RETENTION STUDY OF PACIFIC GAS AND ELECTRIC COMPANY'S 1996 RESIDENTIAL APPLIANCE EFFICIENCY INCENTIVES PROGRAM

1996 Lighting Third Year Retention: Study ID 372R1

April 2000

Measurement and Evaluation
Customer Energy Efficiency Policy & Evaluation Section
Pacific Gas and Electric Company
San Francisco, California

Disclaimer of Warranties and Limitation of Liabilities

As part of its Customer Energy Efficiency Programs, Pacific Gas and Electric Company (PG&E) has engaged consultants to conduct a series of studies designed to increase the certainty of and confidence in the energy savings delivered by the programs. This report describes one of those studies. It represents the findings and views of the consultant employed to conduct the study and not of PG&E itself.

Furthermore, the results of the study may be applicable only to the unique geographic, meteorological, cultural, and social circumstances existing within PG&E's service area during the time frame of the study. PG&E and its employees expressly disclaim any responsibility or liability for any use of the report or any information, method, process, results or similar item contained in the report for any circumstances other than the unique circumstances existing in PG&E's service area and any other circumstances described within the parameters of the study.

All inquiries should be directed to:

Janice Frazier-Hampton
Revenue Requirements
Pacific Gas and Electric Company
P. O. Box 770000, Mail Code B9A
San Francisco, CA 94177

Retention Study of Pacific Gas and Electric Company's 1996 Residential Appliance Efficiency Incentives Program

1996 Residential Lighting Third Year Retention: Study ID 372R1

Purpose of Study

This study was conducted in compliance with the requirements specified in "Protocols and Procedures for the Verification of Costs, Benefits, and Shareholders Earnings from Demand-Side Management Programs," as adopted by California Public Utilities Commission Decision 93-05-063, revised June 1999, pursuant to Decisions 94-05-063, 94-10-059, 94-12-021, 95-12-054, 96-12-079, 98-03-063, and 99-06-052.

This study measures the Effective Useful Life (EUL) of lighting measures for which rebates were paid through Pacific Gas and Electric Company's (PG&E) 1996 Residential Appliance Efficiency Incentives Programs. The EUL is the estimated time at which half the units installed through these programs will no longer be in place and operable. Although the Protocols specify that this study applies to program years 1996 and 1997, there was no 1997 program. Therefore, results are for 1996 only.

Methodology

The general method of study is to collect measure retention data from a sample of participants and fit a parametric survival function to those data. The survival function gives the probability of surviving to any positive time t. These parameters of the function are estimated from the retention data. Once the survival function parameters are estimated, median lifetime or EUL is determined as the time t^* such that the survival probability is equal to 50 percent.

For the lighting measures, which were rebated through PG&E's Multifamily Rebate Program, retention data were collected via onsite inspections for a sample of 59 participating premises.

Study Results

The results of this study are summarized in the table below. For the lighting measures, the *ex post* EUL estimates are not significantly different from the *ex ante* values. The *ex ante* EULs for these measures are therefore not to be revised. In summary, none of the *ex ante* EULs are to be revised based on the study findings.

1996 Residential Appliance Efficiency Incentives Program
Summary of *ex post* Effective Useful Life Estimates

Program Year	Studied Measure Description (Measure Group)	End Use	EUL						p-Value for *ex post* EUL	EUL Realization Rate (*ex post* / *ex ante*)
			ex ante	*ex post* from Study	To Be Used in Claim	*ex post* Standard Error	80% Confidence Interval Lower Bound	80% Confidence Interval Upper Bound		
1996	CFL	Lighting	10	36.5	10.0	123.1	0.0	194.3	0.83	1
(3rd year	HID	Lighting	16	37.1	16.0	149.3	0.0	228.5	0.89	1
retention)	T-8	Lighting	15	36.9	15.0	78.5	0.0	137.5	0.78	1

Regulatory Waivers and Filing Variances

This study is conducted according to the terms of PG&E’s requested retroactive waiver for a modification to third and fourth earnings claim calculation methodology, approved February 17, 1999.

RETENTION STUDY OF PACIFIC GAS AND ELECTRIC COMPANY'S 1996 RESIDENTIAL APPLIANCE EFFICIENCY INCENTIVES PROGRAM

FINAL REPORT

1996 RESIDENTIAL LIGHTING THIRD YEAR RETENTION
PG&E STUDY ID: 372R1

Prepared for

Pacific Gas and Electric Company
San Francisco, California

Prepared by

XENERGY Consulting Inc.
Oakland, California
Madison, Wisconsin

April 2000

LIST OF TABLES

E EXECUTIVE SUMMARY

E.1 BACKGROUND

This report provides results of the third-year retention study of Pacific Gas and Electric Company's (PG&E's) 1996 Residential Appliance Efficiency Incentives Program, as required by the Measurement and Evaluation Protocols of the California DSM Measurement Advisory Committee (CADMAC). The results of the analysis will be used in the third earnings claims filed for the 1996 program year.

