In general, those RRPMs initially having the highest SI values continued to have the highest values at each of the subsequent evaluations.

2. Averaging the reflectivity retention percentages of all types of RRPMs at each site prior to washing, it appears that the markers had between 35 and 70 percent of their original SI values remaining after less than two weeks exposure. At approximately 4 weeks exposure, the range in remaining reflectivity by site was still between 35 and 65 percent.

3. After washing the RRPMs of the accumulated dirt and road grime, laboratory-measured SI values after two weeks exposure were approximately 70 to 85 percent of new SI values, and between 60 and 75 percent after four weeks exposure. Whereas the unwashed RRPMs showed little additional degradation in reflectivity between the two week and four week evaluation, reflectivity measurements taken after washing the RRPMs indicates that SI values continued to decrease between the two-week and four week evaluation.

4. The much greater discrepancy in average percent remaining reflectivity between unwashed and washed RRPMs at site suggests that residue from the new asphalt pavement may have caused more reflectivity degradation than would have been expected under normal pavement conditions.

5. Field-measured SI values were found to show generally good agreement with measurements taken in the laboratory. However, considering all RRPMs together at each site, the average percent of remaining reflectivity was slightly less than that estimated using the laboratory measurements.

6. Both laboratory-measured and field-measured reflectivity degradation appears to be most strongly related to the total amount of truck traffic to which the RRPMs are exposed, and to a lesser extent, upon the total traffic demand operating directly adjacent to the RRPMs and the total lane-changing activity across the RRPMs.

7. Correlation analysis indicates very good agreement between RRPM SI measurements made using the portable retroreflectometer and measurements made in the TxDOT laboratory. There is some evidence to suggest that the portable unit may underestimate the SI values of highly reflective RRPMs.

4. REFERENCES

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2. Tielking, J.T. and J.S. Noel. On the Retention of Reflective Raised Pavement Markers. Report No. FWHA/TX-87-477-1F. Texas Transportation Institute, College Station, TX. 1988.

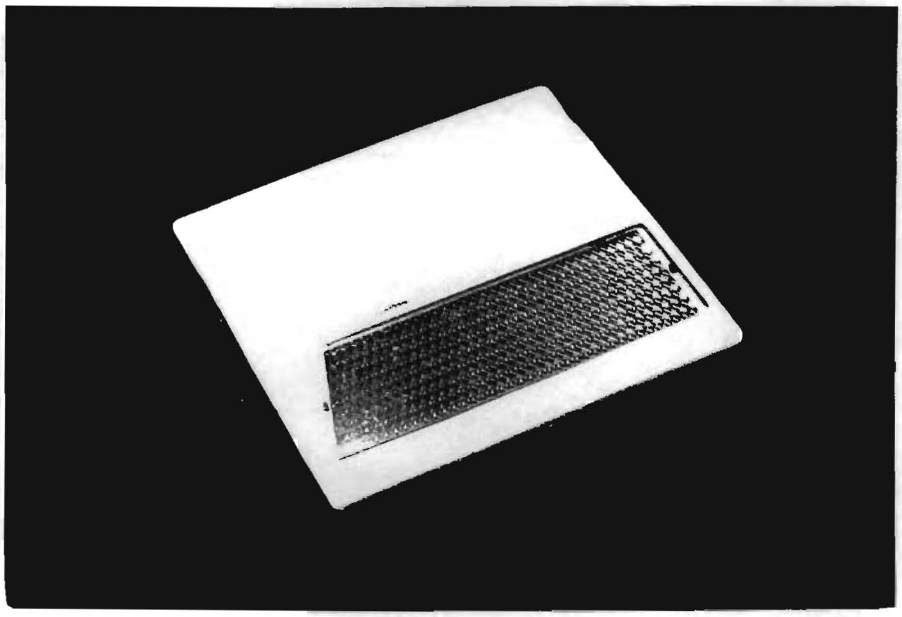
3. McNees, R.W. and J.S. Noel. Executive Summary, Significant Results and Assorted Tests and Procedures for Reflective Raised Pavement Markers. Report No. FWHA/TX-86/13+322-4F. Texas Transportation Institute, College Station, TX. 1986.

4. Pezoldt, V.J., R.J. Koppa, R.A. Zimmer, A.T. Perry, and H.W. Milsap. "Raised Pavement Marker Reflectivity." Report No. TX-90/1151-1F. Texas Transportation Institute, College Station, TX. 1990.

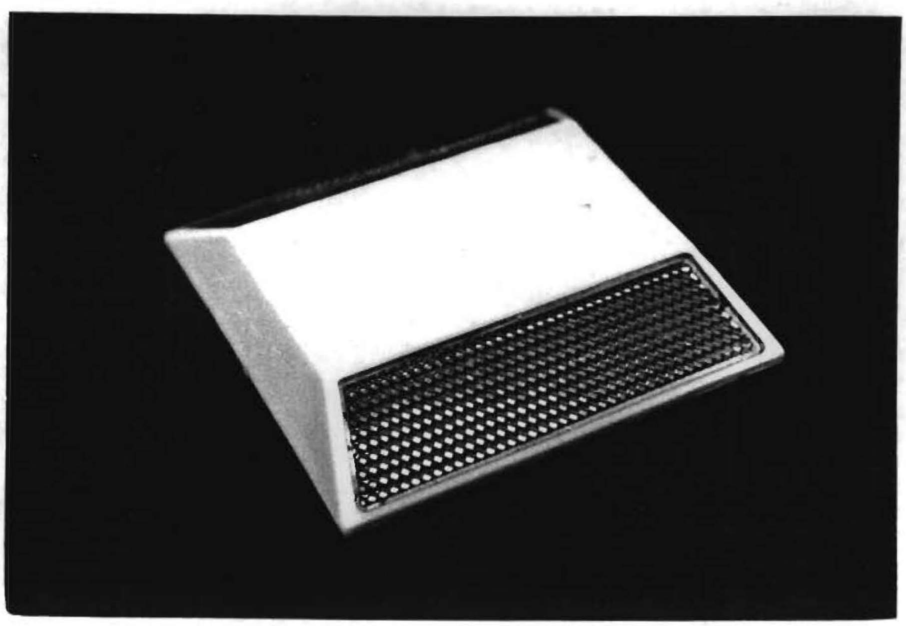
5. Instruction Manual, Raised Pavement Marker Retroreflectometer Models 1200B and 1200C. Advanced Retro Technology, Inc., Spring Valley, CA. 1992.

6. Greenshields, B.D. and F.M. Weida. Statistics with Applications to Highway Traffic Analyses. Eno Foundation for Transportation, Inc., Westport, CT. 1978.

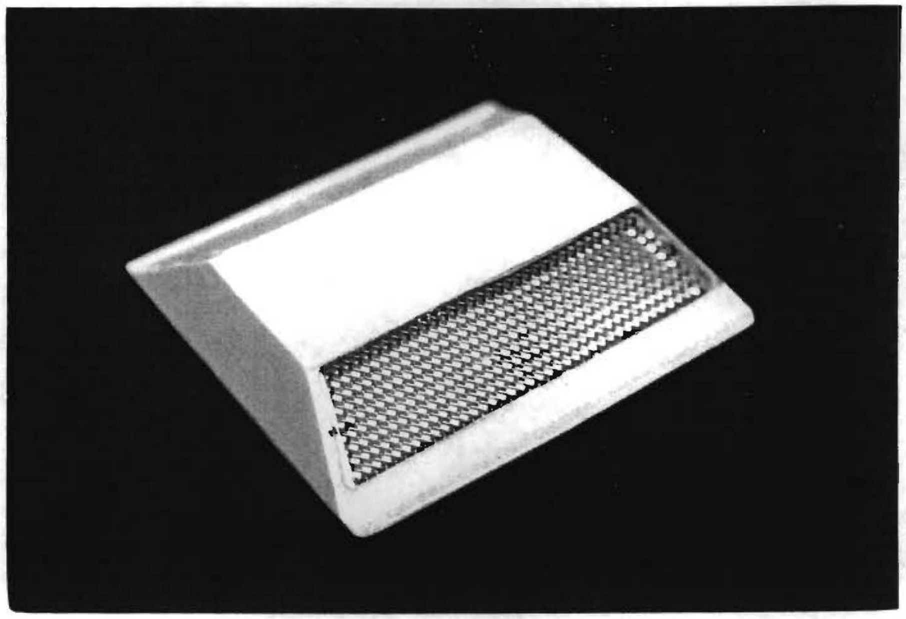
APPENDIX A: RRPM PHOTOGRAPHS



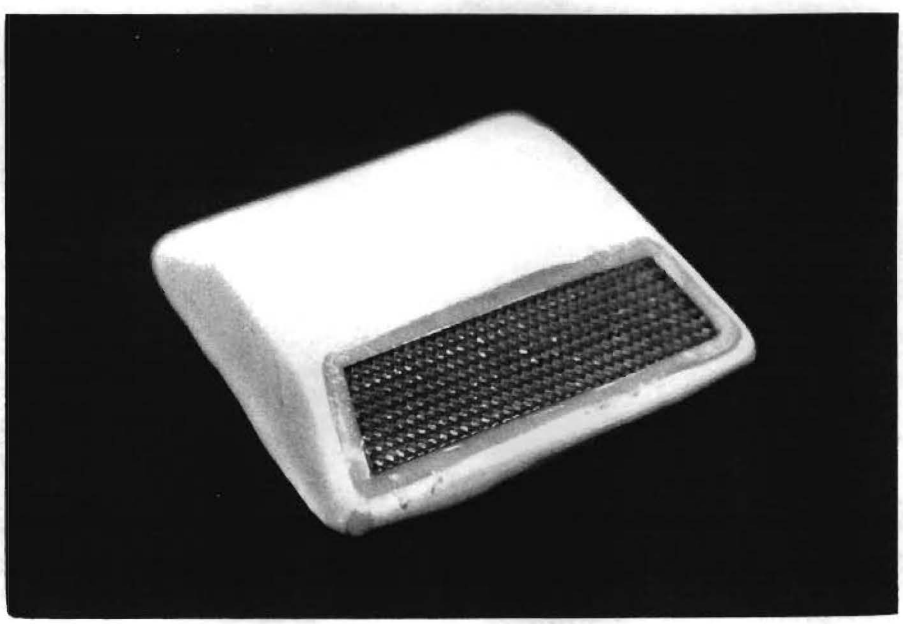
Apex Model 921



Apex Model 918



Apex Model 928



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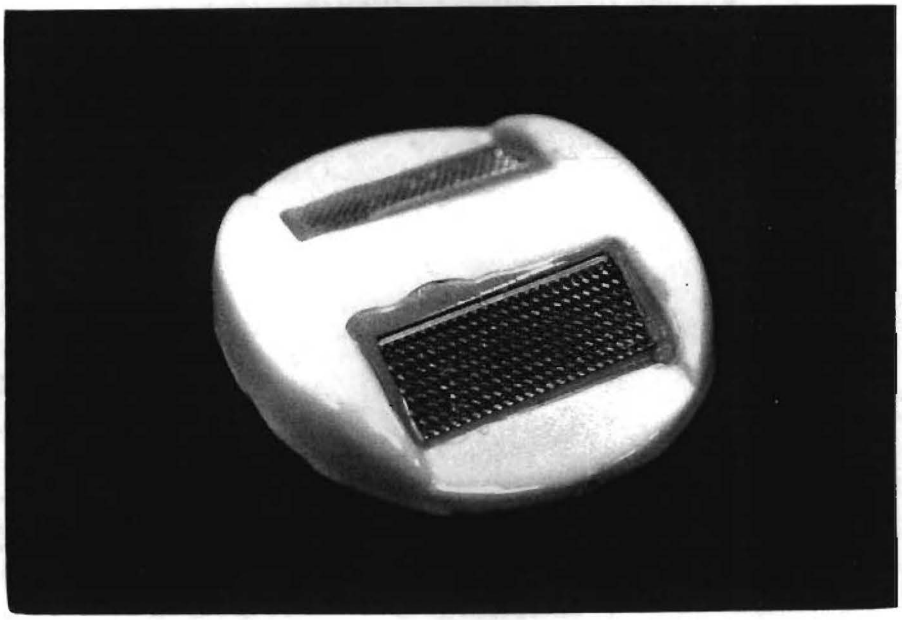
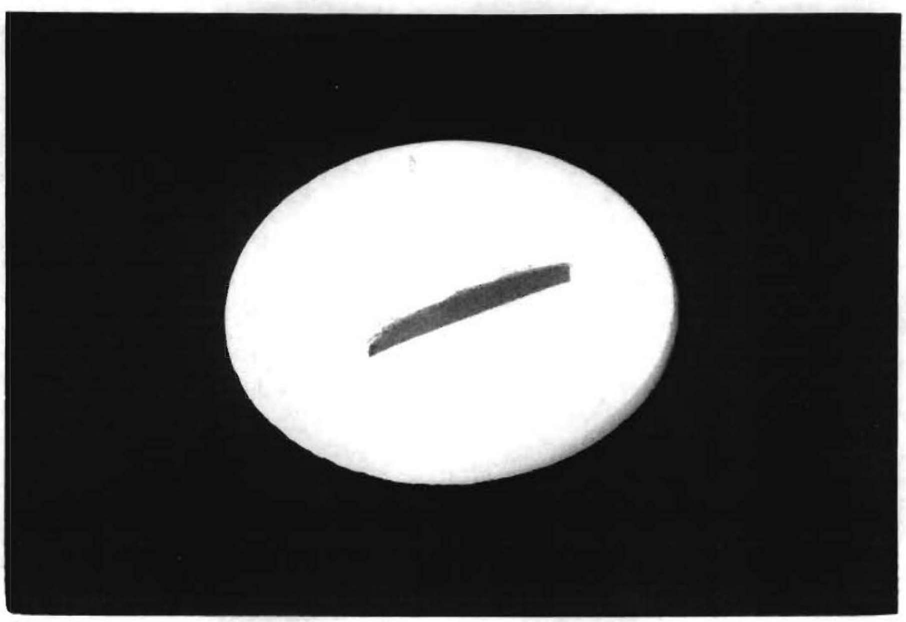
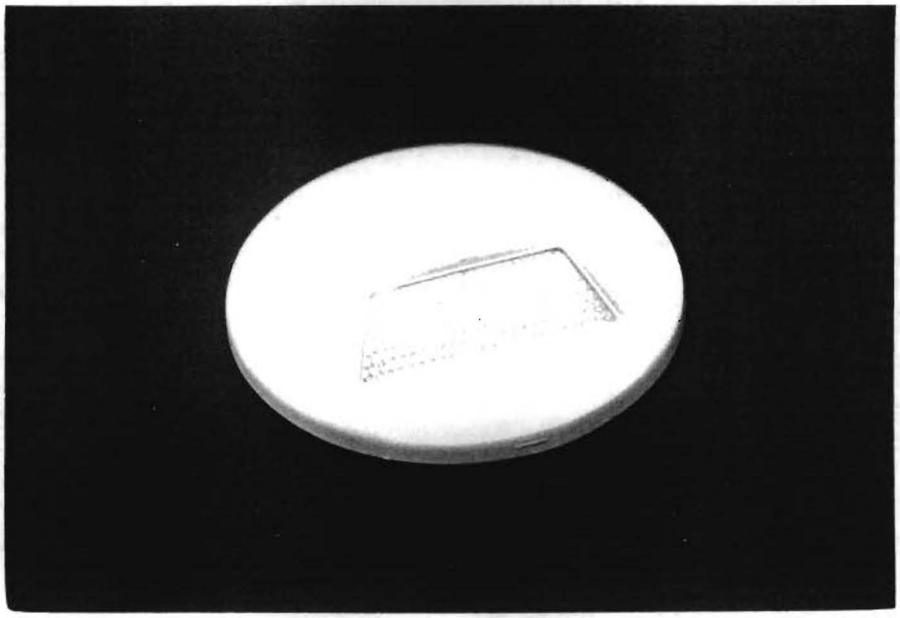


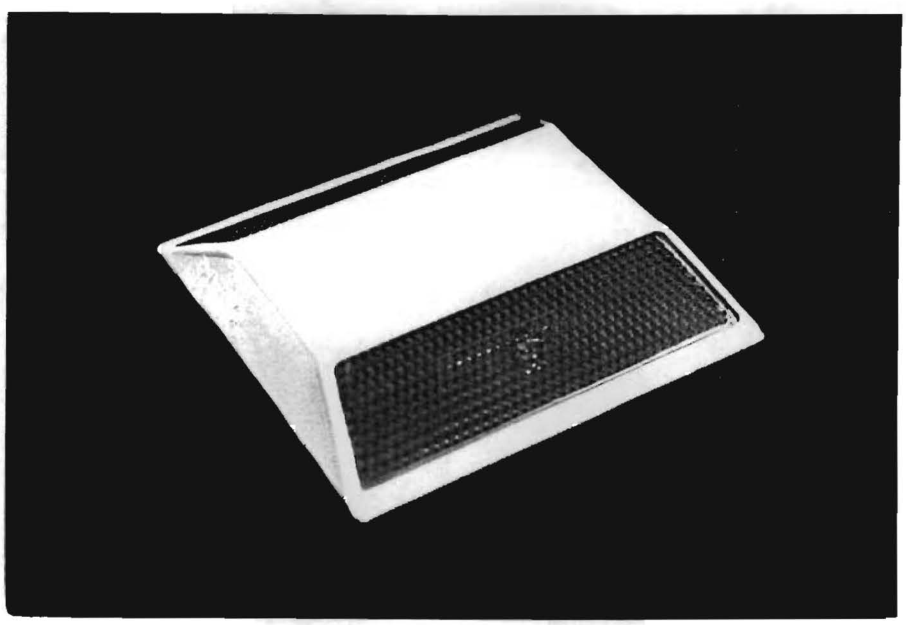
Apex Model 817



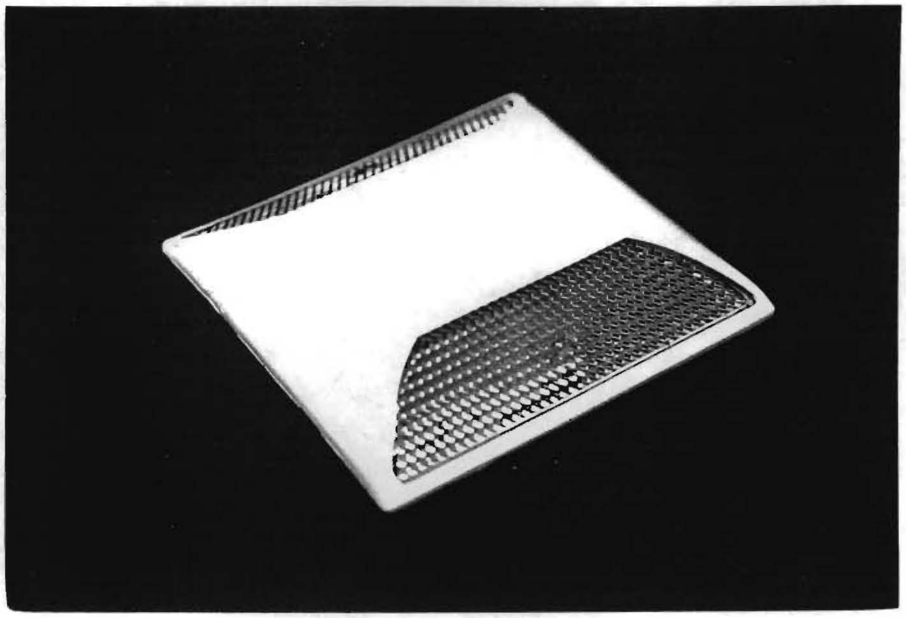
Batterson Reflective Button



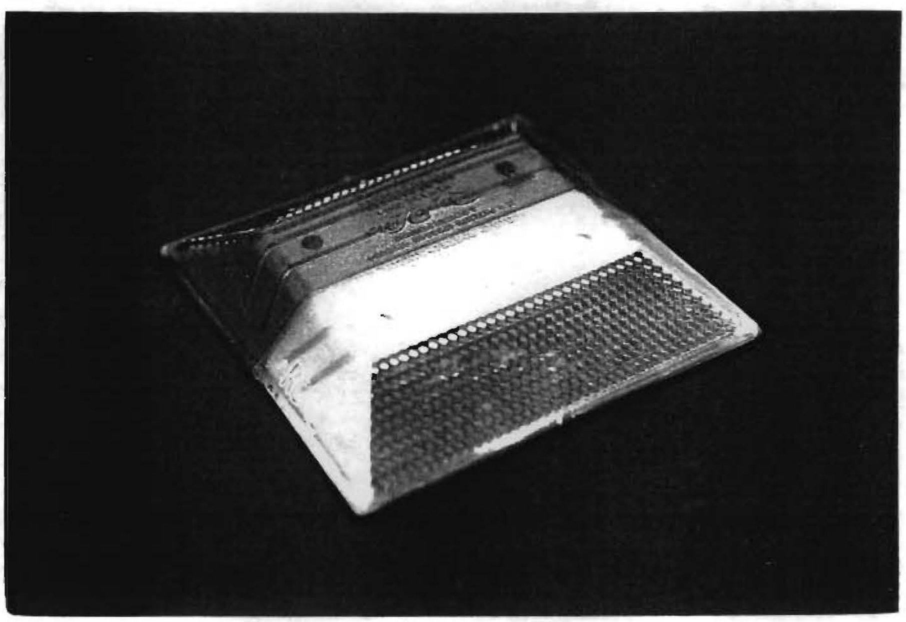
Empco Model 901



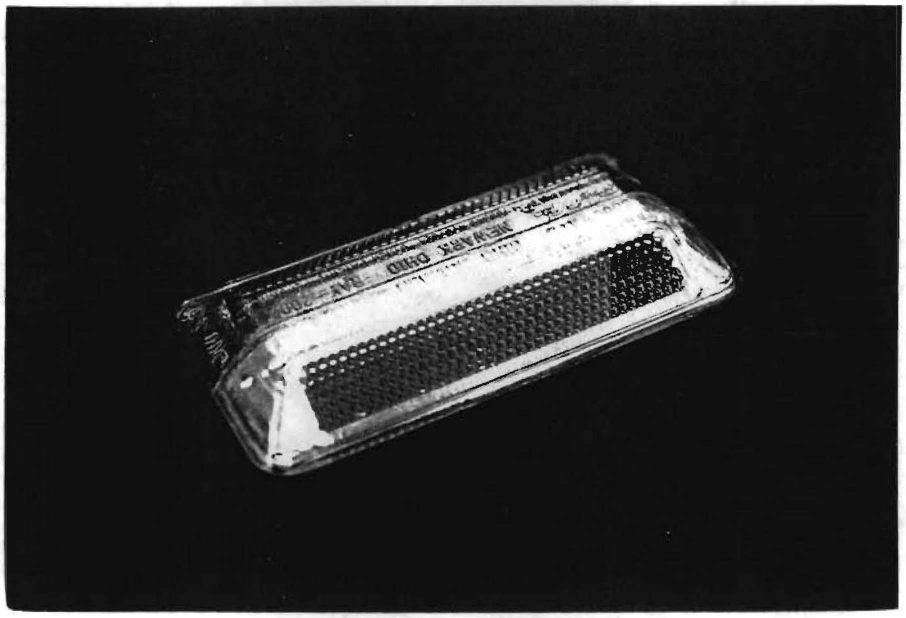
Ray-O-Lite Model 8704 (S)



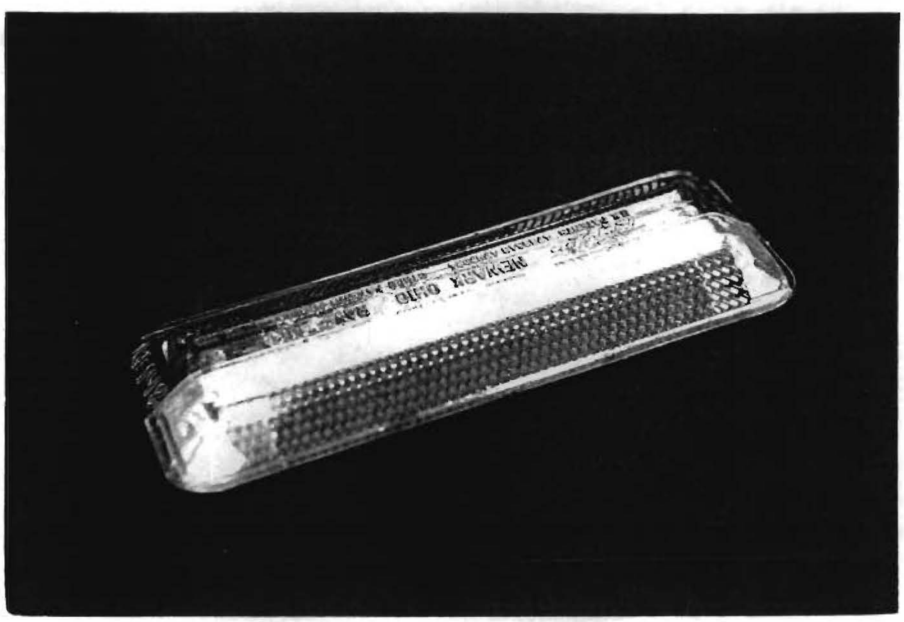
Ray-O-Lite Model 8704 (R)



Ray-O-Lite Model 9704



Ray-O-Lite Model 2002

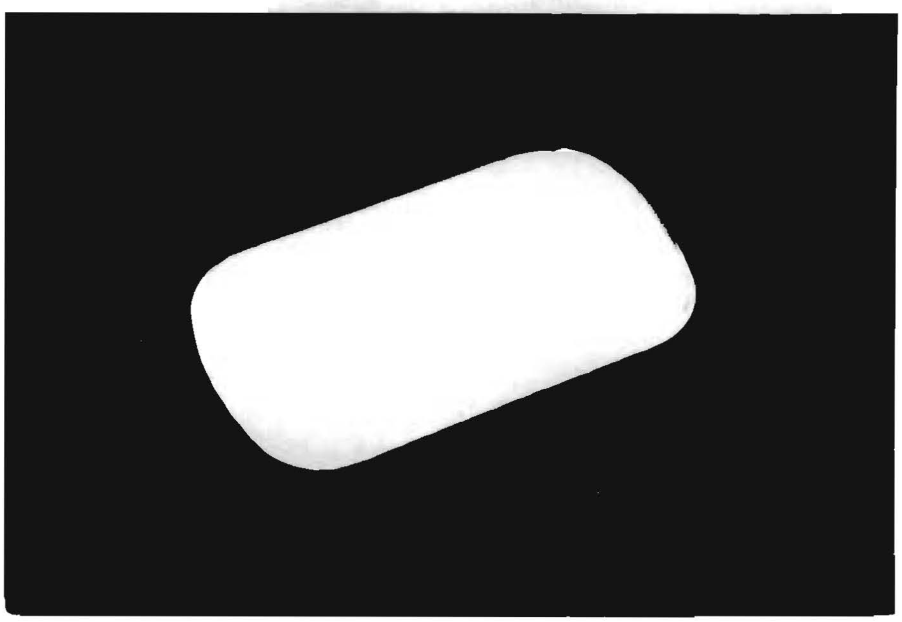


Ray-O-Lite Model 2003

Stimsonite Model 88

Stimsonite Model 911

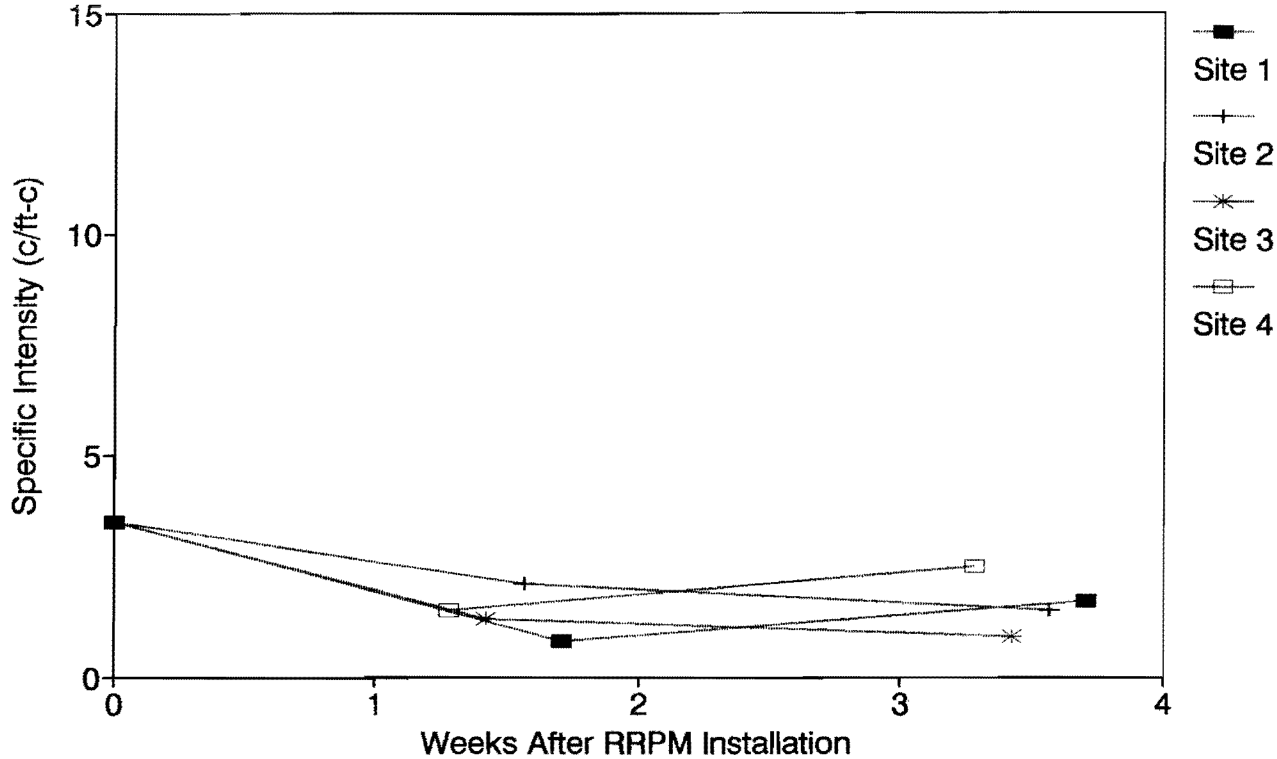
Stimsonite Model 948



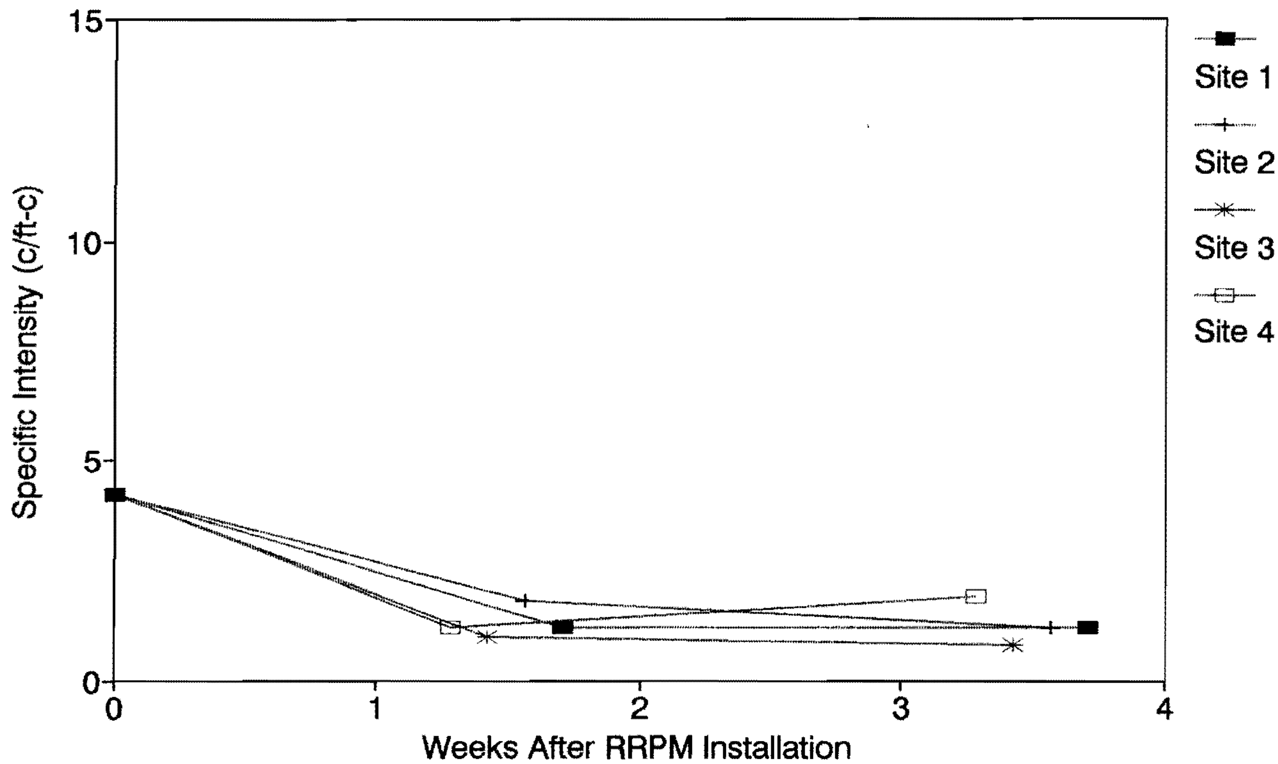
Stimsonite Model 953

Swareflex RRPM

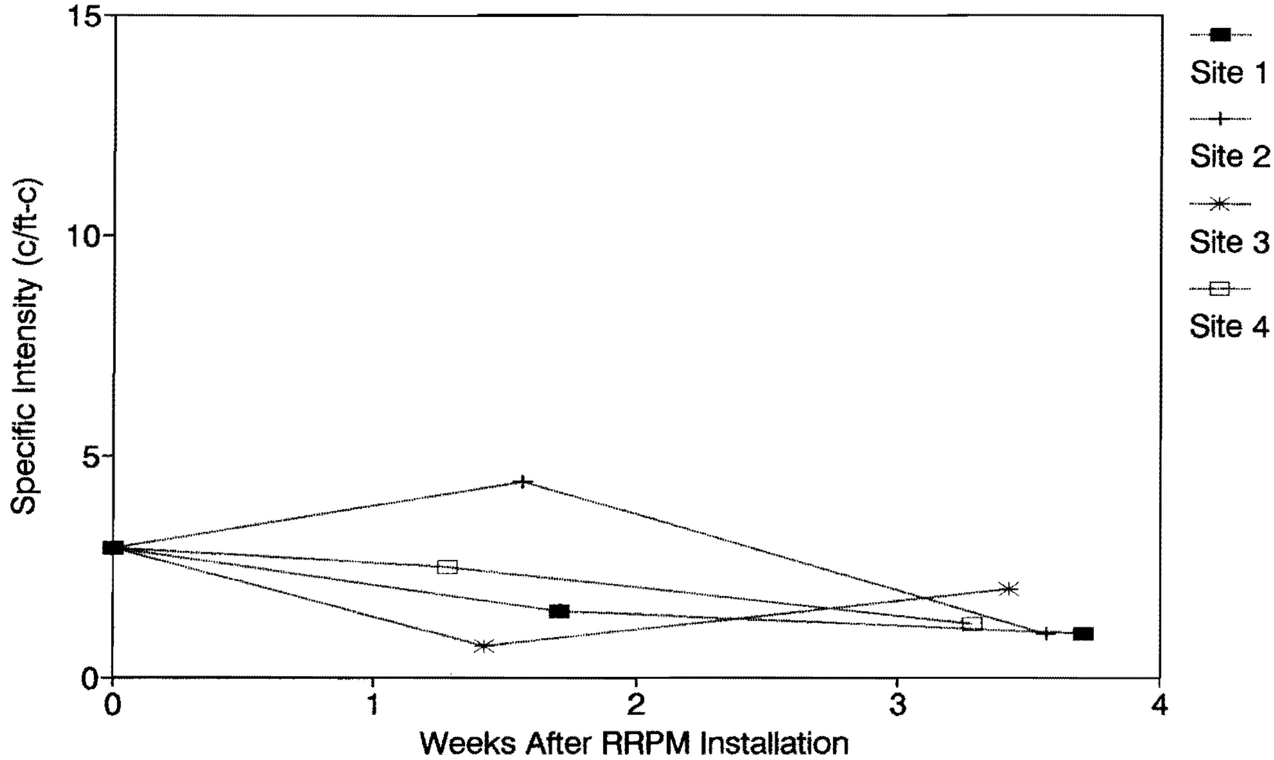
APPENDIX B: RRPM SI VALUES BY SITE AND LENGTH OF EXPOSURE



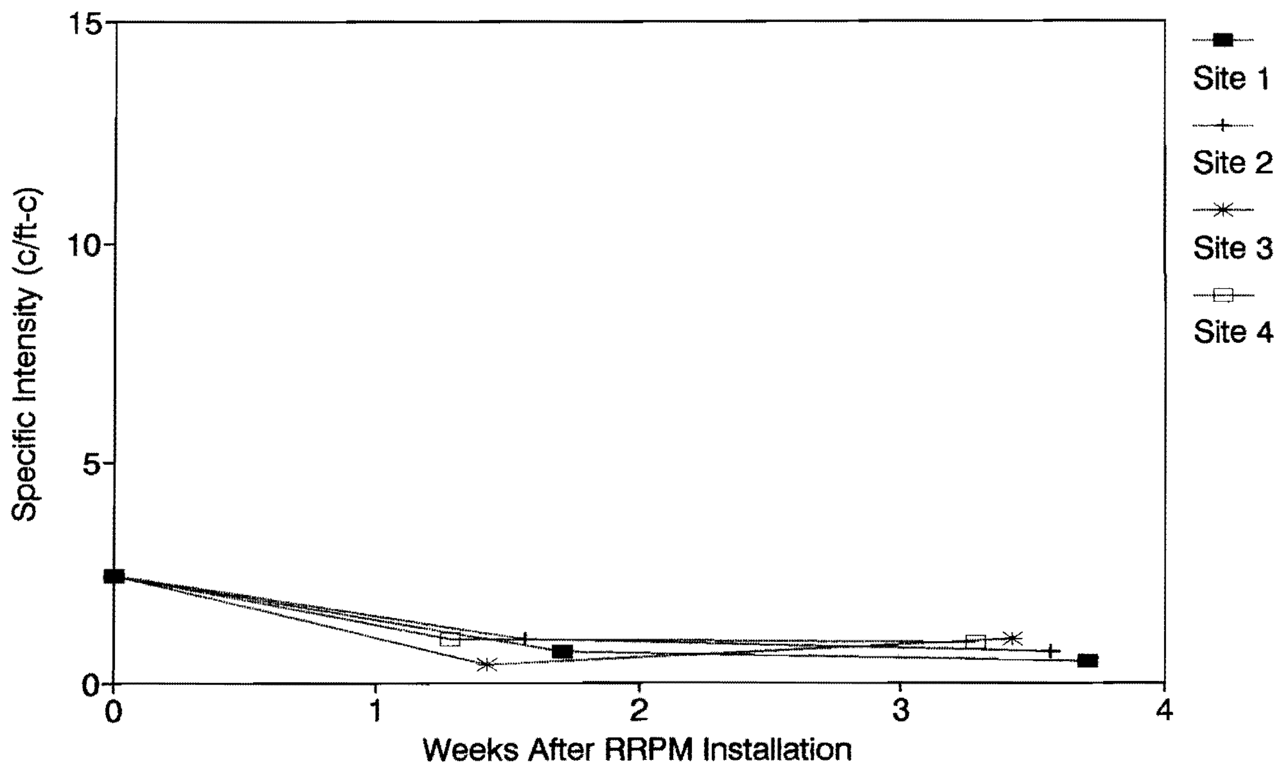
Apex Model 921: Laboratory SI Readings Before Washing



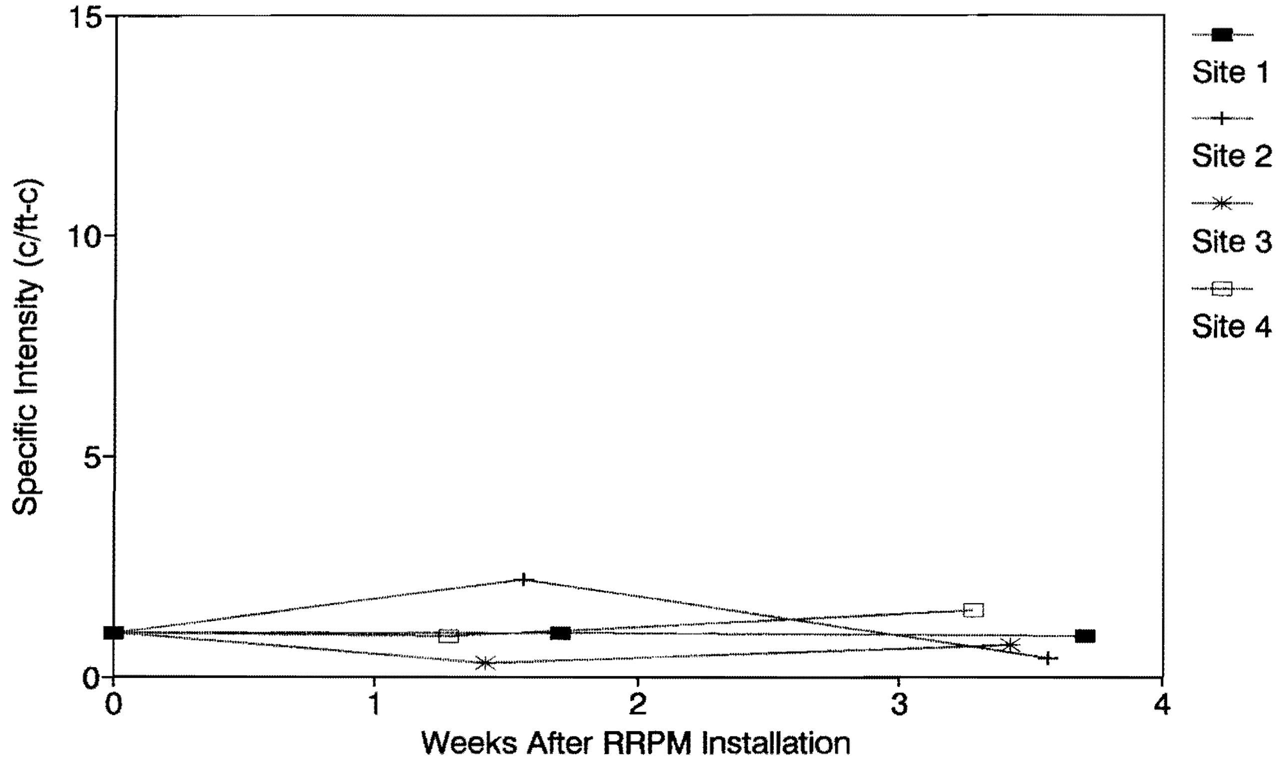
Apex Model 918: Laboratory SI Readings Before Washing



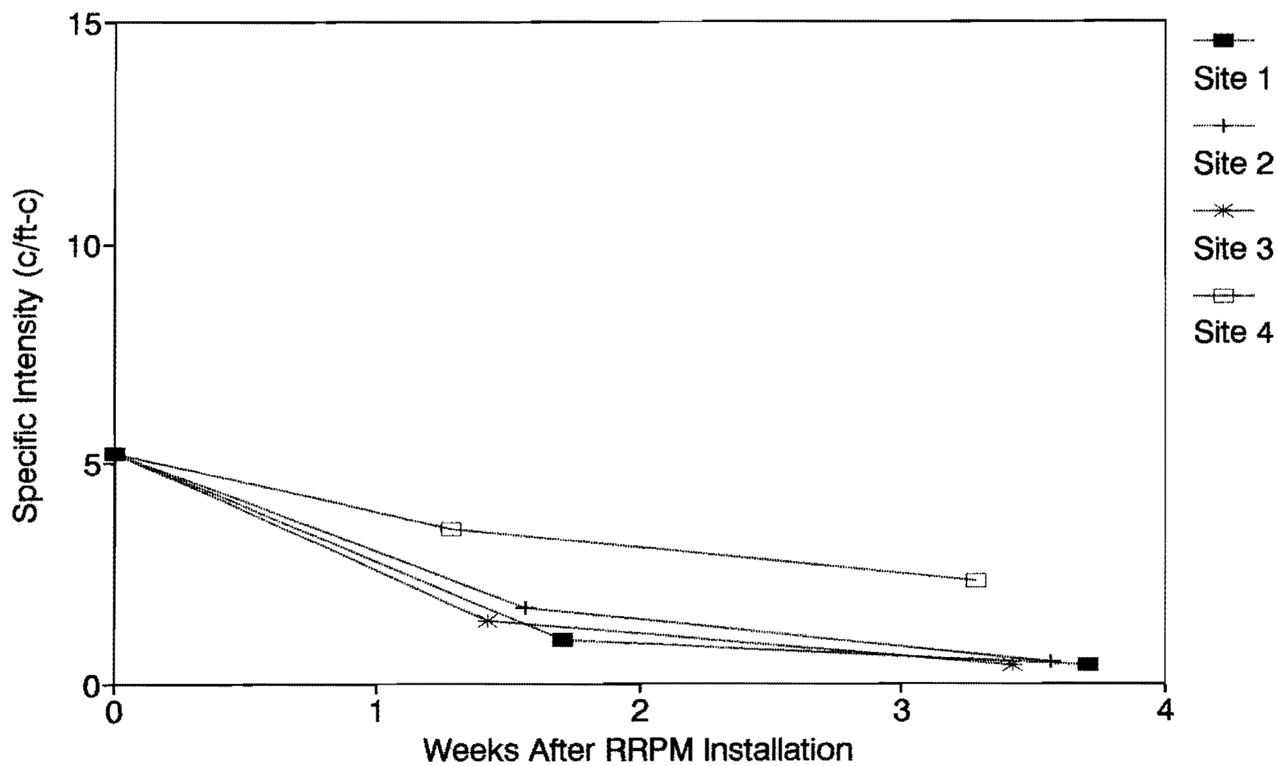
Apex Model 928: Laboratory SI Readings Before Washing



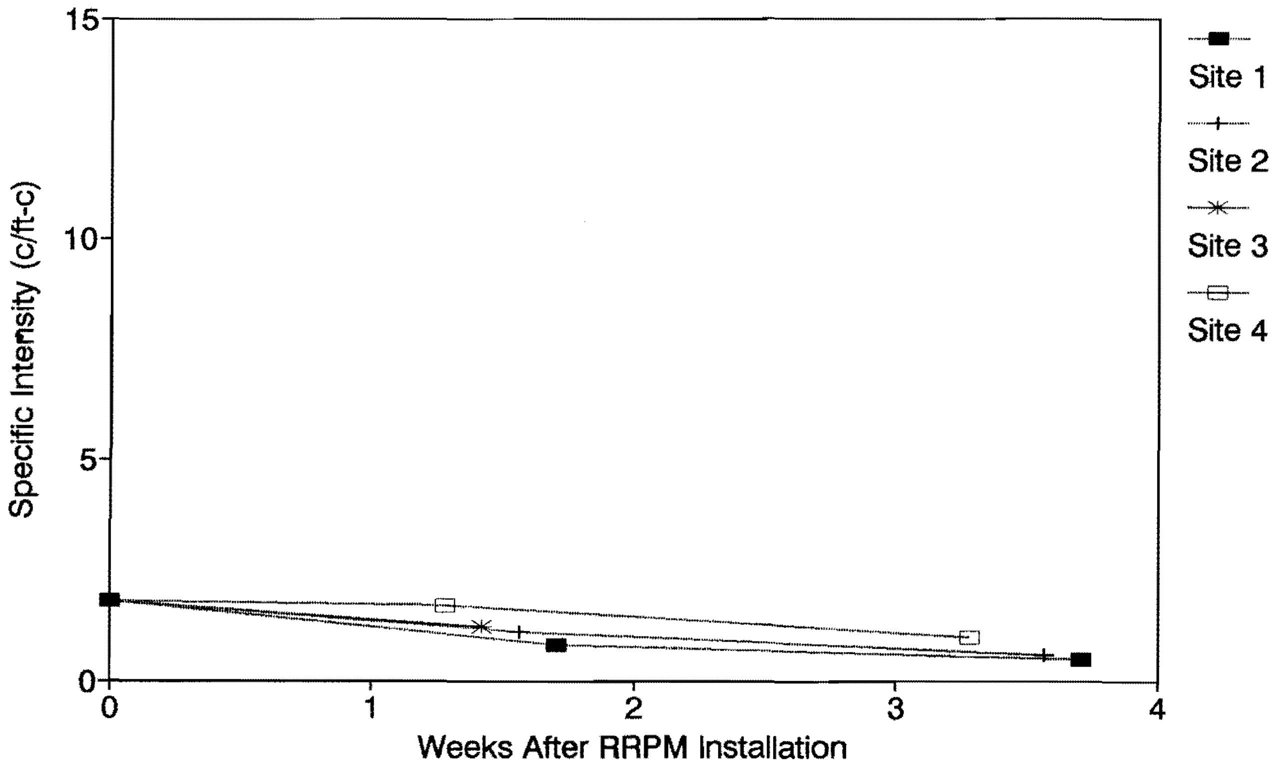
Apex Model 807: Laboratory SI Readings Before Washing