As given in the Protocols, the goal of the measure retention study is to determine "the length of time the measure(s) installed during the program year are maintained in operable condition." As agreed within the CADMAC Persistence Subcommittee, this question is addressed by estimating each measure's Effective Useful Life (EUL). The EUL is defined as the median survival time; that is, as the time until half the units are no longer in place and operable.

Each measure has an *ex ante* estimate of the EUL, which has been used in the first and second earnings claims. If the *ex post* EUL determined by the retention study for a particular measure is statistically significantly different from the *ex ante* EUL at the 20 percent significance (80 percent confidence) level, the *ex post* EUL will be used for future earnings claims. If there is no statistically significant difference, the *ex ante* EUL will be retained. Whether or not the EUL is revised as a result of this study, the EUL may be revised in the future based on subsequent retention studies required by the Protocols.

E.2 STUDY METHODS

E.2.1 Survival Analysis

The General Survival Function

The general method of study for each measure is to collect measure retention data from a sample of participants, and fit a parametric survival function to those data. The survival function is a function that gives the probability a unit will survive to any positive time *t*. The parameters of the survival function are estimated from the retention data. Once the survival function parameters are estimated, the median lifetime, or EUL, is determined as the time *t** when the survival probability is 50 percent. This is the estimated time when half the units will be gone.

Interpretation of Survival Model Results

Estimating a survival function and the corresponding median lifetime from retention data requires an assumed functional form. At this point in the life of the measures addressed in this study, the failure rates are generally low. As a result, there is little solid empirical basis for choosing among possible forms. In some cases, it may be possible to match the empirical data reasonably well over the limited domain of the analysis (three to four years since program participation). However, in most cases the resulting estimated median lifetime will be substantially greater than this elapsed lifetime. That is, the EUL estimate entails extrapolating the data far beyond their original range. Such extrapolation is precarious in any modeling exercise. The exception would be if there were a very strong basis for knowing that the model form had been appropriately specified and that its parameters are consistent across the range from the data to the point of extrapolation.

In the present study, there is no such *a priori* basis for specifying the form. Consequently, in cases where the estimated EULs are substantially greater than the four years of observed lifetimes, these estimates should be regarded as indicative, not definitive. This issue is discussed further in Section 2.

Data Required for the Survival Analysis

The retention data required for the survival analysis are data that indicate for each rebated unit at each sampled participant whether the unit was still in place and operable at the time of the survey. A unit not in place and operable is classified as a “failure” for purposes of this analysis. The unit may not have failed physically, but in terms of the program savings objectives, has failed. Wherever possible, the retention data for failed units also include the date when the failure occurred.

E.3 SUMMARY OF RESULTS

The results of this study are summarized in Table E-1. The table shows the estimates for the only functional form of the model for which results were obtained. For all lighting measures, that distributional form was exponential.

For all lighting measures, the EUL estimated is not significantly different from the *ex ante* EUL at the 80 percent confidence level. Moreover, these estimates are based on the Exponential hazard function. This was the only model form to converge, but is not conceptually the most appropriate form. At this time, we have insufficient failures either to determine the appropriate model form empirically or to estimate the EUL accurately. Thus, retaining the *ex ante* EULs is recommended for all three lighting measures.

Table E-1
Summary of EUL Findings
(years)

Program Year	Studied Measure Description (Measure Group	End Use	EUL *ex ante*	EUL *ex pos* from Study	EUL To Be Used in Claim	EUL *ex pos* Standard Error	EUL 80% Confidence Interval Lower Bound	EUL 80% Confidence Interval Upper Bound	p-Value for *ex pos* EUL	EUL Realization Rate (*ex pos* / *ex ante*)
1996	CFL	Lighting	10	36.5	10.0	123.1	0.0	194.3	0.83	1
(3rd year	HID	Lighting	16	37.1	16.0	149.3	0.0	228.5	0.89	1
retention)	T-8	Lighting	15	36.9	15.0	78.5	0.0	137.5	0.78	1

1 INTRODUCTION

1.1 BACKGROUND

This report provides the results of the third-year retention study of Pacific Gas and Electric Company's (PG&E's) 1996 Residential Appliance Efficiency Incentives Program, as required by the Measurement and Evaluation Protocols of the California DSM Measurement Advisory Committee (CADMAC)[1].