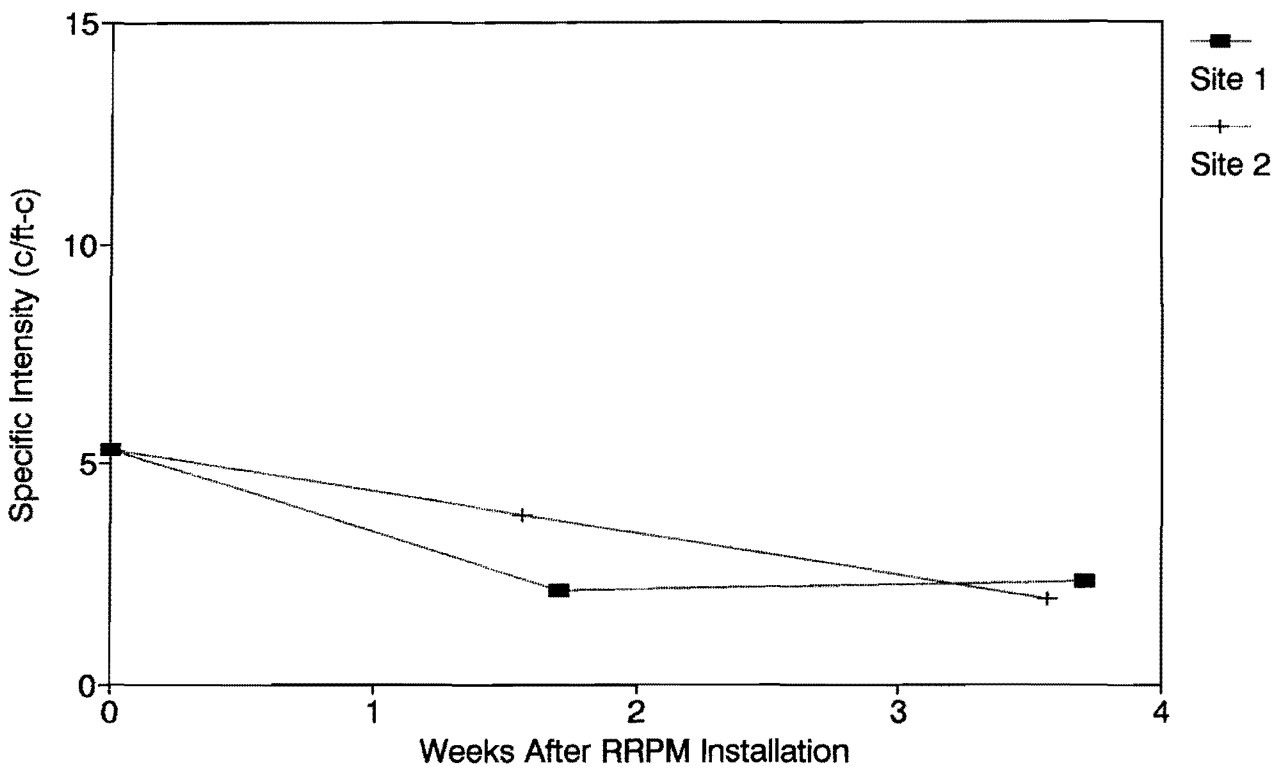
Apex Model 817: Laboratory SI Readings Before Washing



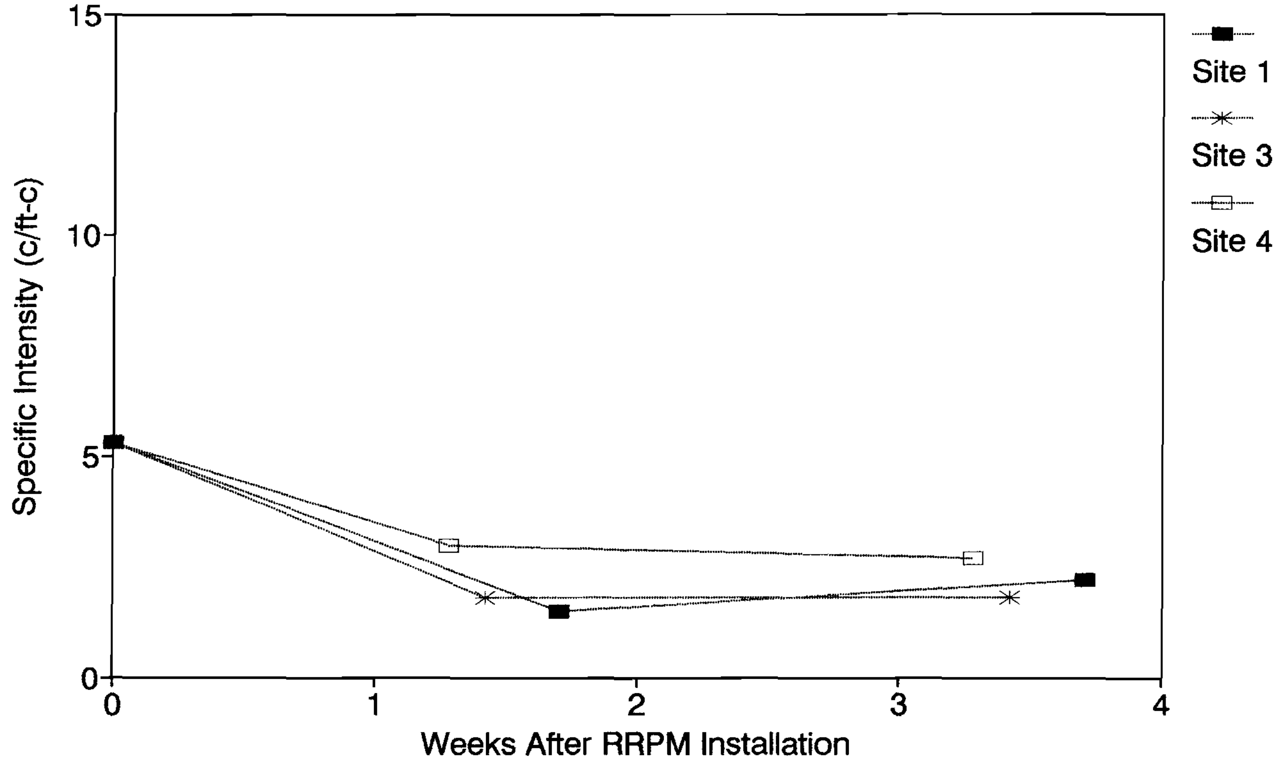
Batterson Reflective Button: Laboratory SI Readings Before Washing



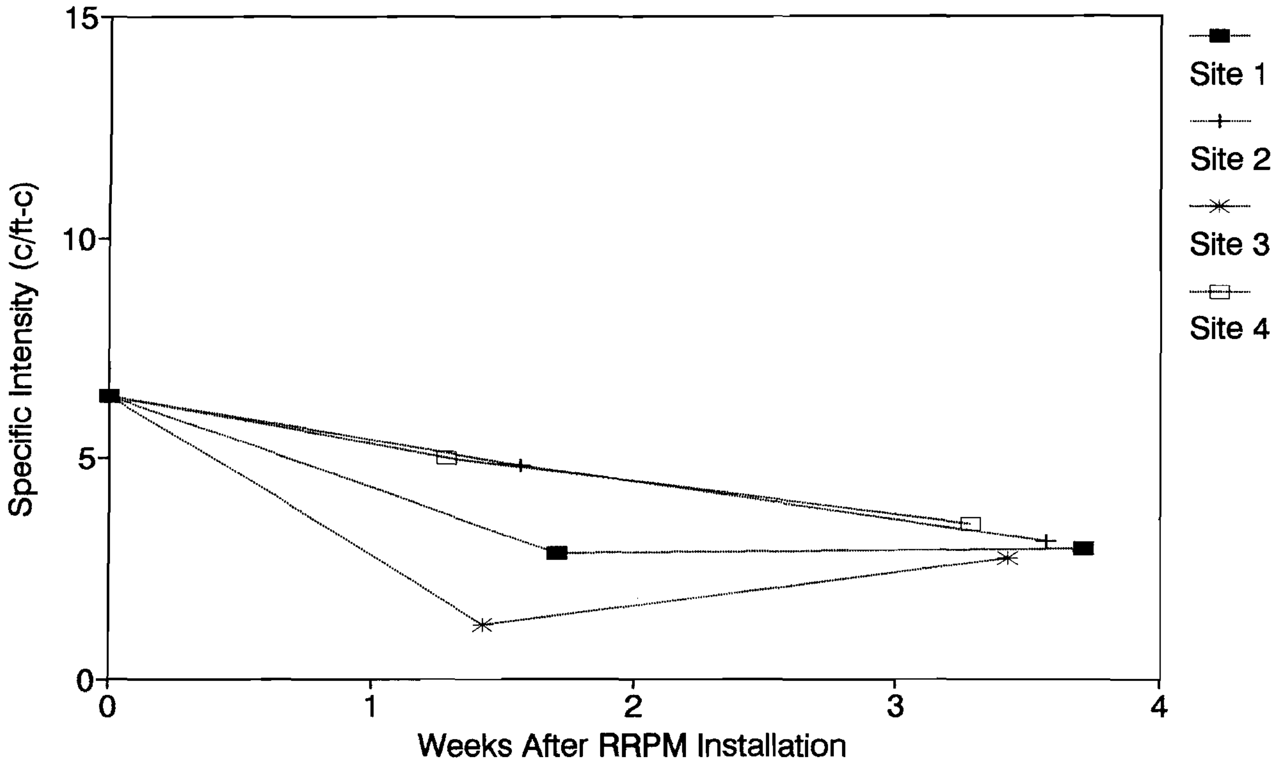
Empco Model 901: Laboratory SI Readings Before Washing



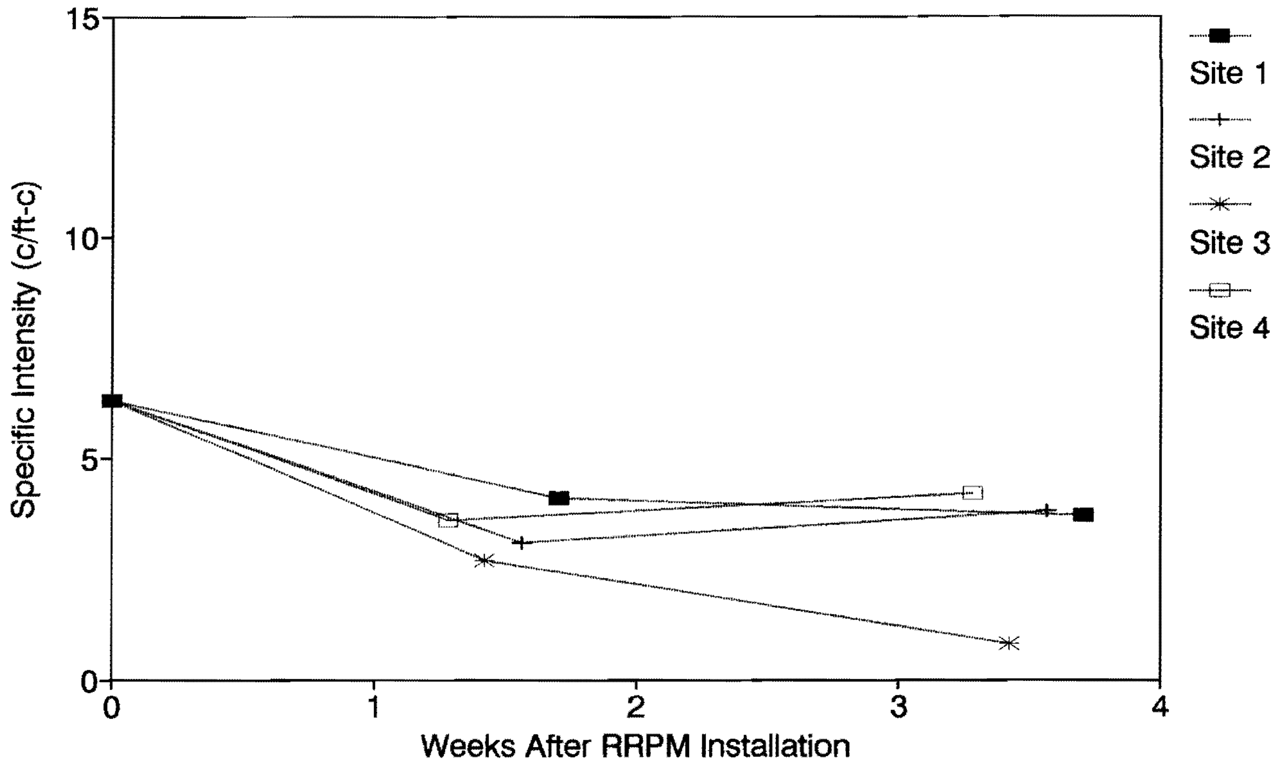
Ray-O-Lite Model 8704 (S): Laboratory SI Readings Before Washing



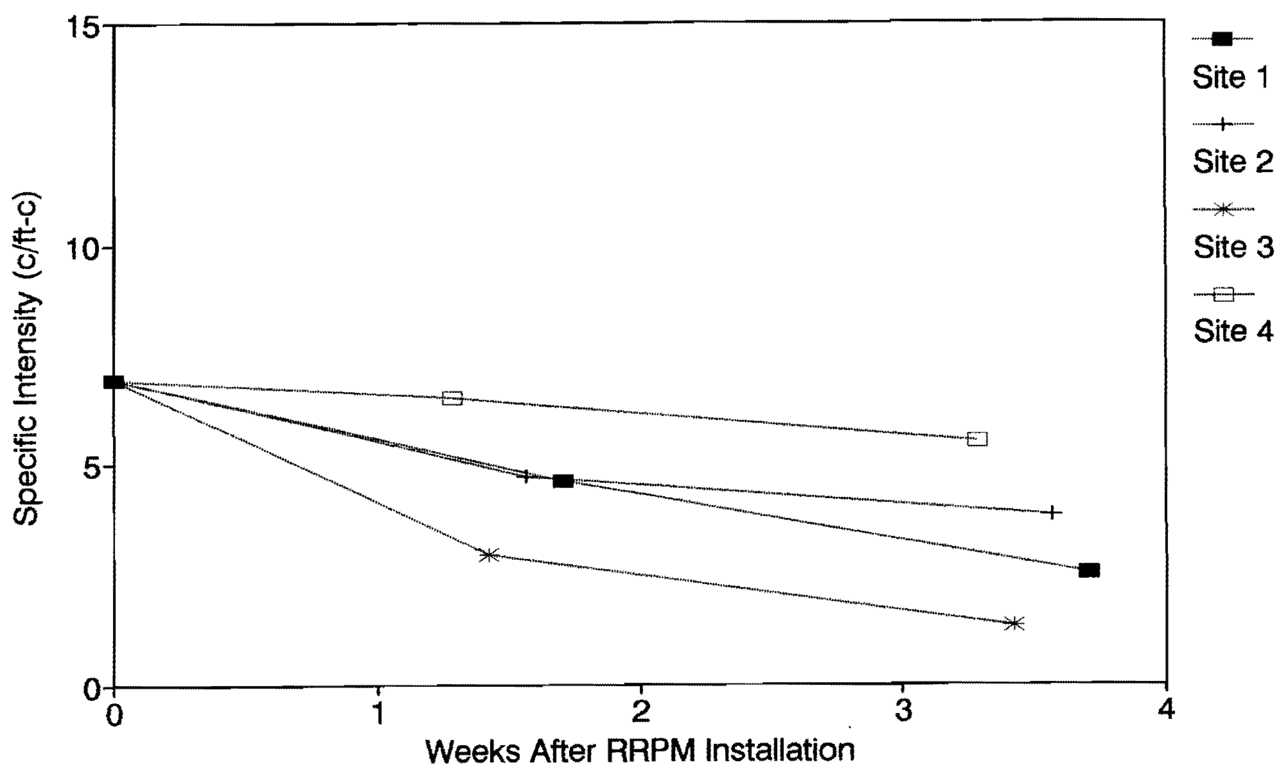
Ray-O-Lite Model 8704 (R): Laboratory SI Readings Before Washing



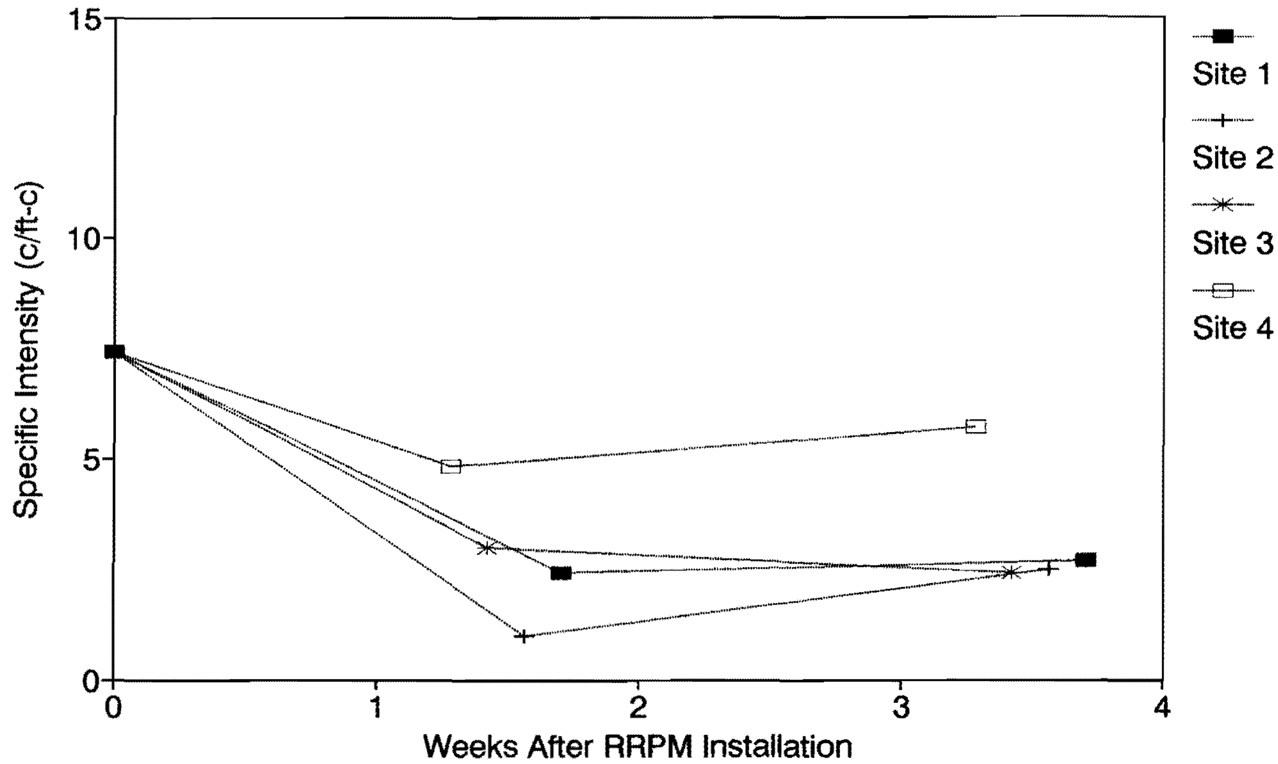
Ray-O-Lite Model 9704: Laboratory SI Readings Before Washing



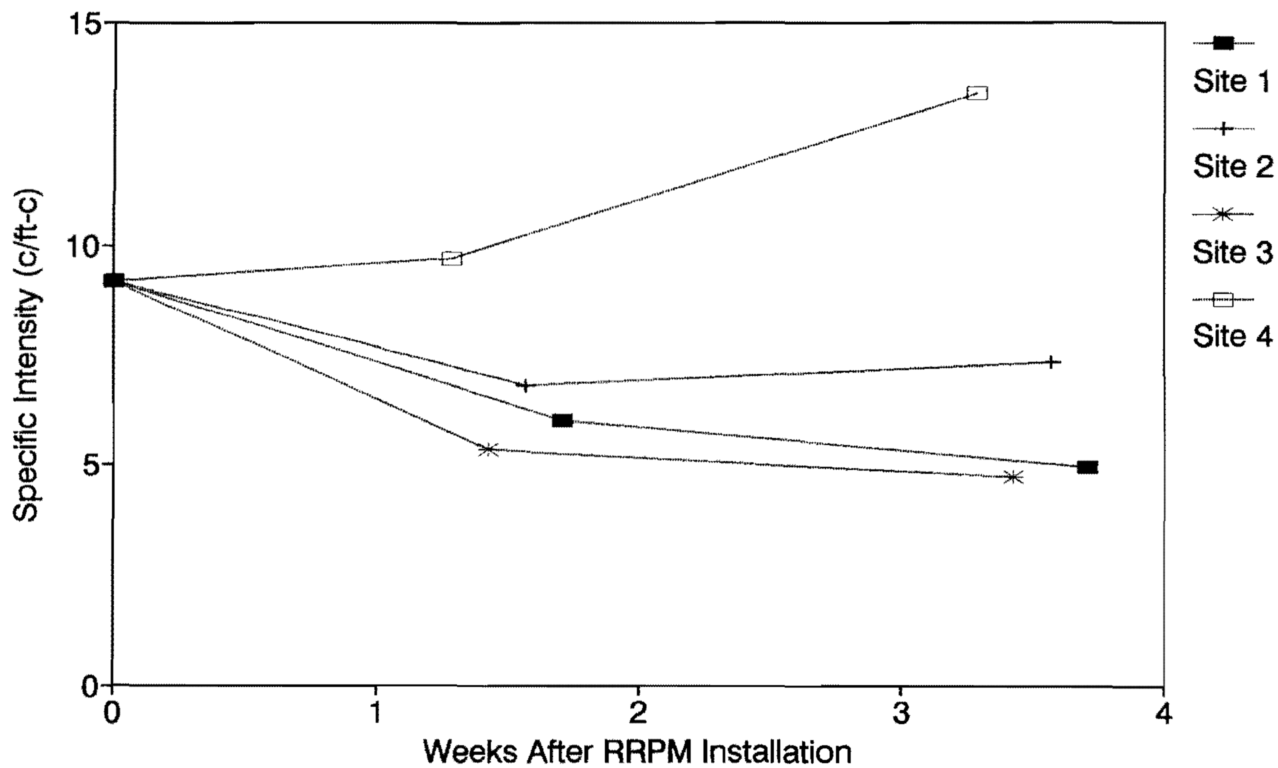
Ray-O-Lite Model 2002: Laboratory SI Readings Before Washing



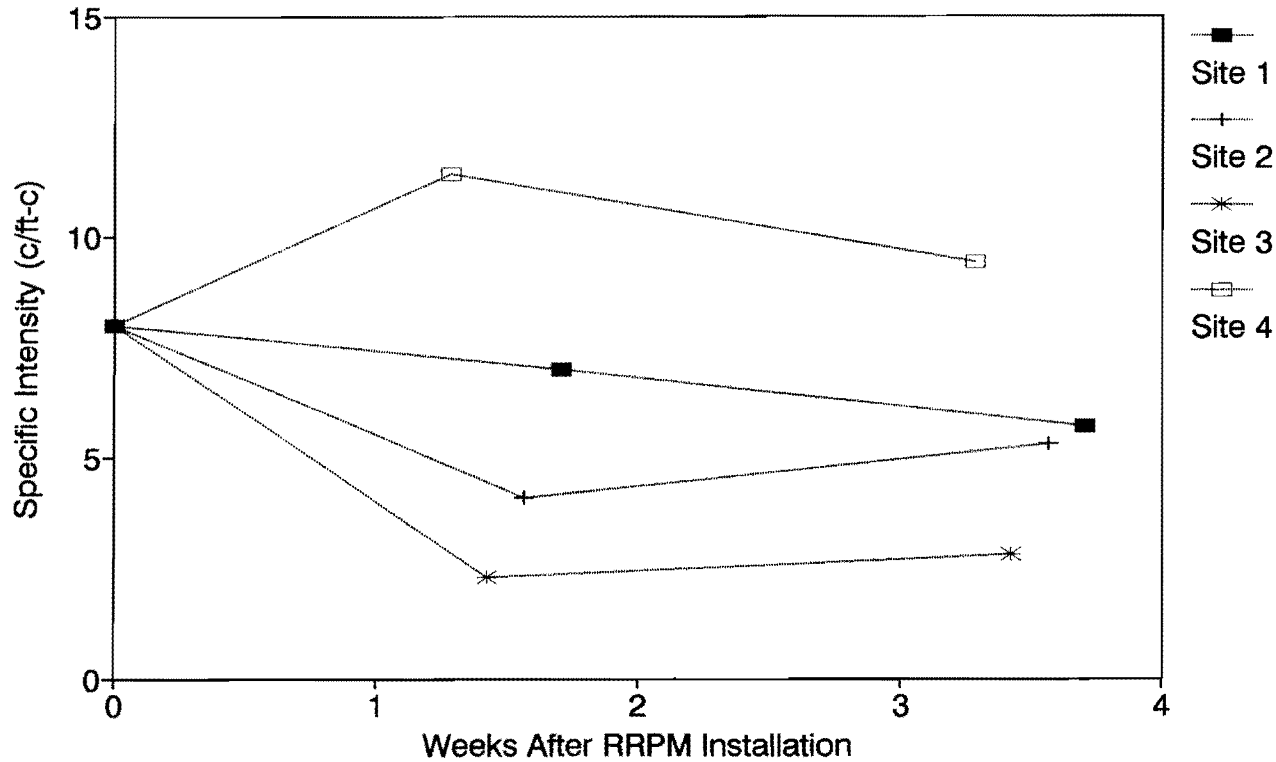
Ray-O-Lite Model 2003: Laboratory SI Readings Before Washing



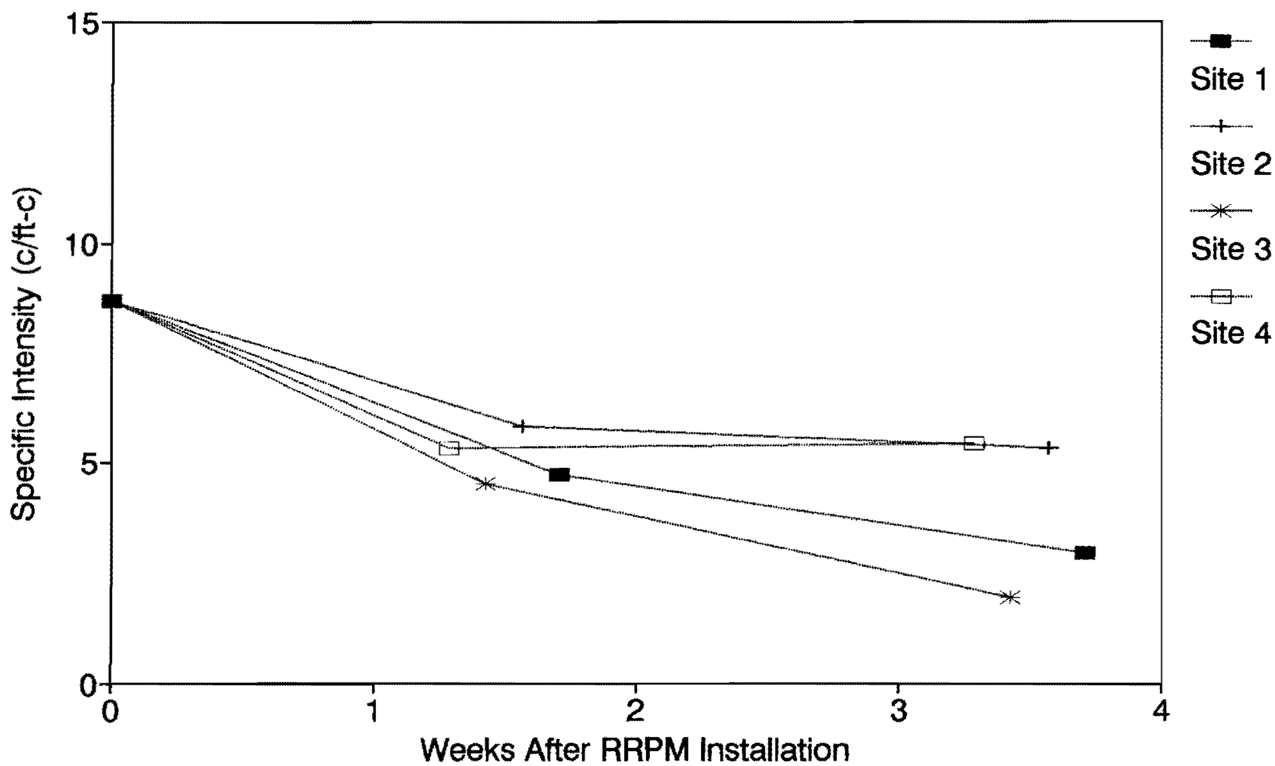
Stimsonite Model 88: Laboratory SI Readings Before Washing



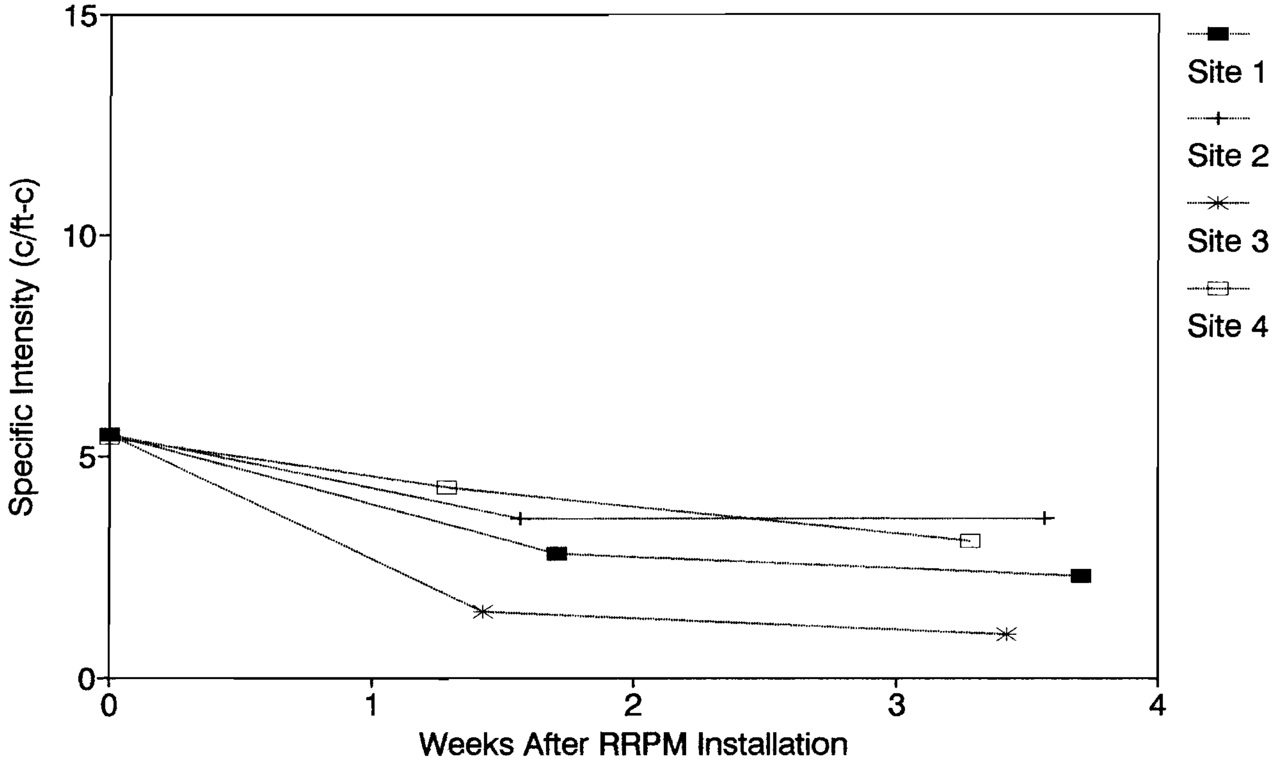
Stimsonite Model 911: Laboratory SI Readings Before Washing



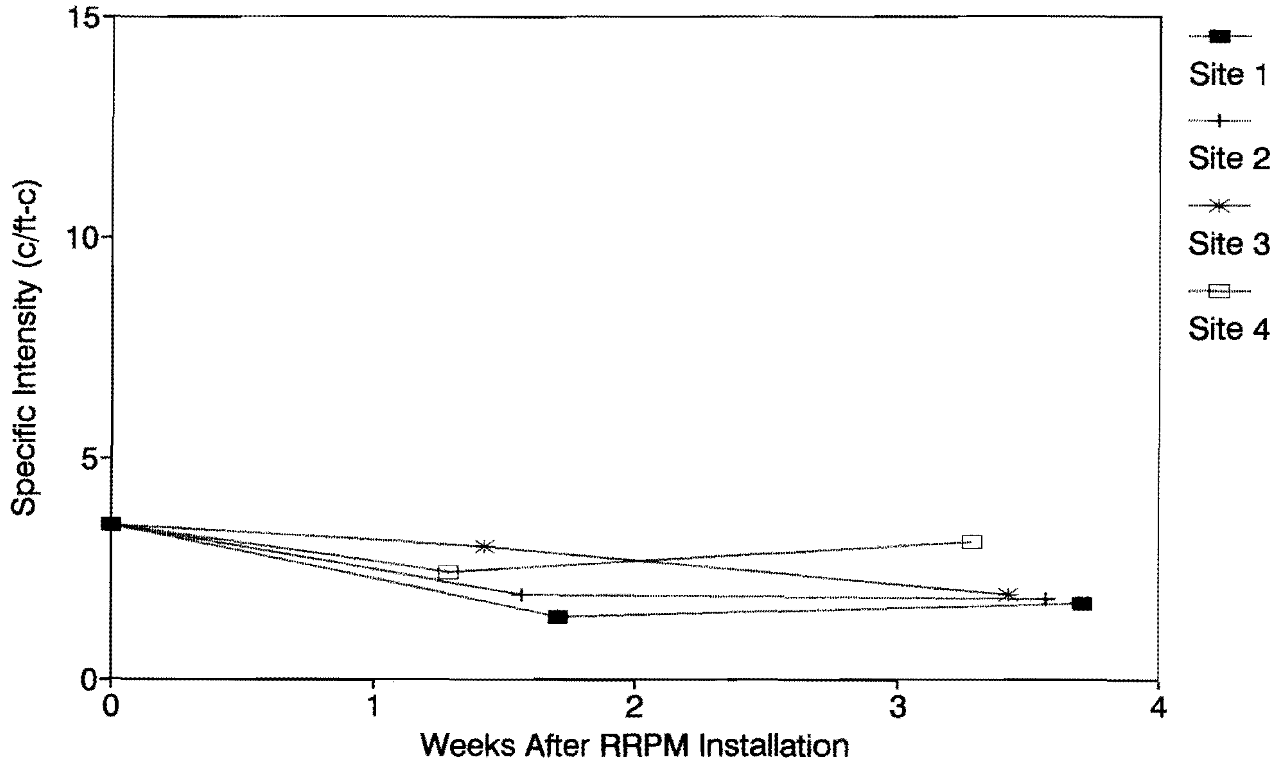
Stimsonite Model 948: Laboratory SI Readings Before Washing



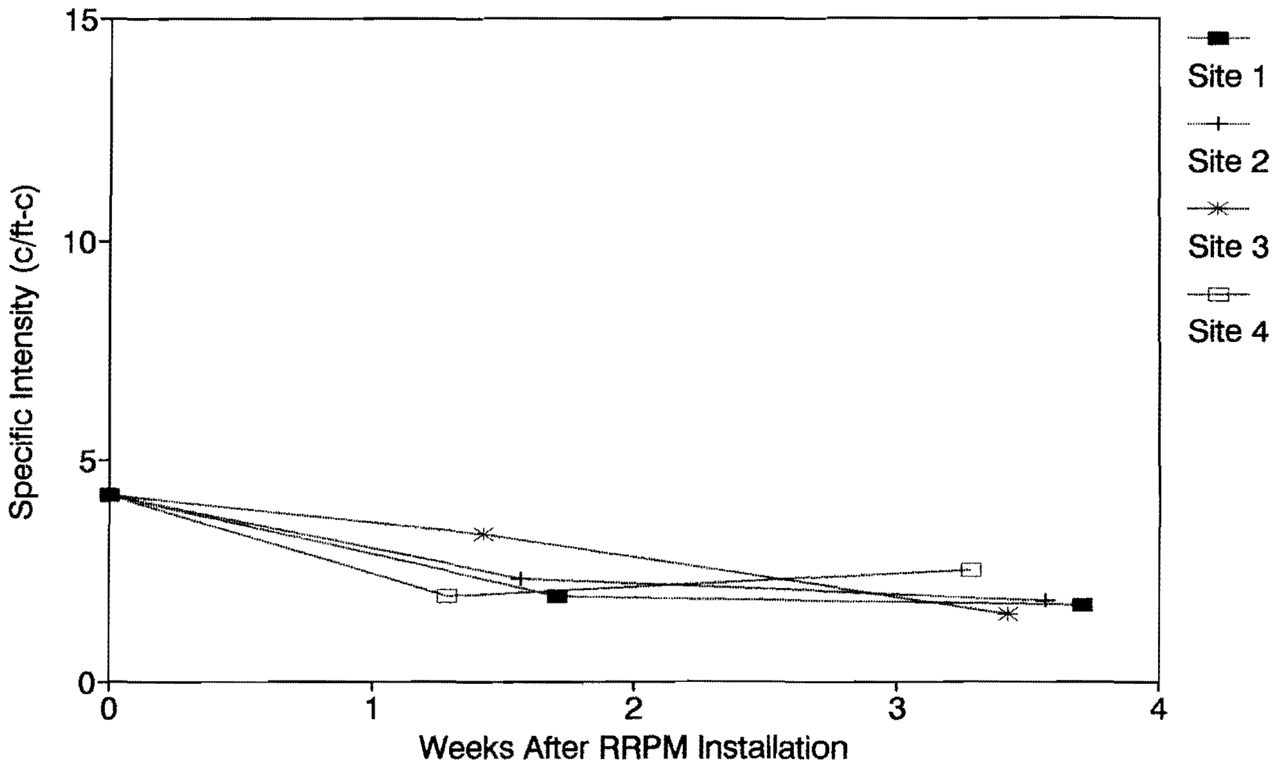
Stimsonite Model 953: Laboratory SI Readings Before Washing



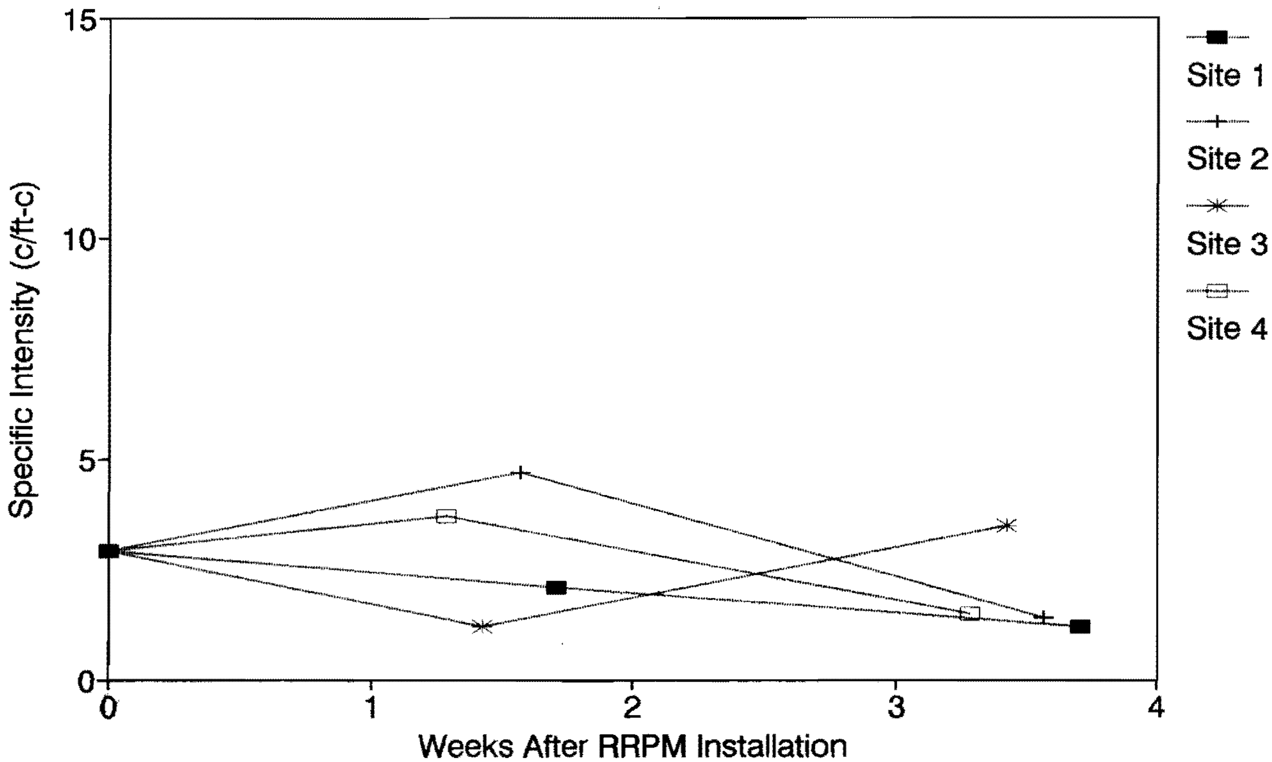
Swareflex RRPM: Laboratory SI Readings Before Washing



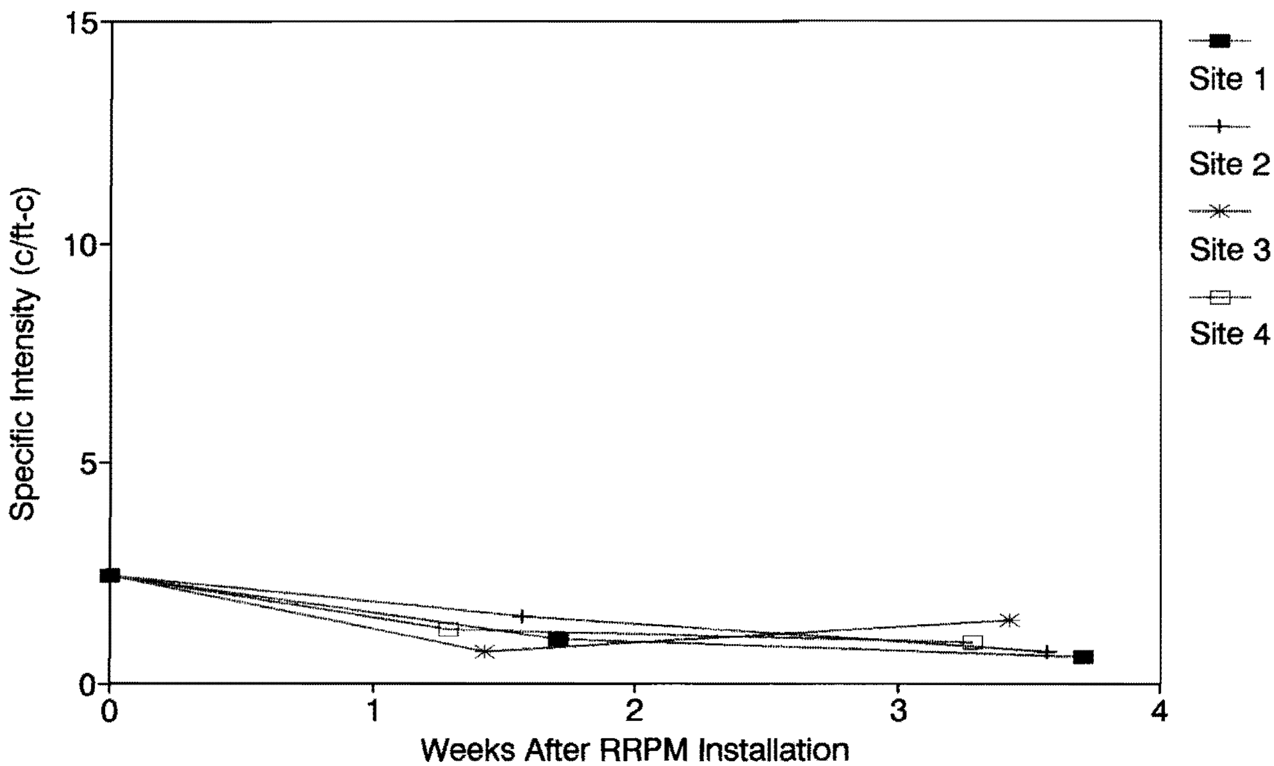
Apex Model 921: Laboratory SI Readings After Washing



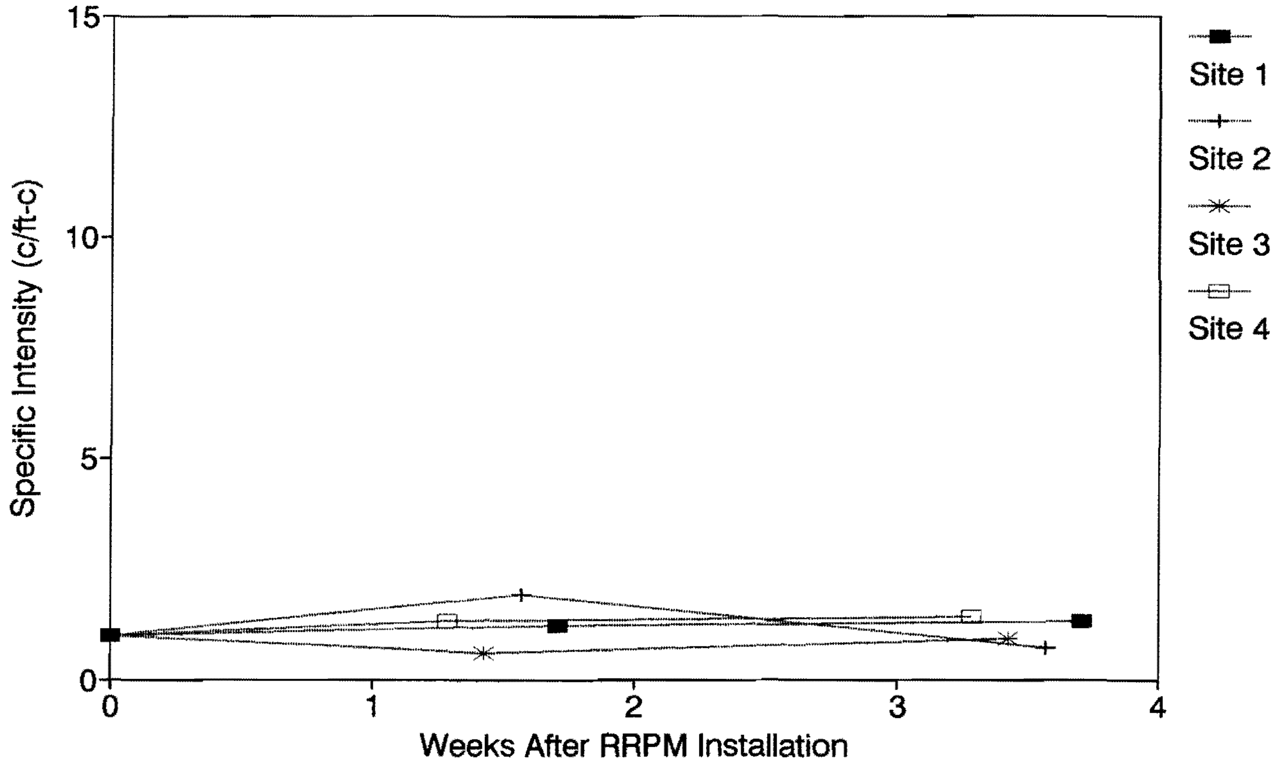
Apex Model 918: Laboratory SI Readings After Washing



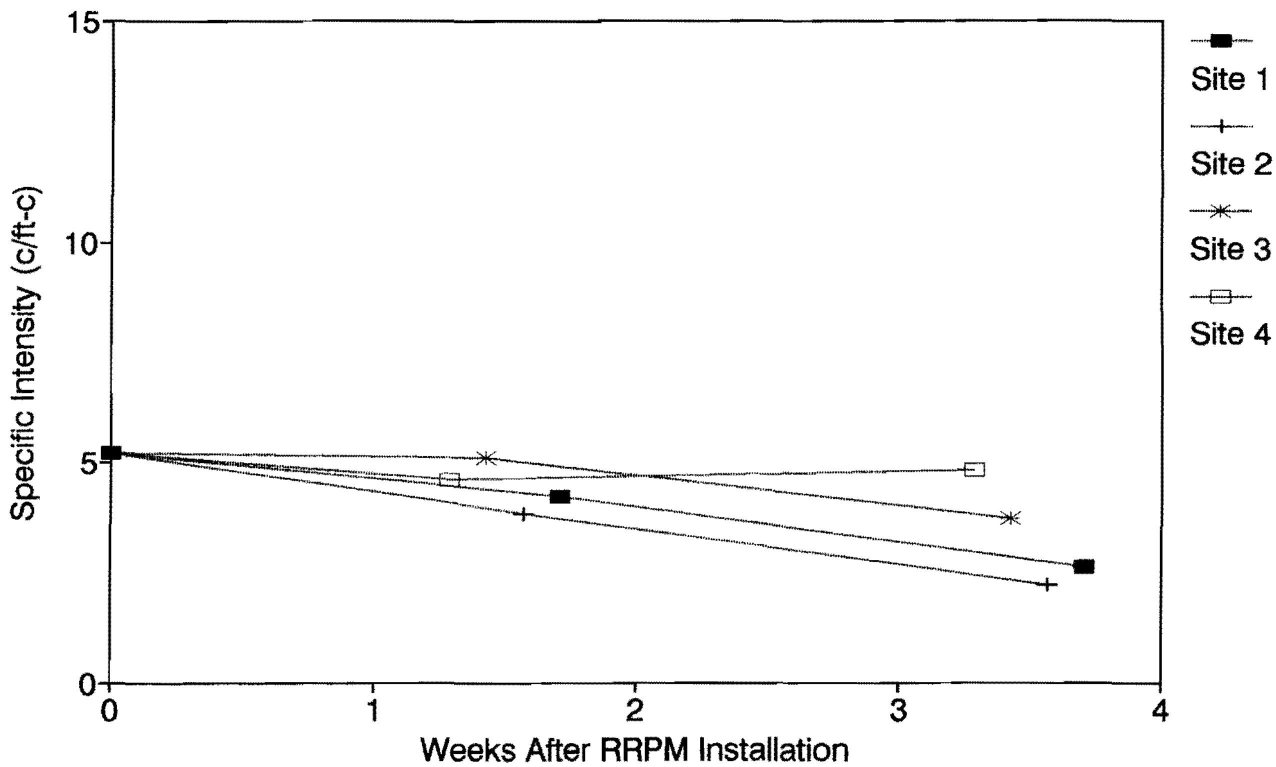
Apex Model 928: Laboratory SI Readings After Washing



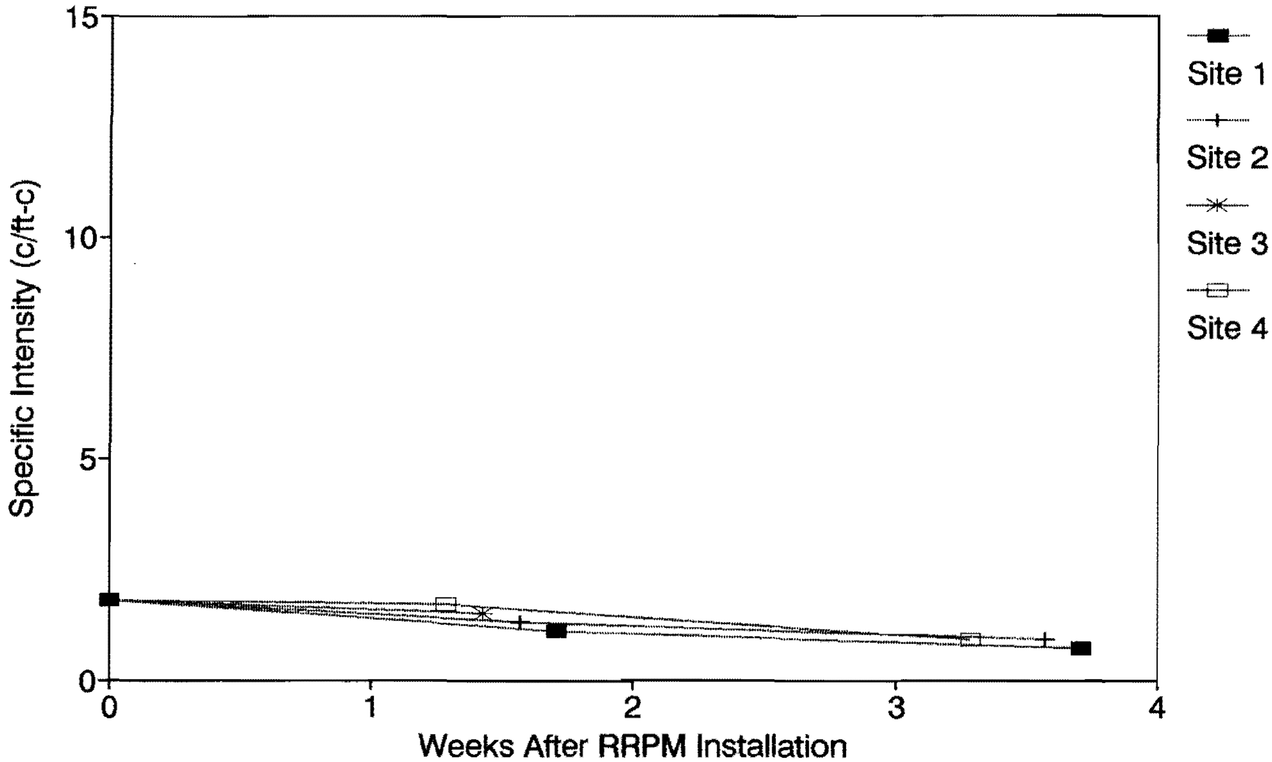
Apex Model 807: Laboratory SI Readings After Washing



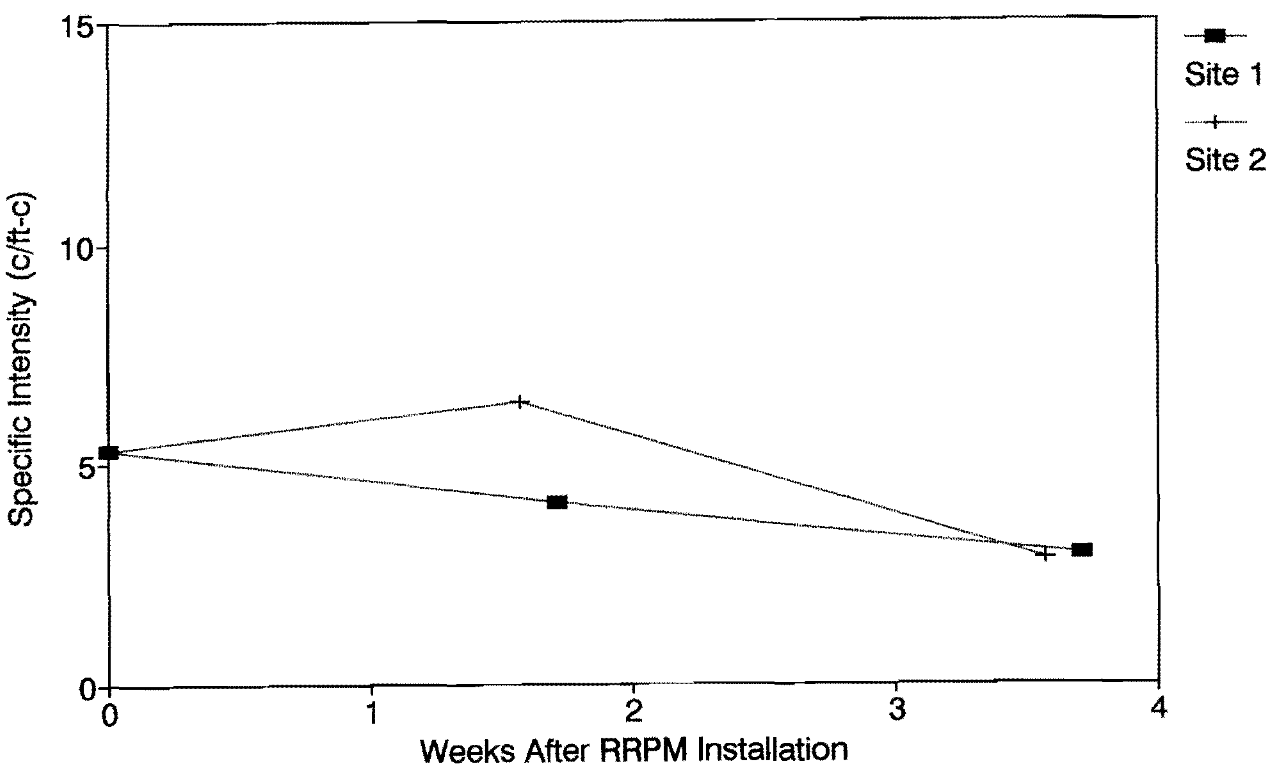
Apex Model 817: Laboratory SI Readings After Washing



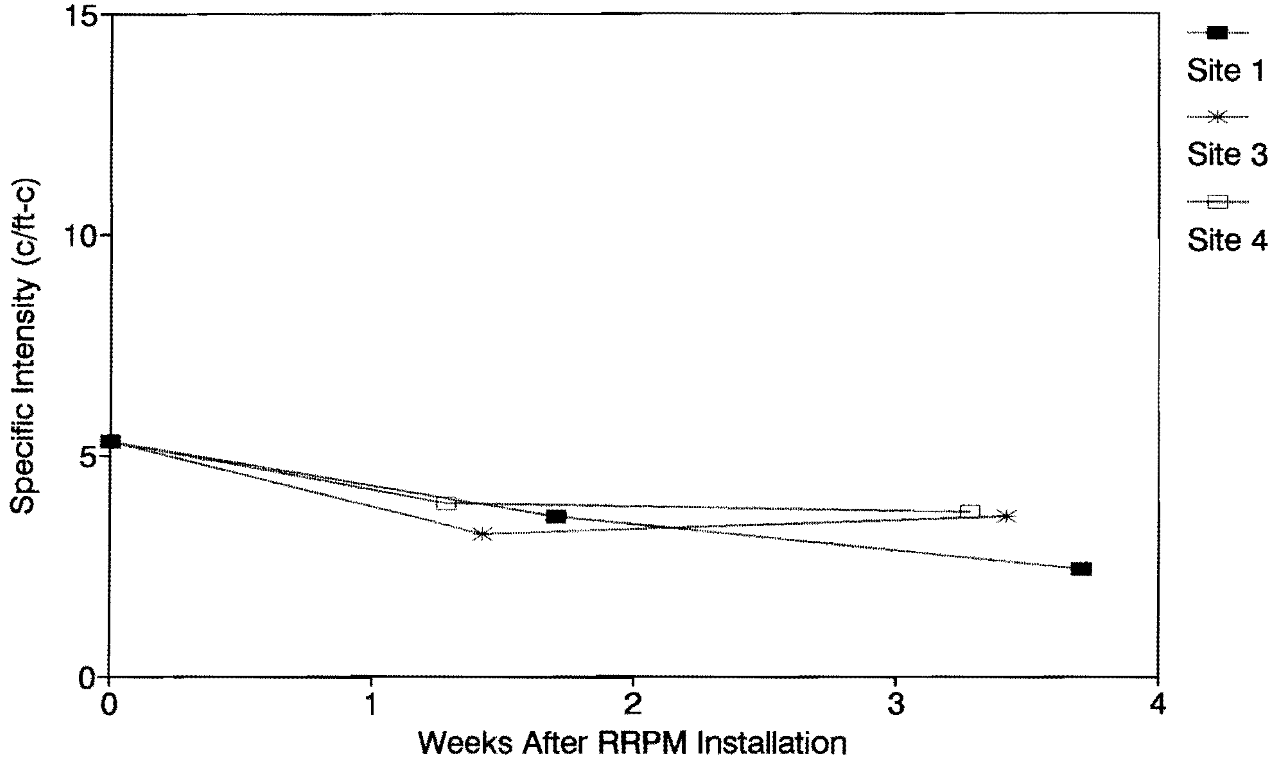
Batterson Reflective Button: Laboratory SI Readings After Washing



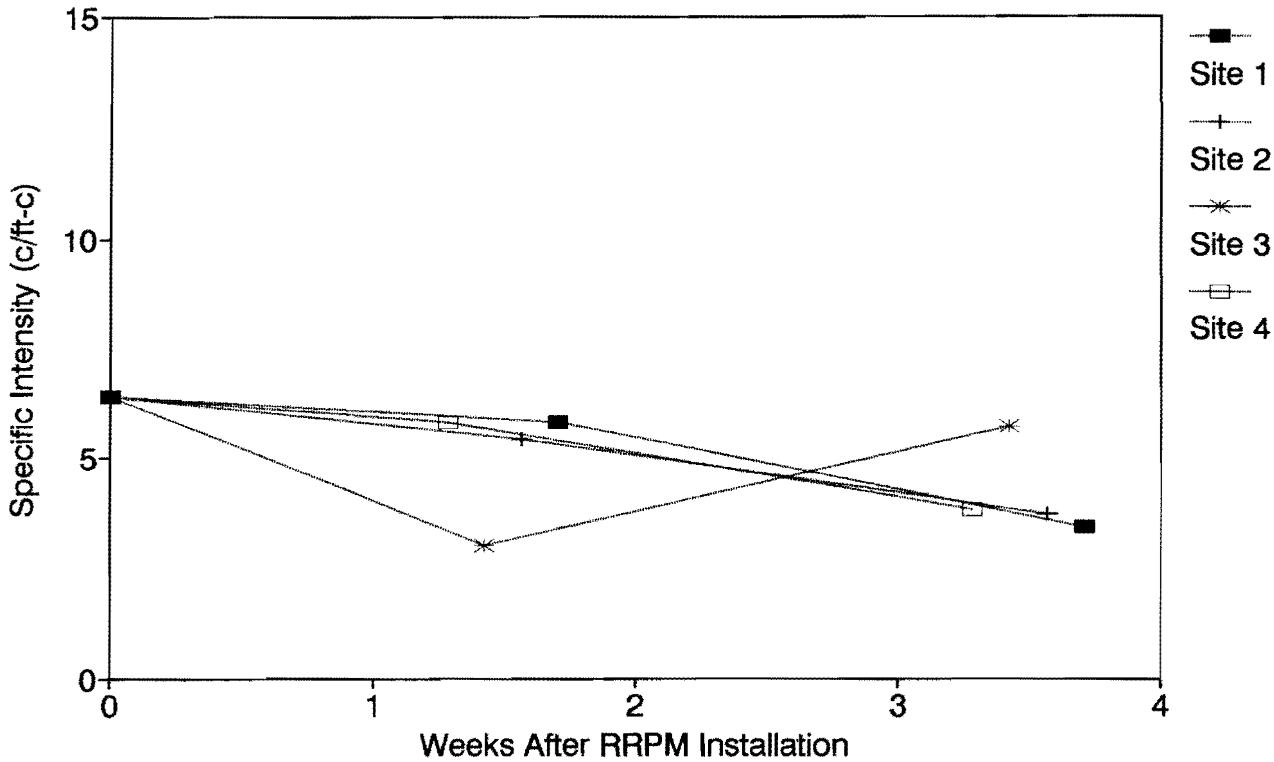
Empco Model 901: Laboratory SI Readings After Washing



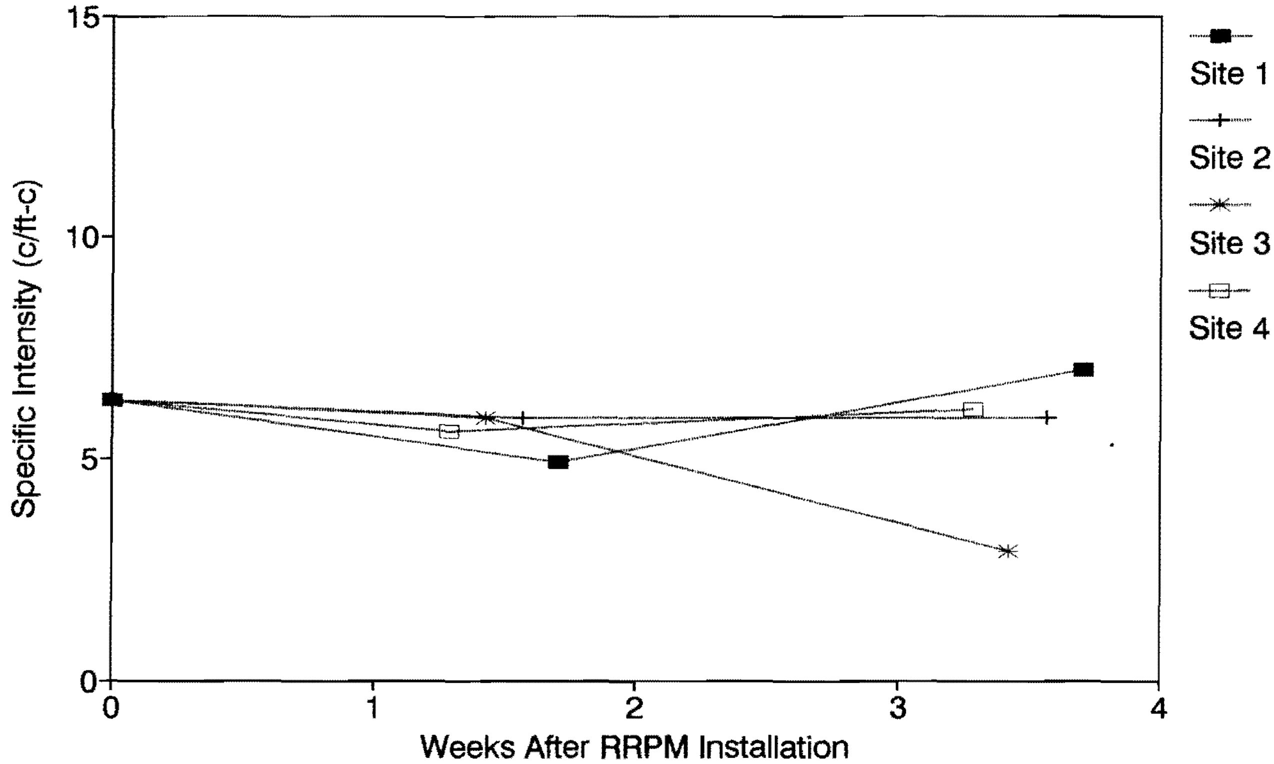
Ray-O-Lite Model 8704 (S): Laboratory SI Readings After Washing



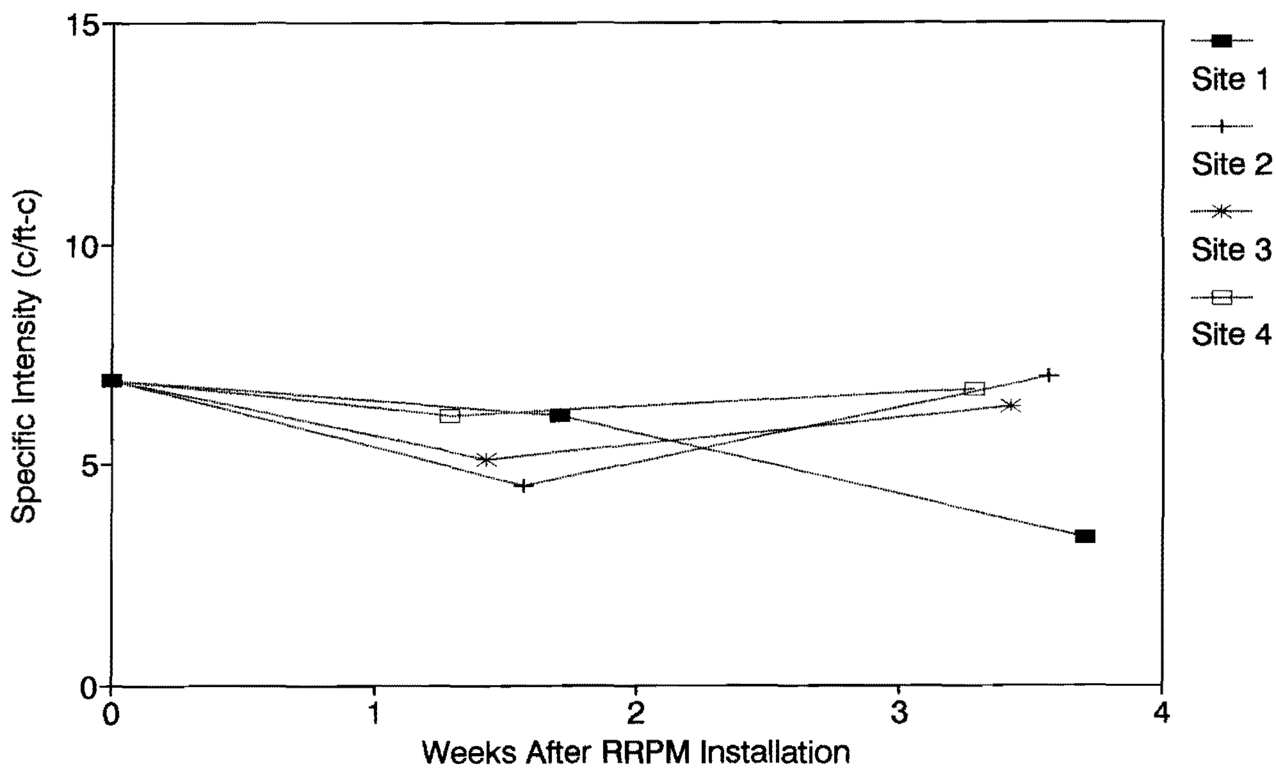
Ray-O-Lite Model 8704 (R): Laboratory SI Readings After Washing



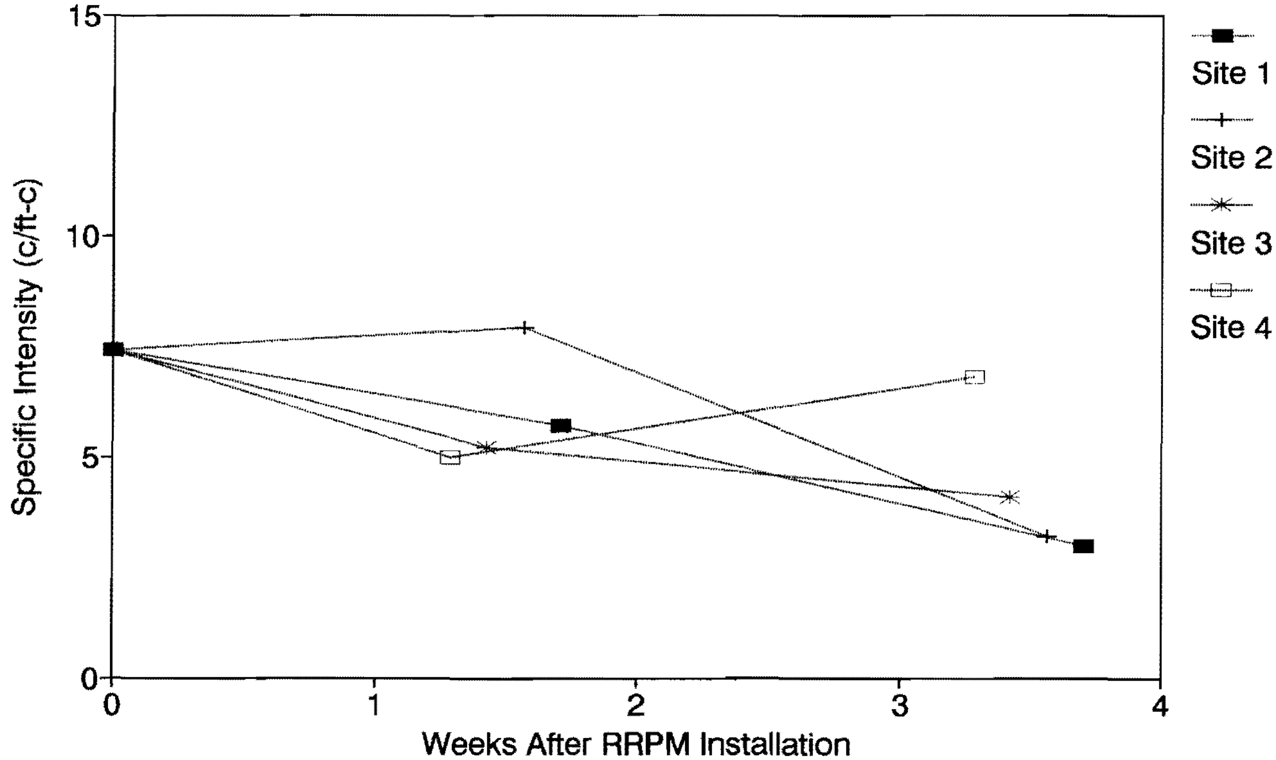
Ray-O-Lite Model 9704: Laboratory SI Readings After Washing



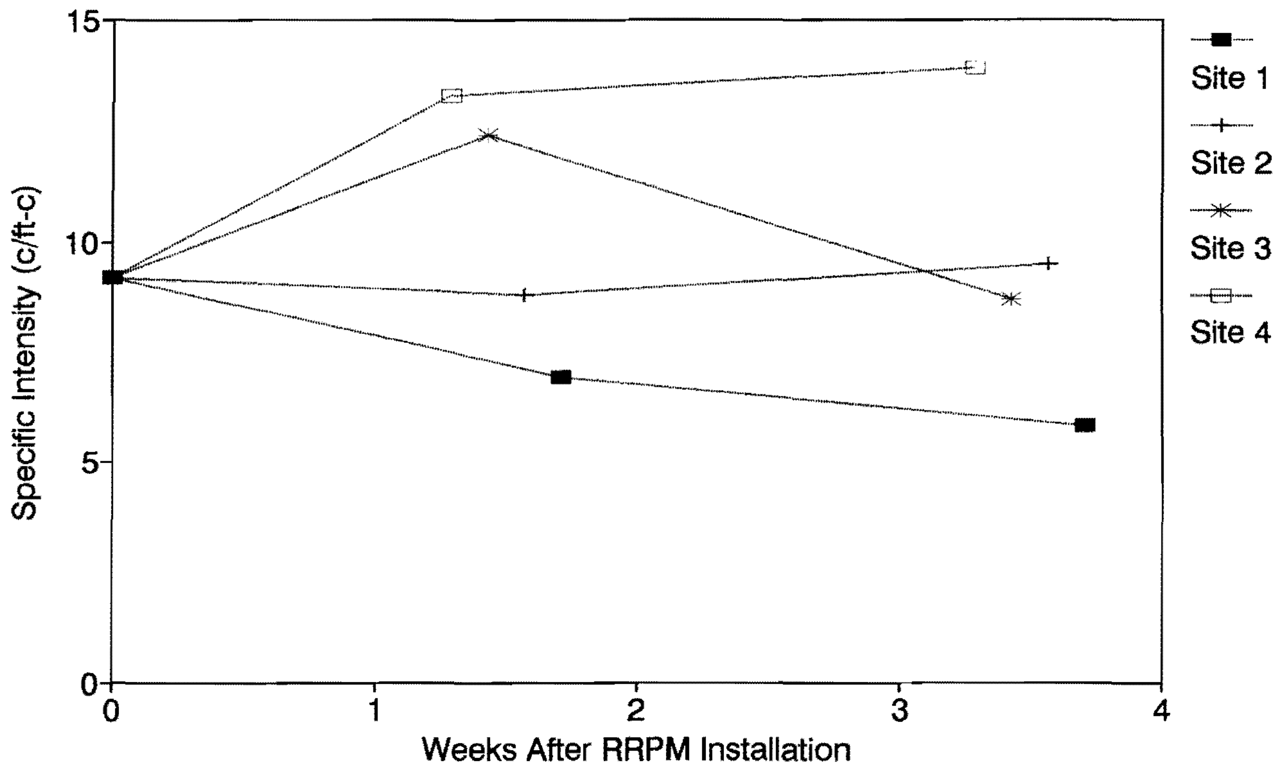
Ray-O-Lite Model 2002: Laboratory SI Readings After Washing



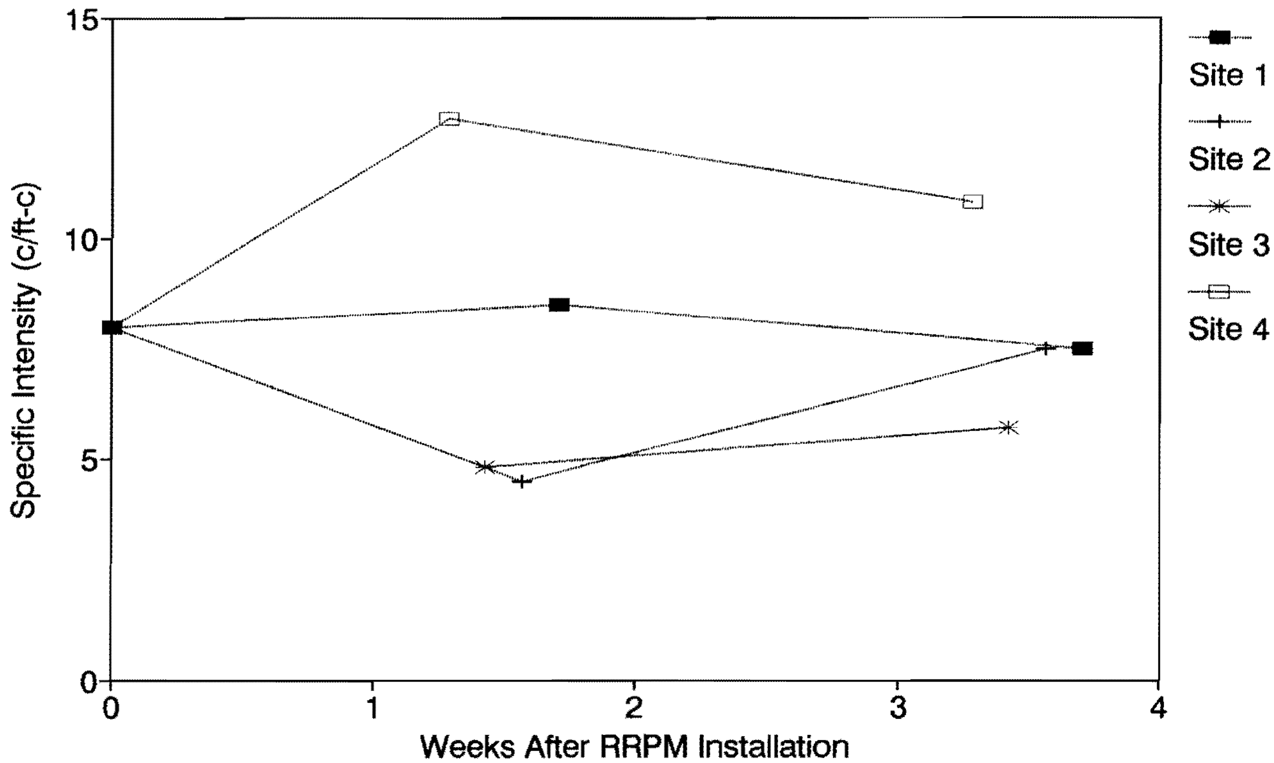
Ray-O-Lite Model 2003: Laboratory SI Readings After Washing



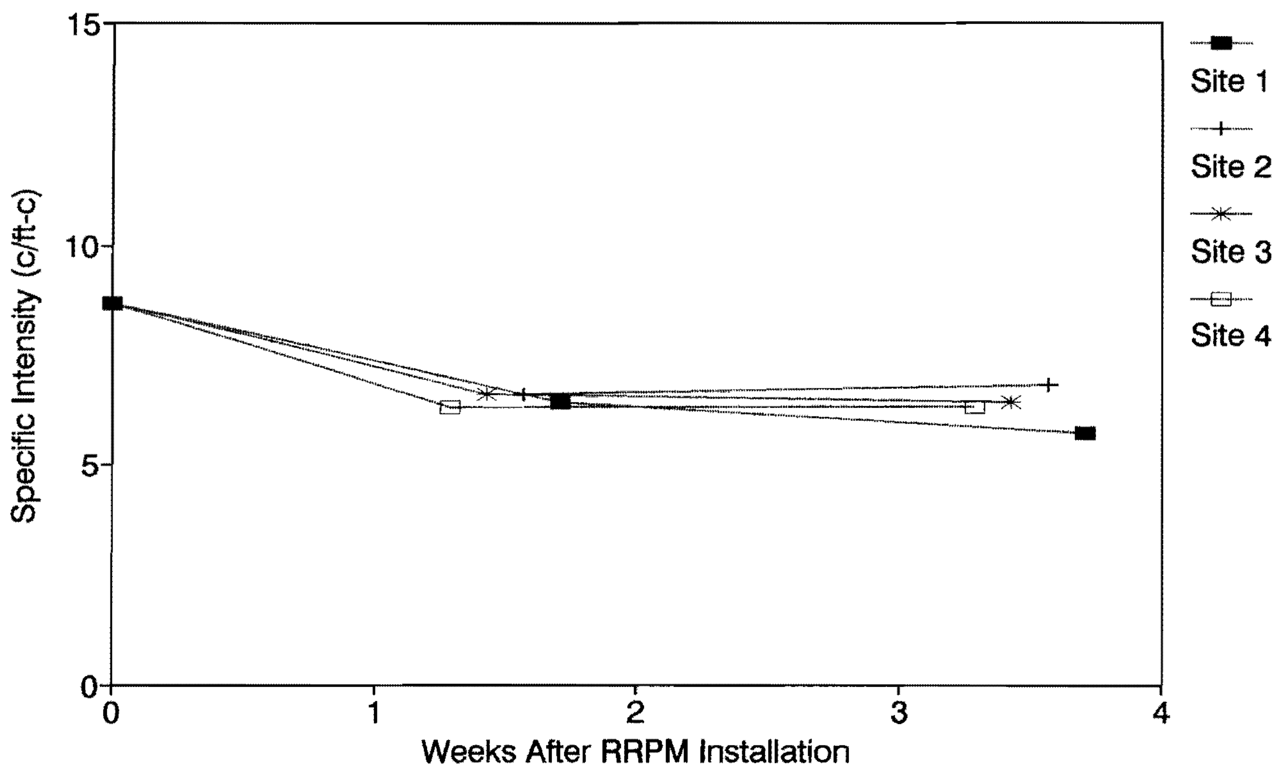
Stimsonite Model 88: Laboratory SI Readings After Washing



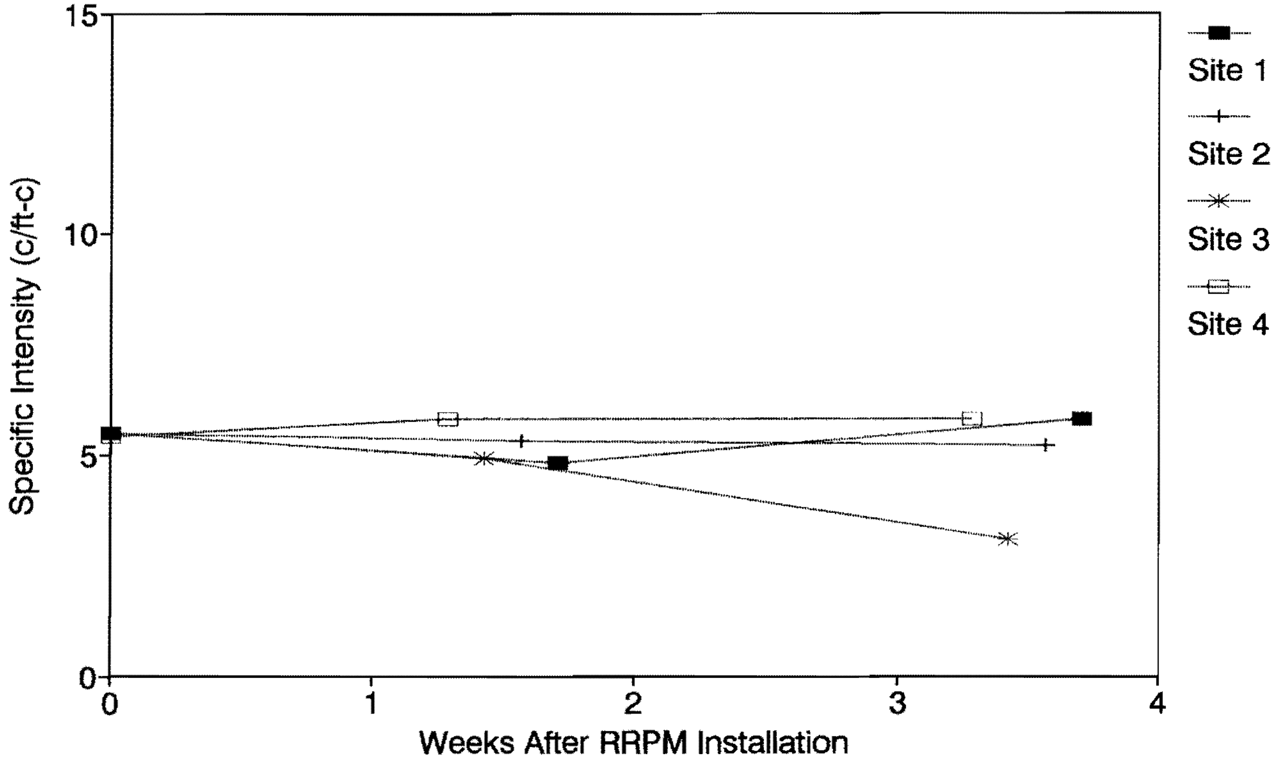
Stimsonite Model 911: Laboratory SI Readings After Washing



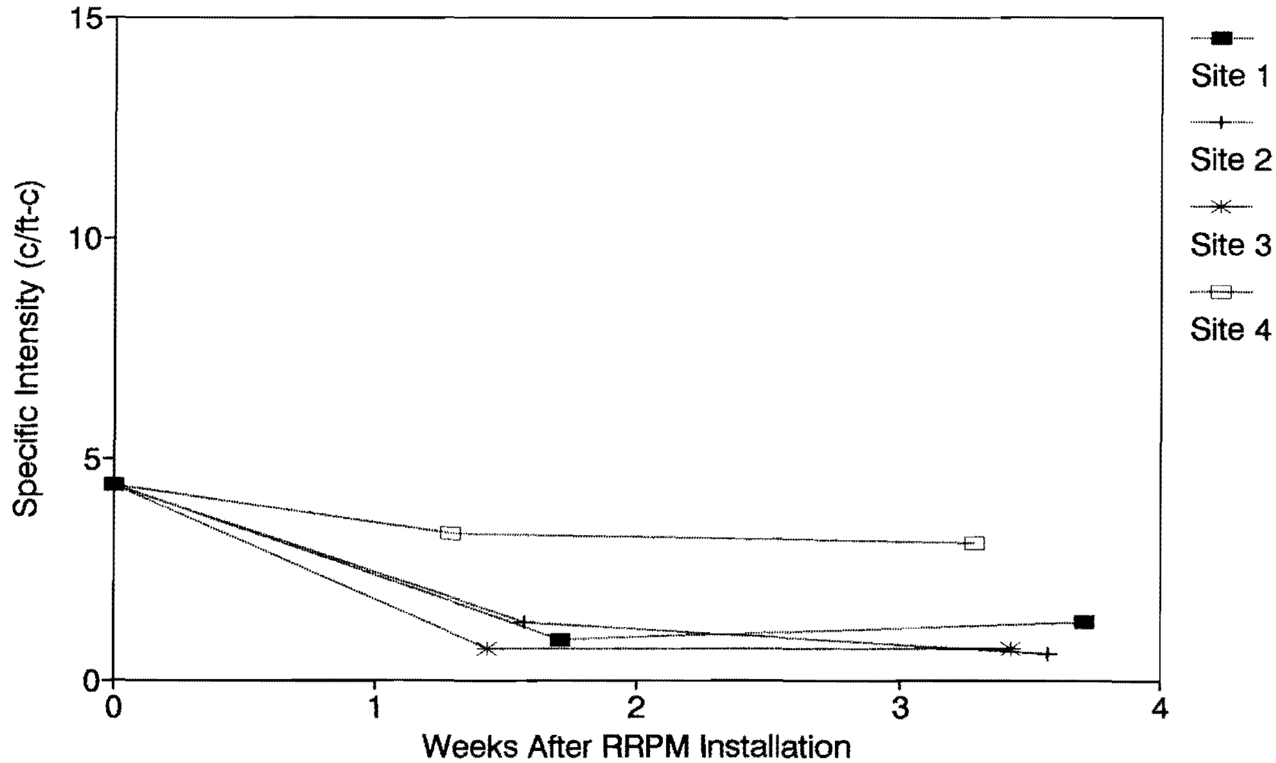
Stimsonite Model 948: Laboratory SI Readings After Washing



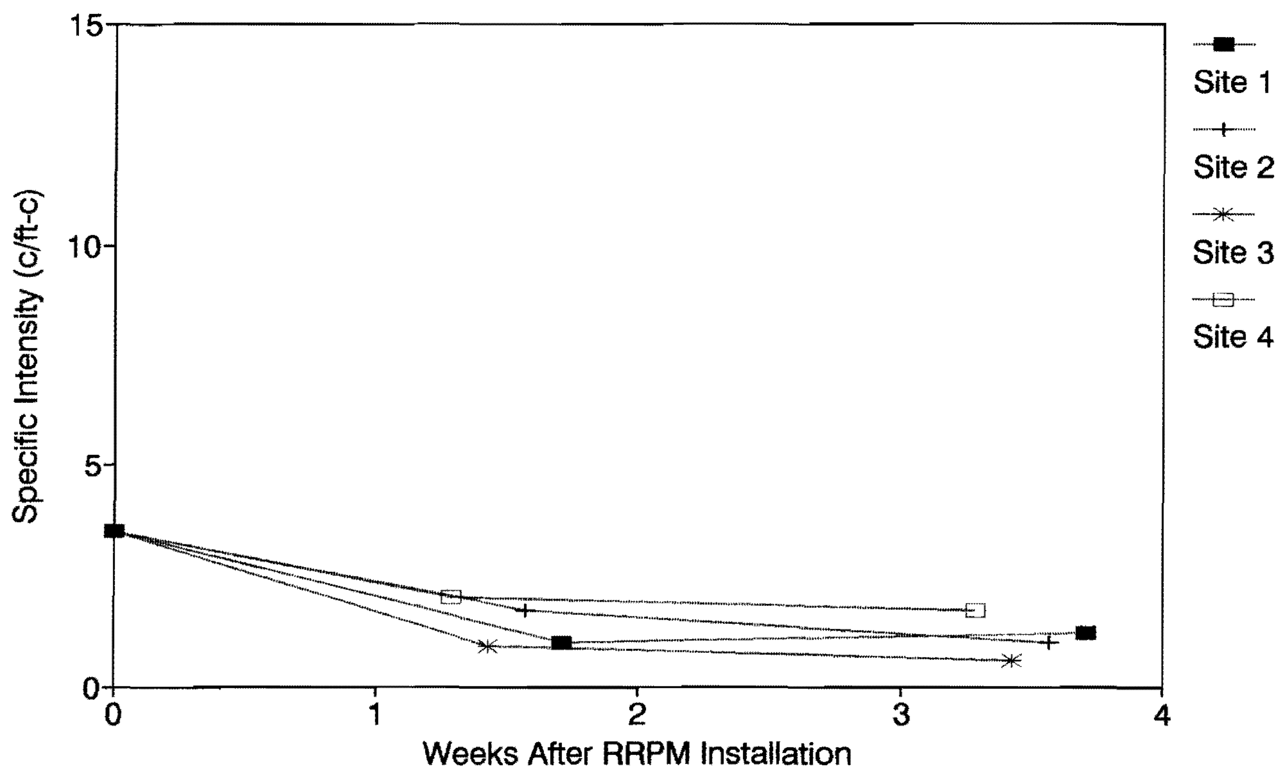
Stimsonite Model 953: Laboratory SI Readings After Washing



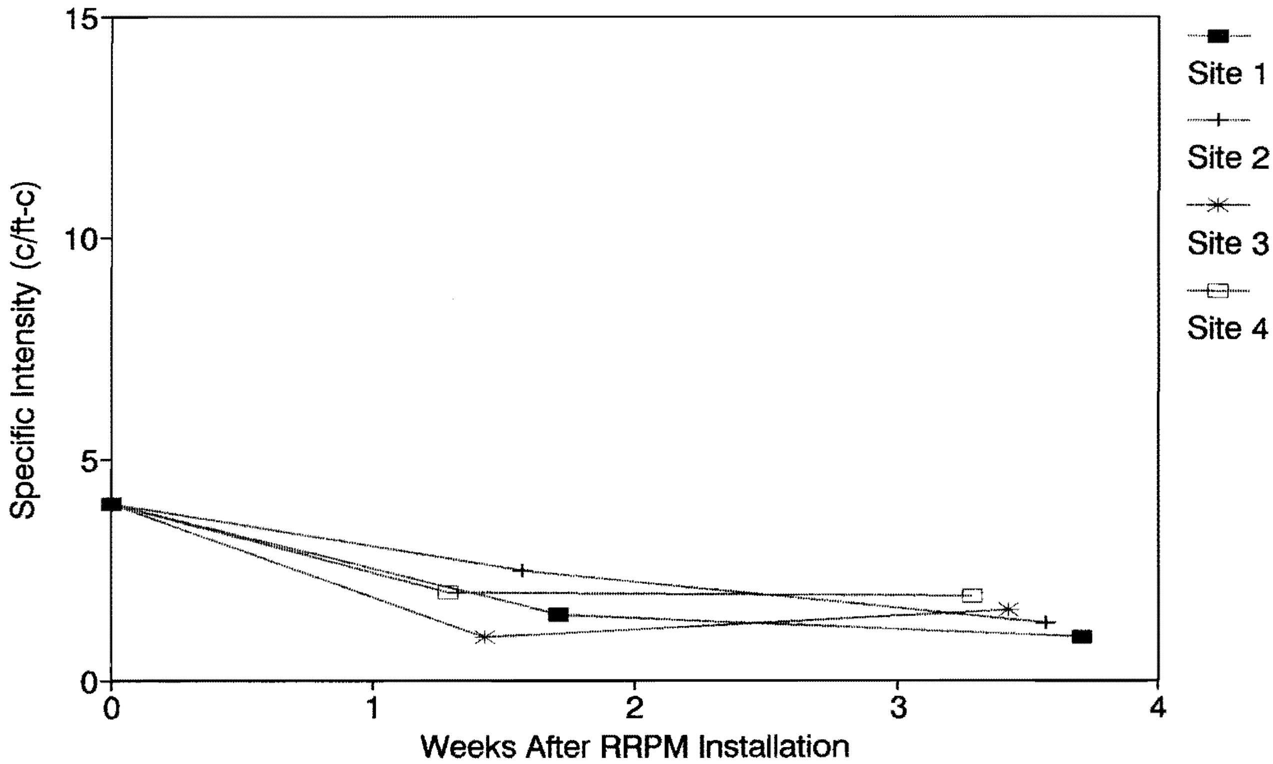
Swareflex RRPM: Laboratory SI Readings After Washing



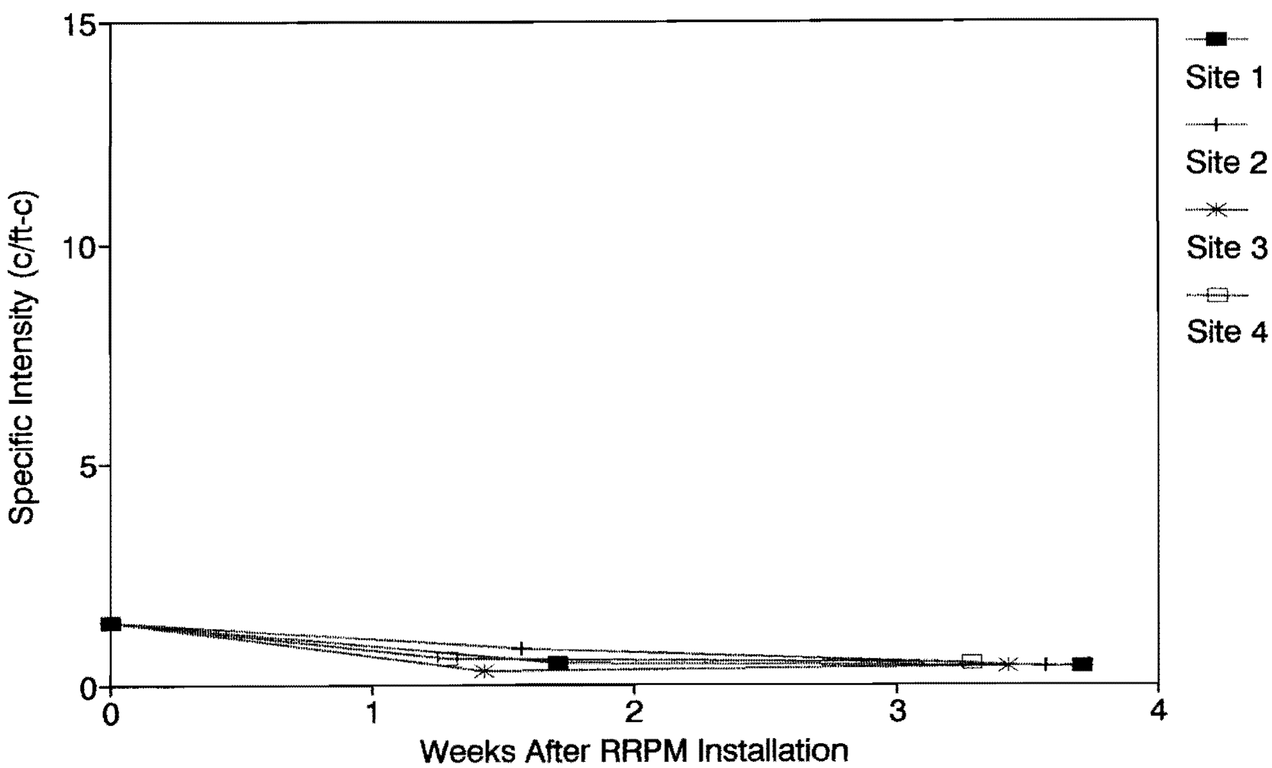
Apex Model 921: Field SI Readings



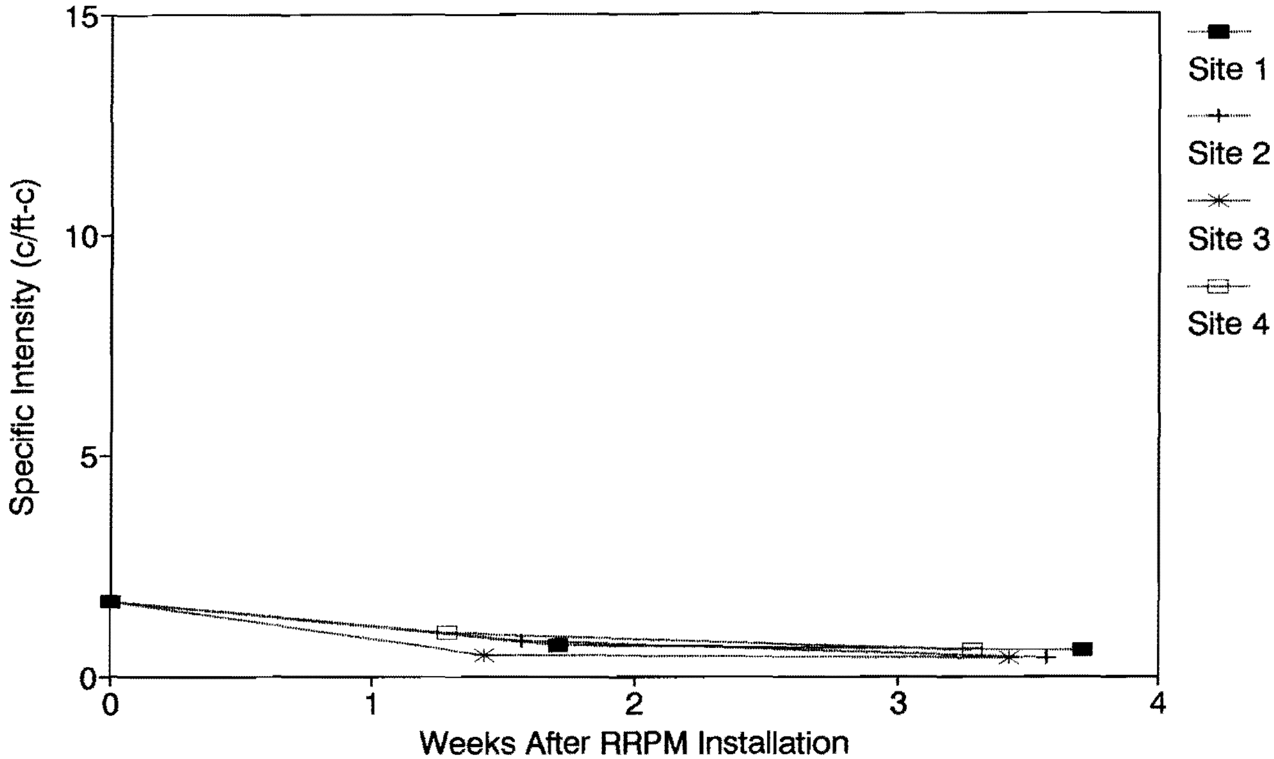
Apex Model 918: Field SI Readings



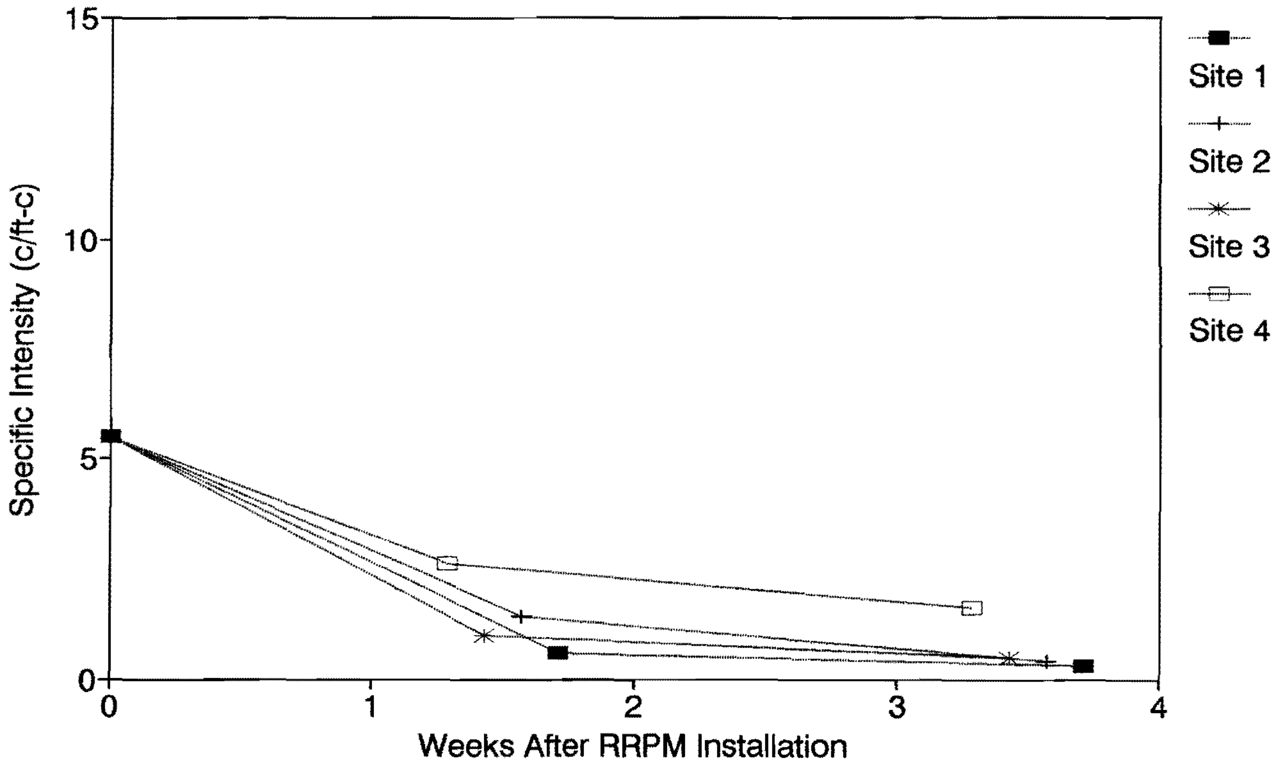
Apex Model 928: Field SI Readings



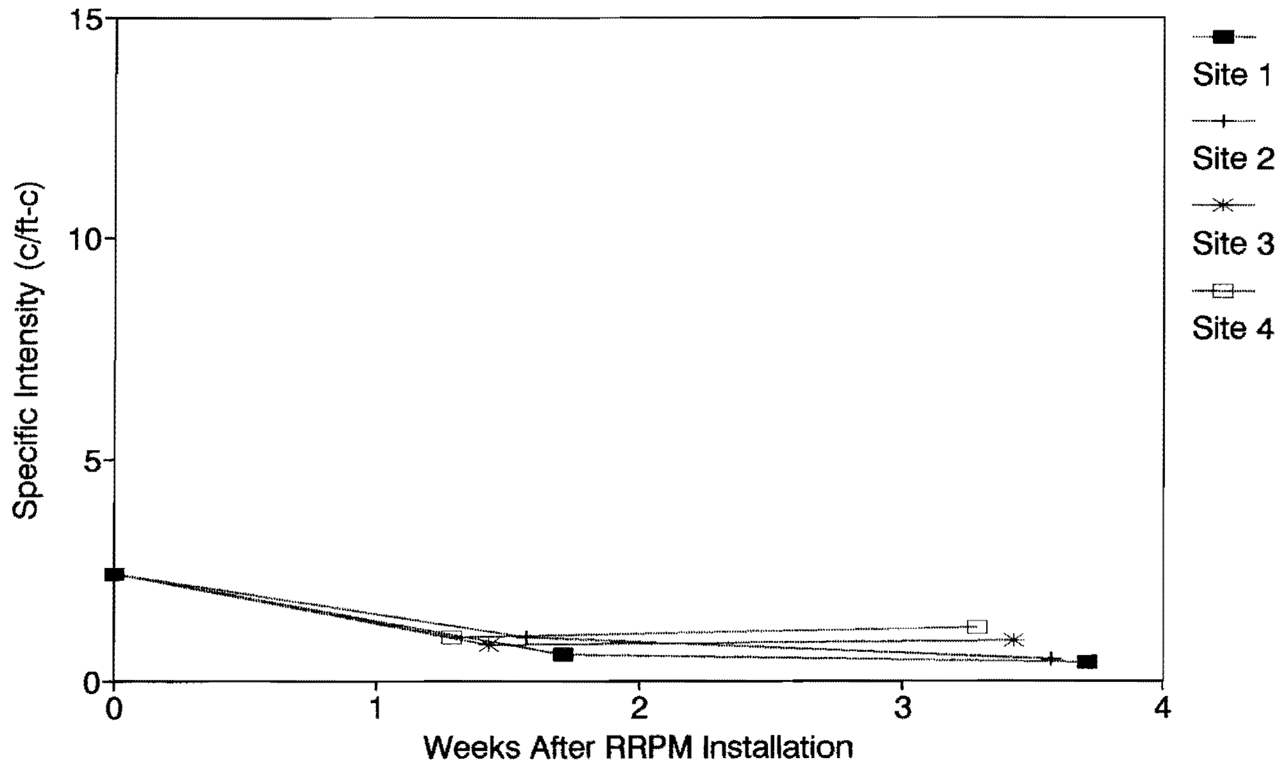
Apex Model 807: Field SI Readings



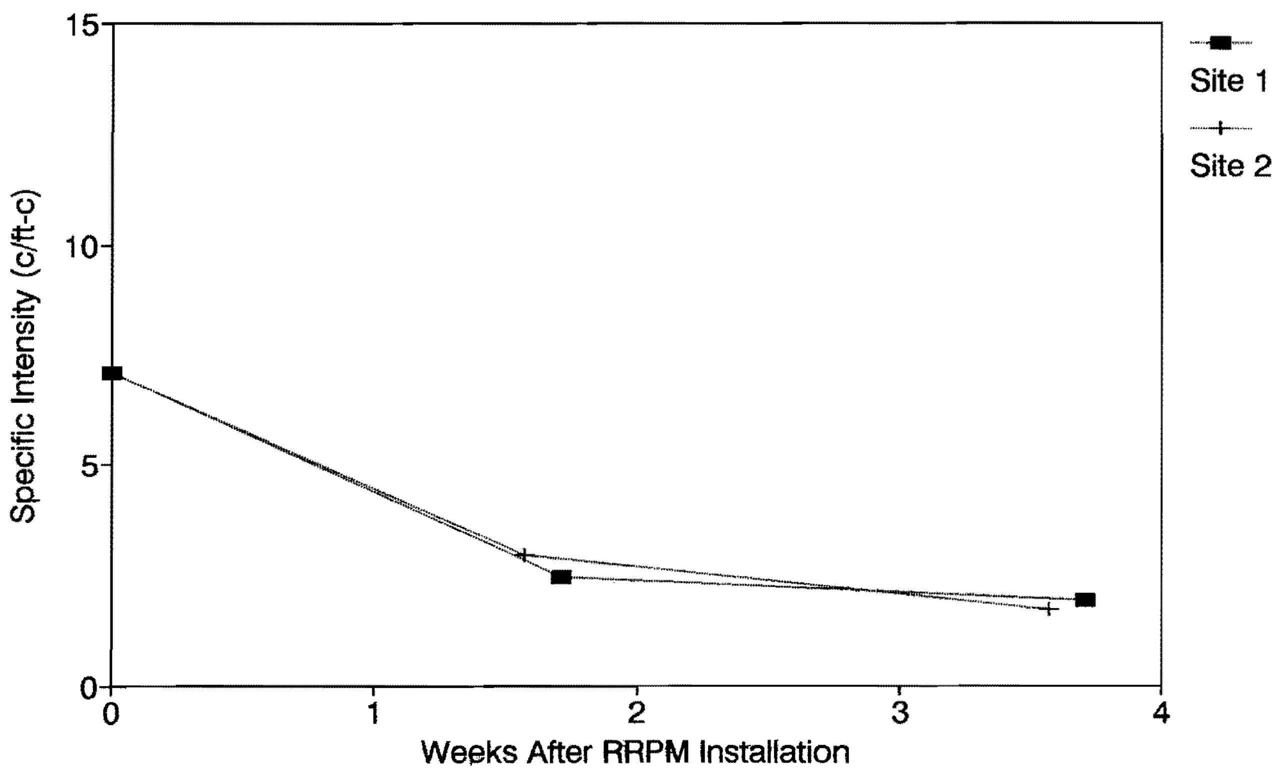
Apex Model 817: Field SI Readings



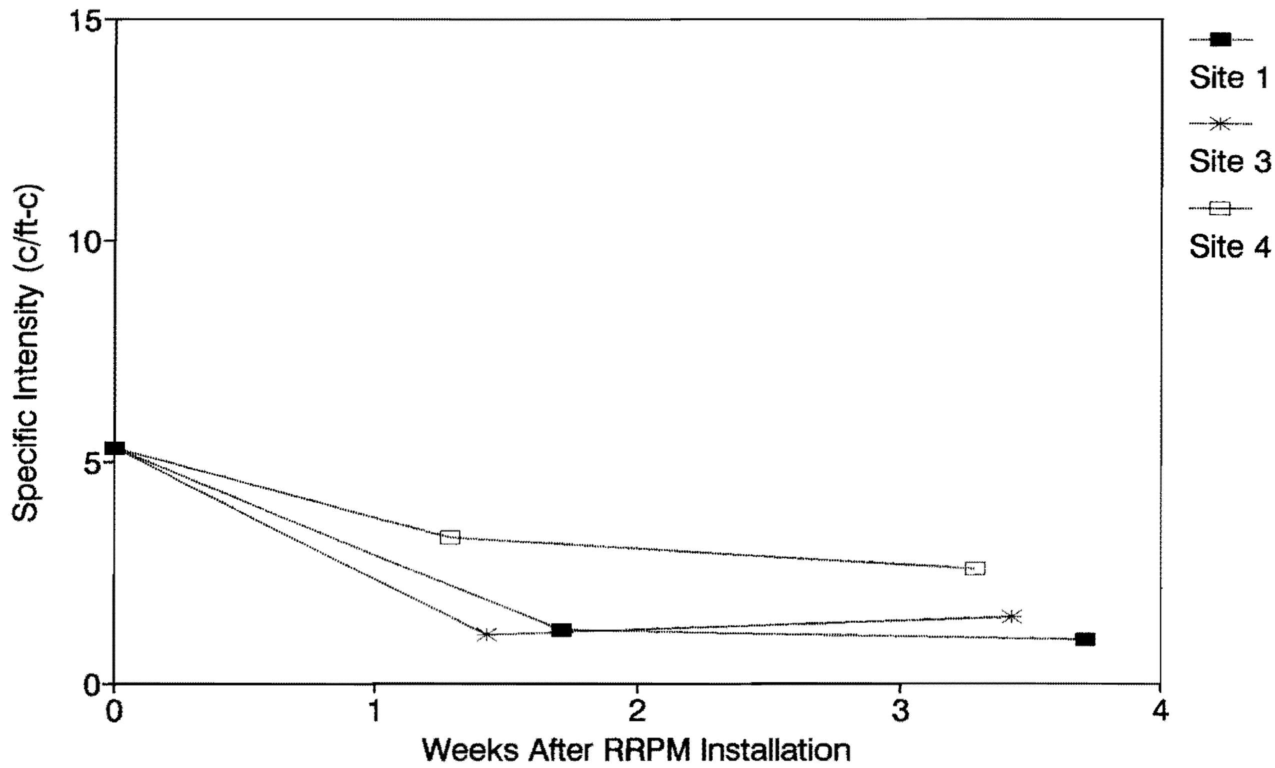
Batterson Reflective Button: Field SI Readings



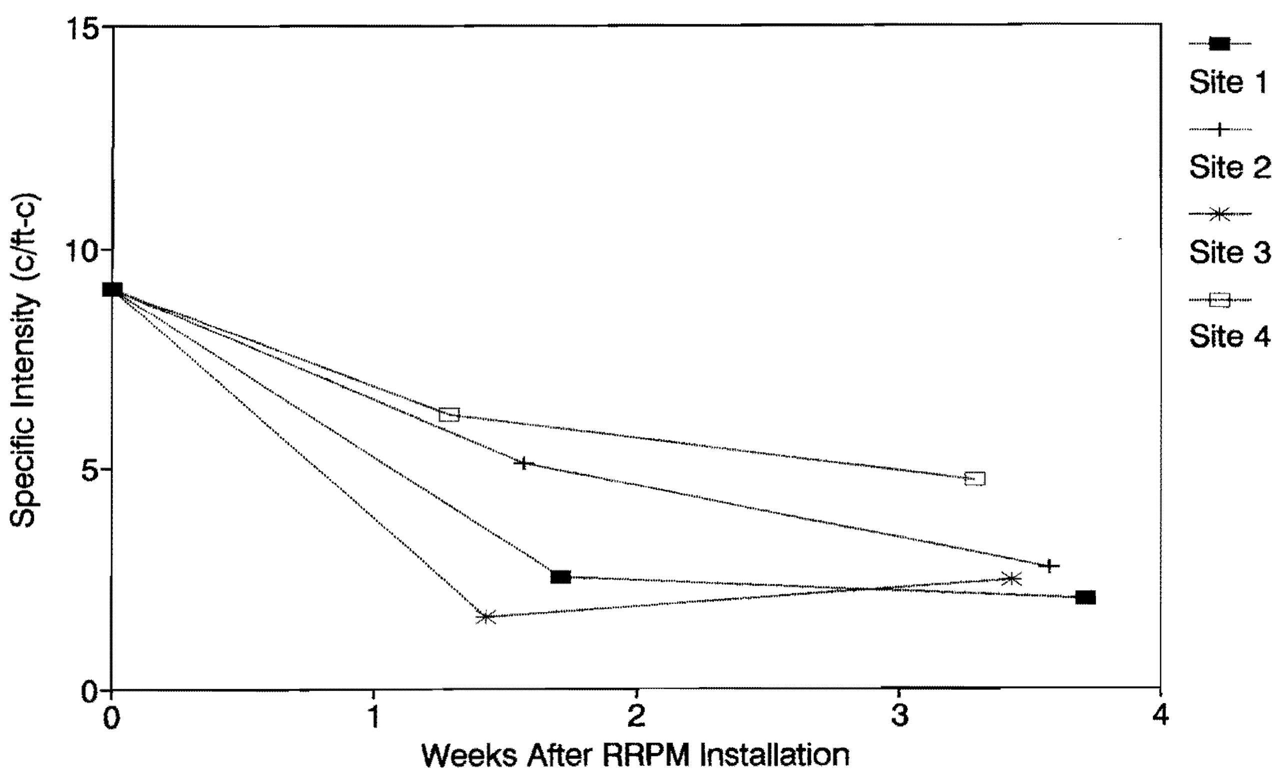
Empco Model 901: Field SI Readings



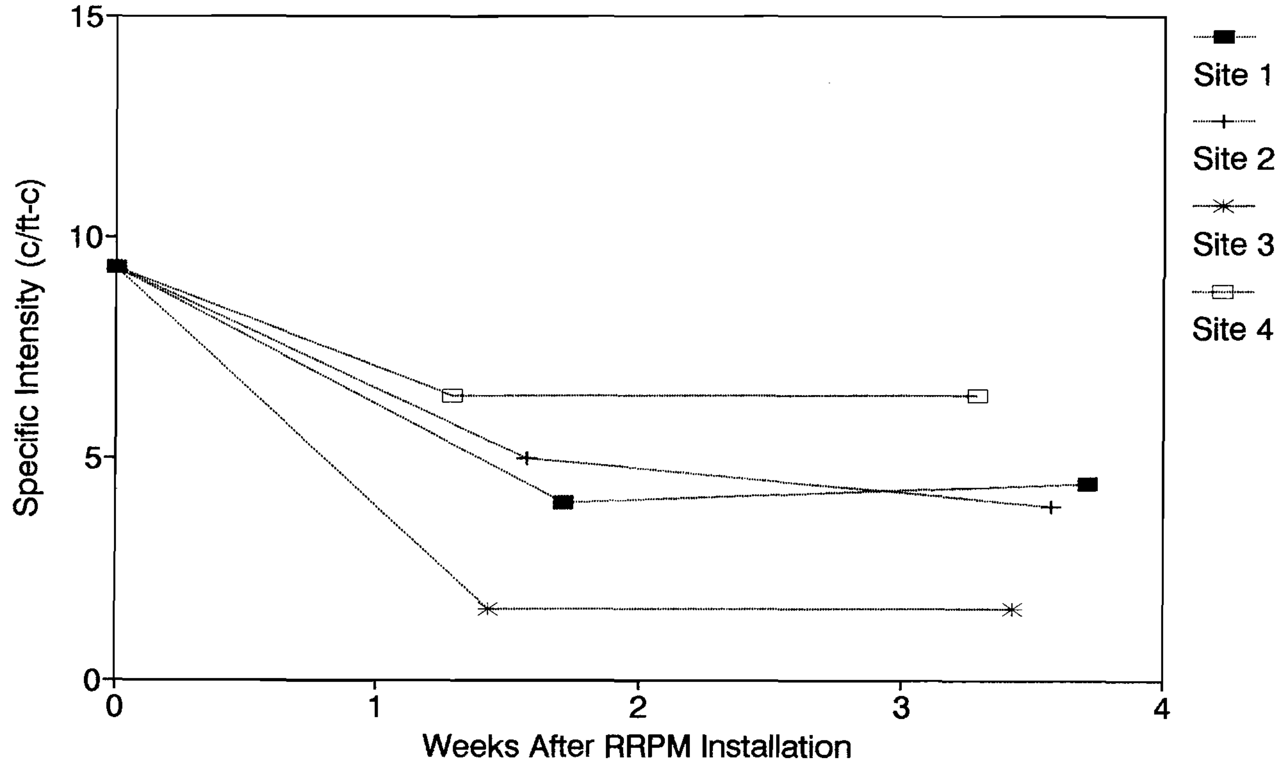
Ray-O-Lite Model 8704 (S): Field SI Readings



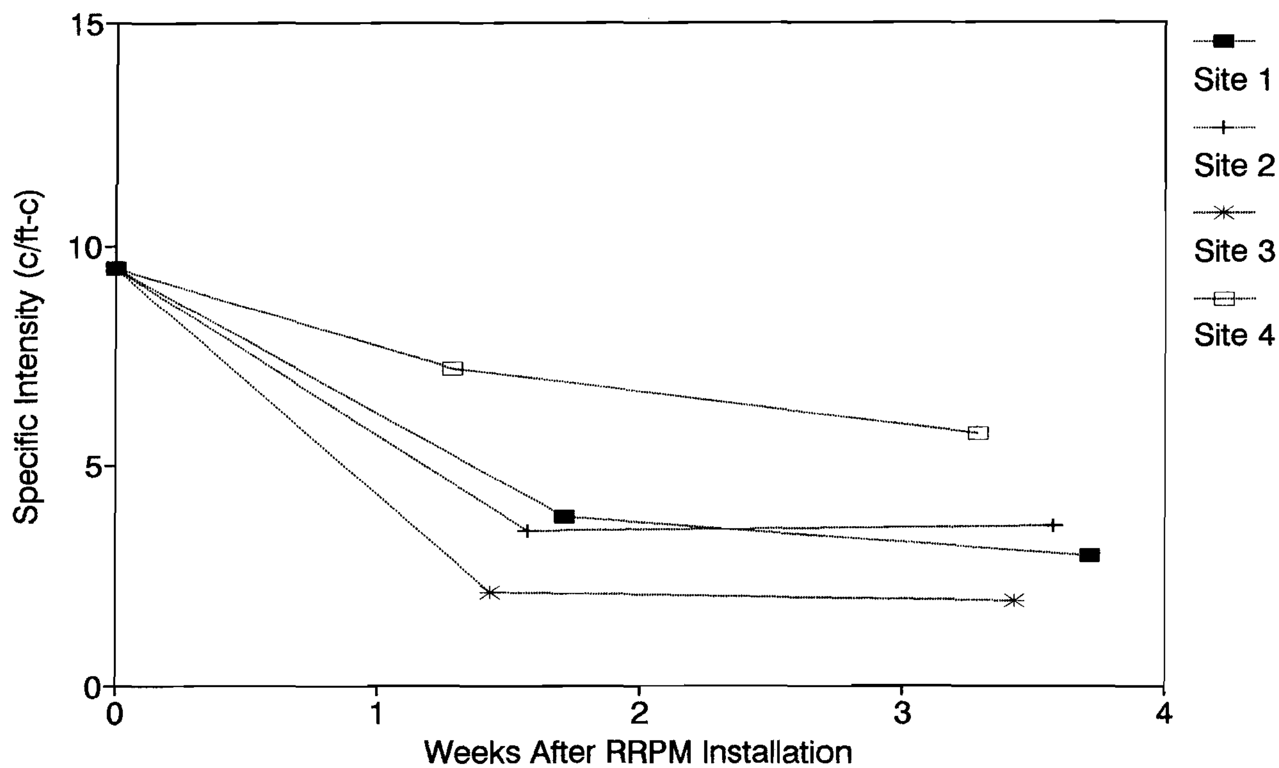
Ray-O-Lite Model 8704 (R): Field SI Readings



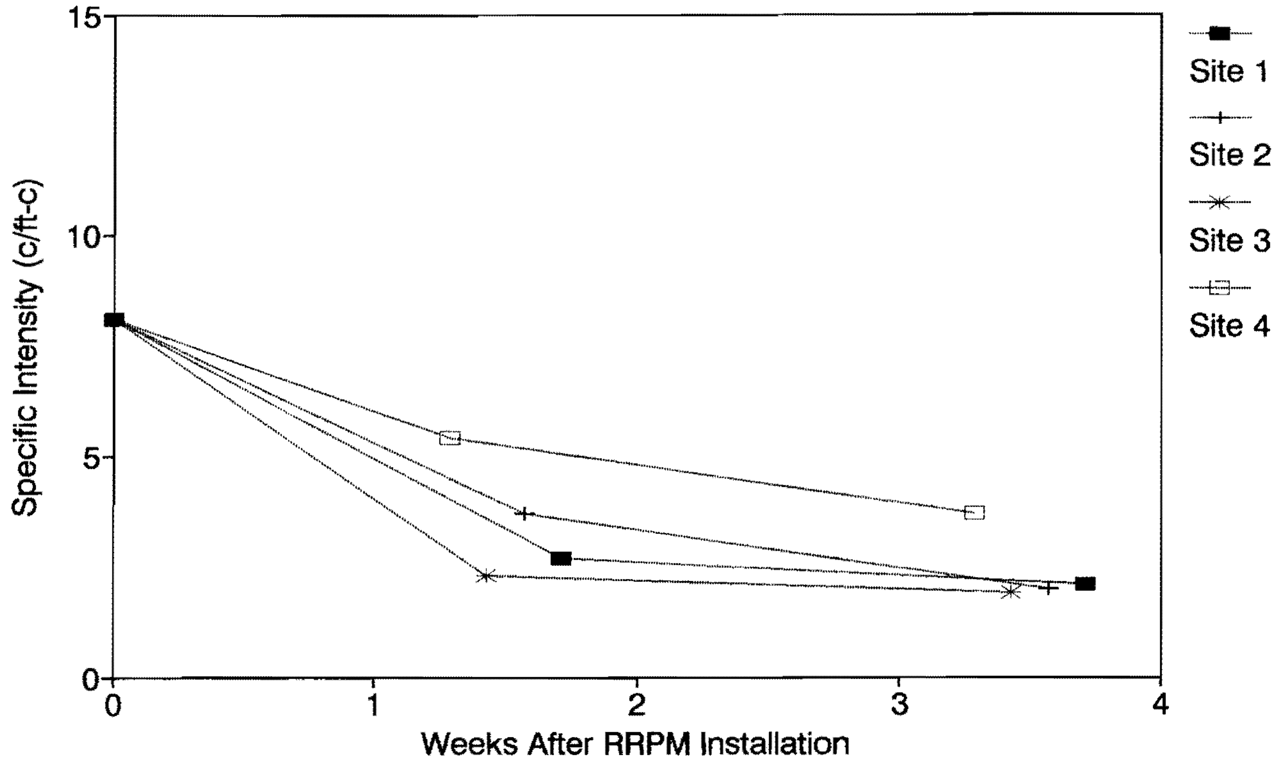
Ray-O-Lite Model 9704: Field SI Readings



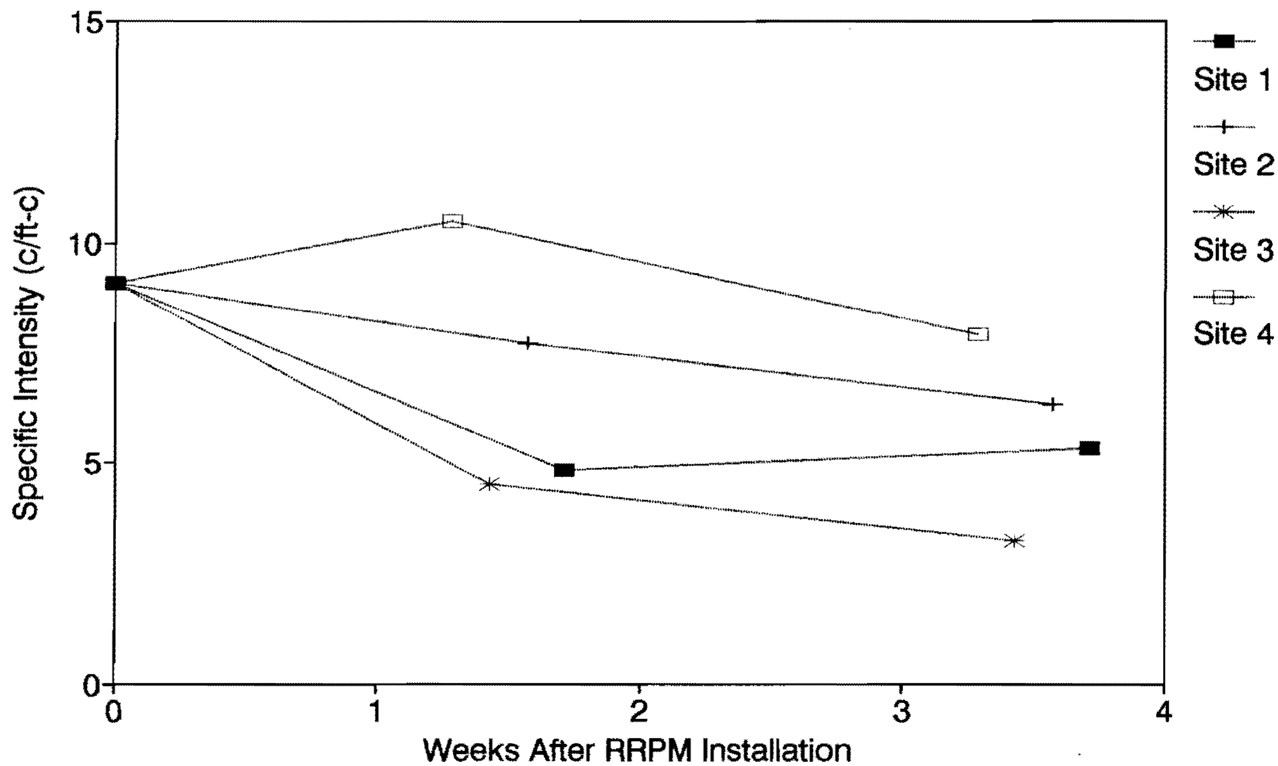
Ray-O-Lite Model 2002: Field SI Readings



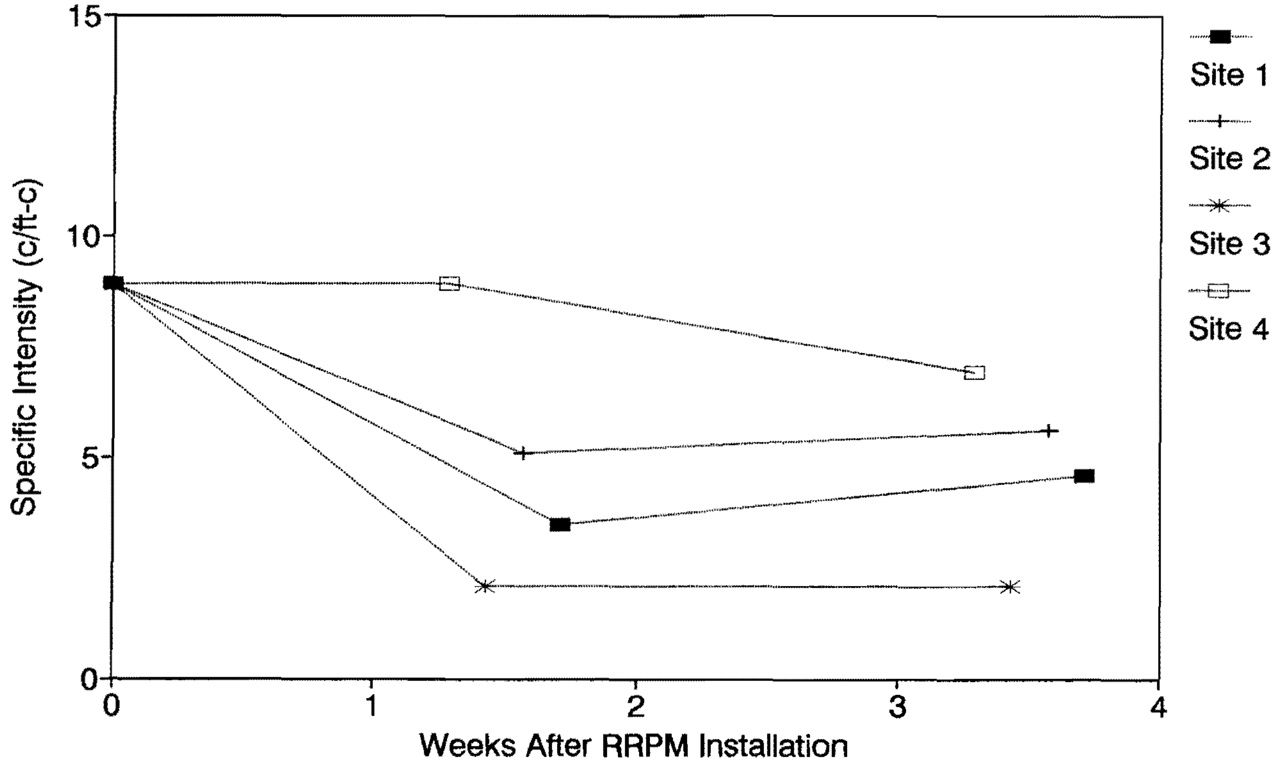
Ray-O-Lite Model 2003: Field SI Readings



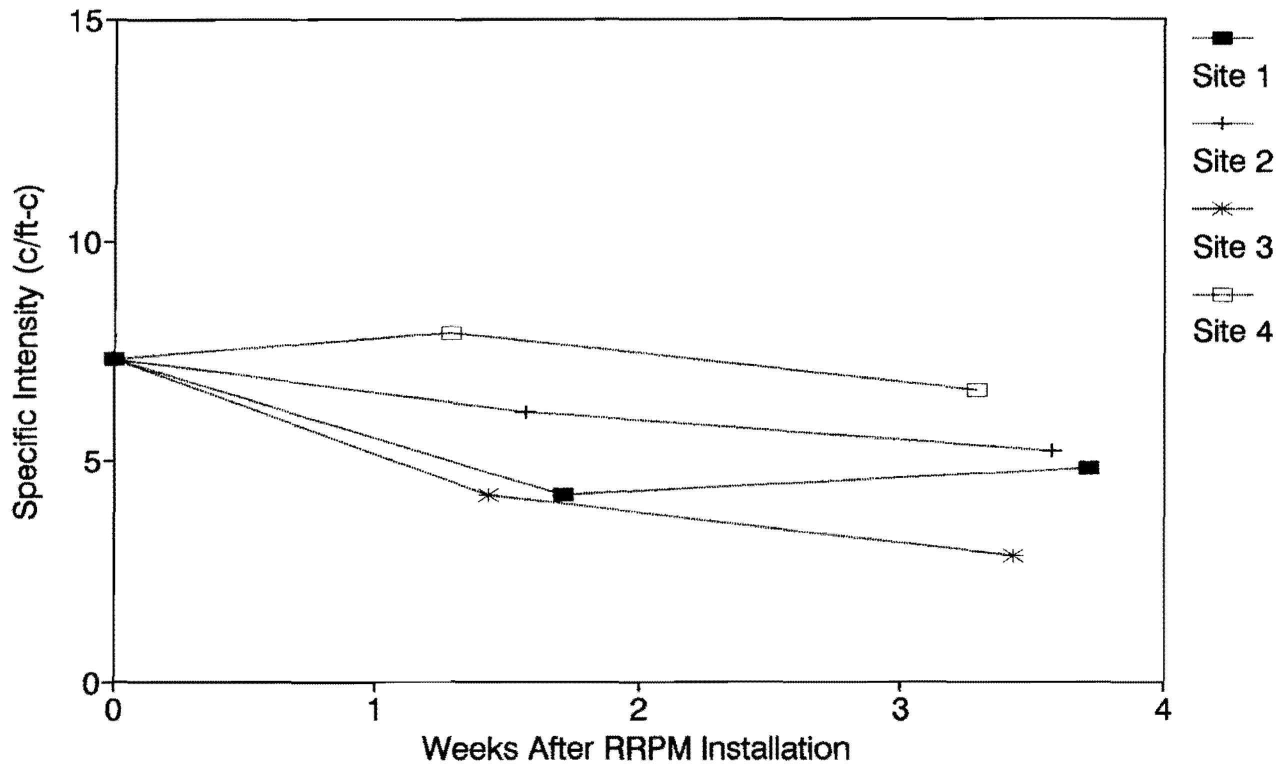
Stimsonite Model 88: Field SI Readings



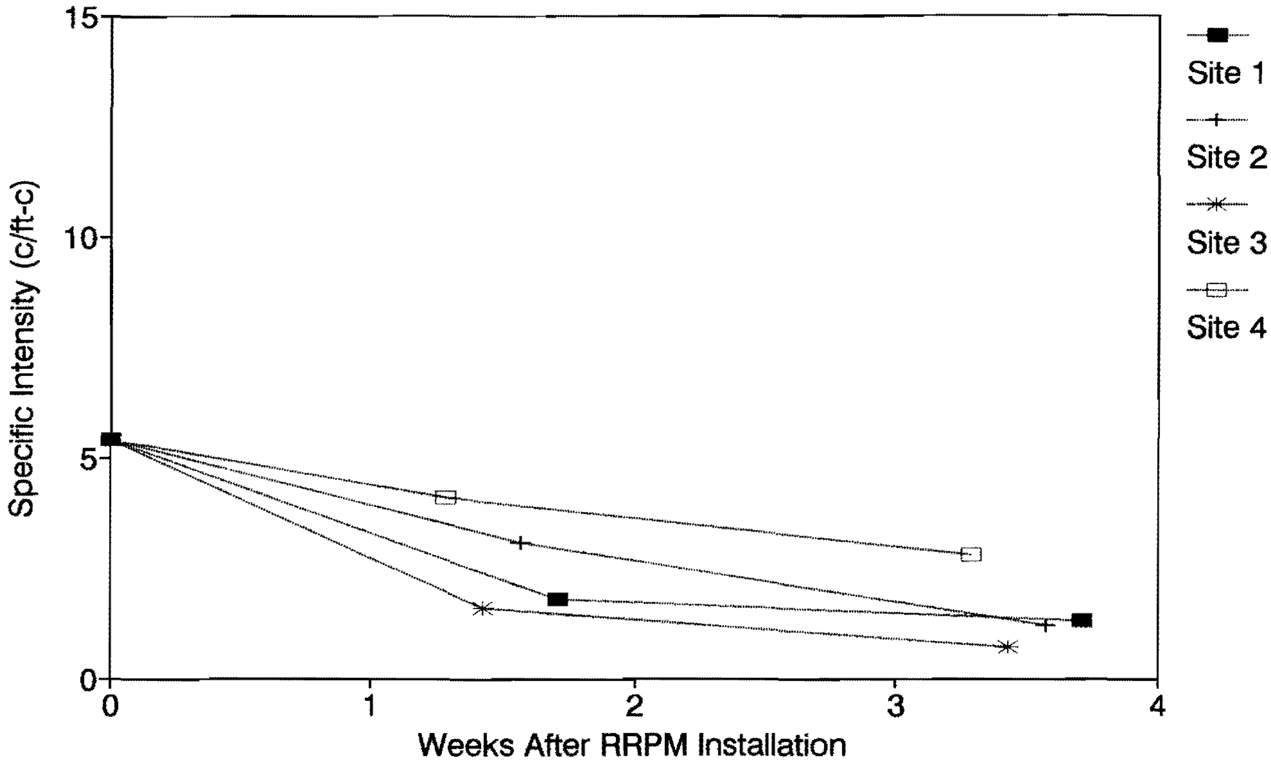
Stimsonite Model 911: Field SI Readings



Stimsonite Model 948: Field SI Readings



Stimsonite Model 953: Field SI Readings



Swareflex RRPM: Field SI Readings

APPENDIX C: MARKER-BY-MARKER FIELD-MEASURED SI VALUES FROM SITES 1 AND 2

One of the difficulties in assessing the degradation of RRPM reflectivity over time is that SI values recorded for a given type of RRPM vary from marker to marker, even when they are new. Some of this variability is due to deviations in the actual measurement process, whereas some of it is due to the small differences between the markers themselves. Furthermore, as illustrated in Chapter 3, the amount of variability depends upon the type of RRPM of interest. Measuring the reflectivity of a large number of each type of RRPM and averaging them can help reduce the effect of this variability when assessing reflectivity degradation. However, when only a few markers are sampled, considerable insight can be gained by evaluating the SI values of the individual RRPMs themselves.

Each RRPM installed at the four study sites was coded with a unique identification number so that the reflectivity of each individual marker could be tracked throughout the two-year study period. The SI values of those RRPMs which were measured in the field (via the portable retroreflectometer) at the time of installation and at either the August 16th or August 30th evaluation were cross-referenced and are presented in Tables C-1 through C-17. An attempt was then made to identify those SI values which appear unreasonable in context with the other readings taken at those sites, and may be due to an incorrect SI measurement. These possible outliers are listed below.

- Apex 921, #112: the initial value (0.7) seems low
- Apex 928, #152: the initial value (7.6) seems high
- Batterson Button, #104: the initial value (7.1) seems high
- Ray-O-Lite 8704 (S), #29: the initial value (9.3) seems high
- Ray-O-Lite 9704, #169: the initial value (12.9) seems high
- Ray-O-Lite 2003, #116 and #112: the initial values (14.6, 16.7) seem high. Conversely, the initial value for #156 (4.8) seems low
- Stimsonite 88, #4: the initial value (16.2) seems high
- Stimsonite 911, #114 and #177: the initial values (14.1, 15.7) seem high.

Certainly, other markers could be added to this list. However, these are the most divergent from the trends displayed from other markers of the same type and the same site.

TABLE C-1. READINGS FOR APEX 921 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
112	0.7	0.4	-.-	154	4.1	1.5	-.-
132	4.6	1.8	-.-	162	2.3	1.2	0.7
131	6.9	0.4	-.-	171	2.0	1.1	0.9
135	4.6	-.-	1.4	169	6.5	-.-	2.8
17	6.1	-.-	1.5				
133	3.3	-.-	1.1				

TABLE C-2. READINGS FOR APEX 918 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
141	1.9	1.0	-.-	67	3.6	1.4	-.-
125	1.8	0.6	-.-	47	3.8	1.4	0.9
121	5.5	1.5	-.-	73	4.0	2.3	1.2
127	4.6	-.-	1.0	66	3.2	-.-	1.0
140	3.7	-.-	1.4				
108	5.0	-.-	1.1				

TABLE C-3. READINGS FOR APEX 928 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
137	2.5	1.5	-.-	112	4.0	2.8	-.-
151	3.6	1.4	-.-	106	3.9	2.5	1.6
153	4.3	1.5	-.-	113	4.5	2.2	1.4
159	2.6	-.-	1.0	111	2.4	-.-	0.8
134	3.9	-.-	1.0				
152	7.6	-.-	1.1				

TABLE C-4. READINGS FOR APEX 807 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
146	0.6	0.6	-.-	33	1.1	0.8	-.-
108	0.9	0.6	-.-	37	0.5	0.3	0.2
102	1.5	0.4	-.-	30	1.2	1.0	0.8
105	2.0	-.-	0.4	35	0.9	-.-	0.2
132	1.6	-.-	0.6				
121	0.9	-.-	0.3				

TABLE C-5. READINGS FOR APEX 817 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
65	0.4	0.8	-.-	165	2.6	1.3	-.-
88	1.9	0.7	-.-	161	2.5	1.1	0.5
91	2.0	0.5	-.-	153	1.7	0.0	0.0
89	1.4	-.-	0.5	156	1.7	-.-	0.7
62	2.2	-.-	0.8				
197	1.7	-.-	0.5				

TABLE C-6. READINGS FOR BATTERSON REFLECTIVE BUTTONS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
154	4.9	0.3	-.-	2	5.3	1.4	-.-
117	4.7	0.7	-.-	134	5.0	1.5	0.4
104	7.1	0.7	-.-	131	5.1	1.4	0.4
98	5.7	-.-	0.3	90	4.7	-.-	0.5
144	5.5	-.-	0.4				
141	4.6	-.-	0.2				

TABLE C-7. READINGS FOR EMPCO 901 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
115	1.4	0.5	-.-	167	2.2	1.0	-.-
135	1.6	0.7	-.-	162	3.4	0.9	0.7
132	3.1	0.5	-.-	169	1.8	1.1	0.4
138	1.1	-.-	0.3	168	2.0	-.-	0.4
114	1.5	-.-	0.5				
143	2.3	-.-	0.5				

TABLE C-8. READINGS FOR RAY-O-LITE 8704 (S) MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
146	6.3	2.6	-.-	106	7.9	4.0	-.-
159	7.5	2.6	-.-	29	9.3	3.4	-.-
164	7.6	1.9	-.-	10	7.5	3.2	1.9
163	7.7	-.-	2.1	134	7.3	2.7	2.1
140	8.0	-.-	1.7	99	6.8	1.6	1.8
152	8.1	-.-	1.8	125	6.3	-.-	1.6

TABLE C-9. READINGS FOR RAY-O-LITE 8704 (R) MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
117	5.3	1.3	-.-	---	-.-	-.-	-.-
135	4.6	1.1	-.-	---	-.-	-.-	-.-
130	6.0	1.3	-.-	---	-.-	-.-	-.-
127	3.8	-.-	1.3	---	-.-	-.-	-.-
118	6.2	-.-	0.9	---	-.-	-.-	-.-
136	5.4	-.-	0.9	---	-.-	-.-	-.-

TABLE C-10. READINGS FOR RAY-O-LITE 9704 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
33	6.5	2.0	-.-	19	8.6	5.0	-.-
152	9.7	3.4	-.-	1	10.7	4.3	2.8
169	12.9	2.1	-.-	3	10.3	5.9	3.7
167	10.5	-.-	2.4	20	7.3	-.-	1.6
25	9.1	-.-	1.7				
168	8.6	-.-	2.0				

TABLE C-11. READINGS FOR RAY-O-LITE 2002 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
35	9.5	4.5	-.-	7	7.4	4.1	-.-
41	7.5	3.4	-.-	19	9.0	4.7	3.6
56	11.3	4.2	-.-	13	8.4	6.1	3.9
71	10.1	-.-	4.3	11	7.7	-.-	3.4
72	10.9	-.-	4.6				
50	10.8	-.-	4.3				

TABLE C-12. READINGS FOR RAY-O-LITE 2003 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
116	14.6	7.8	-.-	142	7.6	3.7	-.-
156	4.8	1.6	-.-	143	8.1	5.0	3.2
180	8.2	2.1	-.-	125	7.9	1.9	4.0
175	5.6	-.-	2.0	1	9.0	-.-	3.6
112	16.7	-.-	5.0				
171	7.3	-.-	1.8				

TABLE C-13. READINGS FOR STIMSONITE 88 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
82	7.4	2.0	-.-	21	10.3	3.8	-.-
3	9.0	3.1	-.-	18	5.5	2.7	1.4
4	16.2	3.1	-.-	43	8.3	4.6	2.4
30	4.5	-.-	1.8	19	7.5	-.-	2.3
11	9.8	-.-	2.9				
78	7.5	-.-	1.7				

TABLE C-14. READINGS FOR STIMSONITE 911 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
111	4.8	2.8	-.-	147	7.3	6.8	-.-
134	11.3	6.0	-.-	167	7.7	6.4	7.1
177	15.7	5.5	-.-	166	9.2	10.0	8.2
132	3.4	-.-	5.1	148	3.8	-.-	3.8
114	14.1	-.-	4.5				
156	9.3	-.-	4.5				

TABLE C-15. READINGS FOR STIMSONITE 948 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
147	8.5	4.4	-.-	164	8.0	3.2	-.-
119	6.1	2.4	-.-	157	7.9	8.2	7.0
120	11.0	3.6	-.-	169	8.0	3.9	3.6
116	6.9	-.-	5.8	158	7.0	-.-	6.1
148	11.4	-.-	4.3				
101	8.1	-.-	3.8				

TABLE C-16. READINGS FOR STIMSONITE 953 MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
47	7.5	5.6	-.-	91	7.8	6.9	-.-
24	6.2	4.1	-.-	83	5.7	4.8	4.2
23	8.9	2.9	-.-	93	6.2	6.7	4.4
40	7.0	-.-	4.9	80	7.2	-.-	7.0
45	6.6	-.-	4.8				
9	7.1	-.-	4.6				

TABLE C-17. READINGS FOR SWAREFLEX MARKERS

Site 1				Site 2			
Marker #	8/3/92	8/16/92	8/30/92	Marker #	8/4/92	8/16/92	8/30/92
170	5.1	1.1	-.-	112	4.6	2.9	-.-
130	5.7	2.5	-.-	82	4.9	2.4	1.4
153	3.0	1.8	-.-	106	4.8	4.0	1.4
155	5.3	-.-	1.5	83	5.2	-.-	0.8
171	5.4	-.-	1.3				
154	5.7	-.-	1.2				

Table C-18 presents a summary of the standard deviation of the readings for each type of RRPM by site and date of study. The data tend to show more variability of the RRPMs when new than after they have been in the field. However, it must be remembered that the SI values for new RRPMs are also generally higher as well, which may partially explain the greater variability. This is further supported by the fact that those RRPMs having higher SI values overall (i.e., Ray-O-Lite, Stimsonite) also tend to have higher standard deviations. In situations such as this, it is sometimes useful to examine the coefficient of variation, which is the standard deviation of the sample divided by its arithmetic mean (6). These are provided in Table C-19. Unlike the standard deviations, the coefficient of variation does not tend to decrease in subsequent studies, and in fact increases for many of the RRPMs tested. In addition, the coefficients are relatively similar across all types of RRPMs, supporting the hypothesis that the variability between markers is to some degree dependent upon the level of reflectivity they provide.

TABLE C-18. STANDARD DEVIATION OF FIELD READINGS

	Site 1			Site 2		
RRPM	8/3/92	8/16/92	8/30/92	8/4/92	8/16/92	8/30/92
Apex 921	1.4	0.8	0.2	2.1	0.2	1.2
Apex 918	1.6	0.5	0.2	0.3	0.5	0.2
Apex 928	0.8	0.1	0.1	0.9	0.3	0.4
Apex 807	0.5	0.1	0.2	0.3	0.4	0.3
Apex 817	0.6	0.2	0.2	0.5	0.2	0.4
Batterson	0.5	0.2	0.1	0.3	0.1	0.1
Empco 901	0.7	0.1	0.1	0.7	0.1	0.2
Ray-O-Lite 8704 (S)	0.6	0.4	0.2	0.6	0.9	0.2
Ray-O-Lite 8704 (R)	0.9	0.1	0.2			
Ray-O-Lite 9704	1.5	0.8	0.4	1.6	0.8	1.1
Ray-O-Lite 2002	1.4	0.7	0.2	0.7	1.0	0.3
Ray-O-Lite 2003	1.6	3.4	0.6	0.6	1.6	0.4
Stimsonite 88	2.0	0.6	0.7	2.0	1.0	0.6
Stimsonite 911	3.3	1.7	0.3	2.3	2.0	2.3
Stimsonite 948	2.1	1.0	1.0	0.5	2.7	1.8
Stimsonite 953	0.9	1.4	0.2	1.0	1.2	1.6
Swareflex	1.0	0.7	0.2	0.3	0.8	0.3

TABLE C-19. COEFFICIENT OF VARIATION OF FIELD READINGS

	Site 1			Site 2		
Marker	8/3/92	8/16/92	8/30/92	8/4/92	8/16/92	8/30/92
Apex 921	0.27	0.92	0.15	0.56	0.16	0.82
Apex 918	0.43	0.48	0.17	0.08	0.29	0.19
Apex 928	0.24	0.07	0.10	0.24	0.12	0.32
Apex 807	0.40	0.19	0.46	0.32	0.57	0.75
Apex 817	0.38	0.30	0.33	0.24	0.25	1.00
Batterson	0.10	0.35	0.33	0.06	0.07	0.23
Empco 901	0.38	0.18	0.23	0.30	0.10	0.40
Ray-O-Lite 8704 (S)	0.08	0.17	0.11	0.08	0.30	0.11
Ray-O-Lite 8704 (R)	0.17	0.08	0.19			
Ray-O-Lite 9704	0.17	0.32	0.20	0.17	0.16	0.41
Ray-O-Lite 2002	0.14	0.17	0.05	0.09	0.20	0.08
Ray-O-Lite 2003	0.25	0.89	0.20	0.07	0.45	0.11
Stimsonite 88	0.26	0.22	0.33	0.25	0.27	0.30
Stimsonite 911	0.39	0.36	0.06	0.33	0.26	0.36
Stimsonite 948	0.24	0.29	0.22	0.06	0.53	0.32
Stimsonite 953	0.12	0.33	0.04	0.15	0.20	0.31
Swareflex	0.20	0.39	0.15	0.06	0.26	0.25