1.1.1 Protocol Requirements

The Protocols require that retention studies be performed in the third and sixth years for lighting. Although the CADMAC Persistence Subcommittee has directed that the 1996 and 1997 program year retention studies be combined into a single analysis, there was no 1997 program. Therefore, results are for 1996 only.

Estimating Effective Useful Life (EUL)

PG&E calculates net resource benefits for the PY 96 Residential Lighting Program according to the following formula:

$$\textit{Net Resource Benefit} = (\textit{First Year Impact}) \times (\textit{Program Level EUL}) \times (\textit{Program Level TDF})$$

In this equation, EUL represents the retention side of the overall persistence question of how long do energy savings last. TDF represents operational effectiveness or Technical Degradation Factor.

EUL is defined as the median survival time; that is, as the time until half the units are no longer in place and operable. Estimating the EUL is the primary purpose of this report.

Each measure has an *ex ante* estimate of the EUL, which has been used in the first and second earnings claims. If the *ex post* EUL determined by the retention study for a particular measure is statistically significantly different from the *ex ante* EUL at the 20 percent significance (80 percent confidence) level, the *ex post* EUL will be used for future earnings claims. If there is no statistically significant difference, the *ex ante* EUL will be retained. Whether or not the EUL is revised as a result of this study, the EUL may be revised in the future based on subsequent retention studies required by the Protocols.

---

[1] California Public Utilities Commission, *Protocols and Procedures for the Verification of Costs, Benefits, and Shareholder Earnings from Demand-Side Management Programs*, Decision 93-05-063. Revised June 1999, pursuant to Decisions 94-05-063, 94-10-059, 94-12-021, 95-12-054, 96-12-079, 98-03-063, and 99-06-052.

1.2 Study Methods

1.2.1 Survival Analysis

The General Survival Function

The general method of study for each measure is to collect measure retention data from a sample of participants, and fit a parametric survival function to those data. The survival function is a function $S(t;\theta)$ that gives the probability S of surviving to any positive time t, given the parameters θ. These parameters are estimated from the retention data. Once the survival function parameters are estimated, median lifetime or EUL is determined as the time t^* such that the survival probability $S(t^*;\theta) = 0.5$.

The estimation and application of the survival function requires specification of the function's parametric form. This form is typically specified in terms of the *hazard function* $h(t;\theta)$. Roughly, the hazard function can be thought of as the instantaneous probability of failing at time t, given that a unit has survived up to that time.

The survival probability $S(t;\theta)$ is one minus the probability $F(t;\theta)$ that a unit will die by time t. Formally, the hazard function is the ratio of the probability density function of the distribution $F(t;\theta)$ to the survival probability $S(t;\theta)$:

$$h(t;\theta) = (dF/dt)/S(t;\theta).$$

Choices of Parametric Forms for the Survival Function

Several parametric forms are in common use as hazard functions. Those explored in this study include the following:

- Gamma
- Weibull
- Exponential
- Log-normal
- Log-logistic.

The Gamma function is the most general of these, and includes the Weibull, Exponential, and Log-normal as special cases. In essence, the Gamma function allows certain parameters to be determined by data that are constrained by each of the other specifications. As a result, the Gamma function will be able to follow the empirical data most closely. If one of the other forms is a good description of the data, its results will be similar to those of the less constrained Gamma fit. If the other form is not a good match to the data, its results will be at odds with those of the Gamma fit. This "goodness-of-fit" can be formally tested by the log-likelihood test.

Similarly, the Weibull also includes the Exponential as a special case. The goodness-of-fit for the exponential form can be tested against the Weibull results, again using the log-likelihood test.

The Log-normal and Log-logistic forms have decreasing hazard functions after an initial peak. That is, failure rates decline over time. This form may be a reasonable fit over a portion of time for certain types of equipment or processes. However, declining failure rates are unlikely to be an accurate representation of the failure pattern several years out.

The Exponential form represents a constant hazard function. That is, the chance that a unit will fail in the next time increment, given that it has already survived to the current time, is the same no matter what the current time. This form is often used in survival analysis.

The Weibull form has an increasing hazard function. That is, the failure rate increases as equipment ages. In many respects, this basic assumption is the most reasonable of all the distributions explored.

As noted, the Gamma form is the most general. Depending on the empirical data and the resulting parameters estimated, this form may produce an increasing, decreasing, or essentially constant hazard function.

Interpretation of Survival Model Results

At this point in the life of the measures addressed in this study, the failure rates are generally low. As a result, there is little solid empirical basis for choosing among possible forms of the hazard function. In some cases, it may be possible to match the empirical data reasonably well over the limited domain of the analysis (three to four years since program participation). However, in most cases the resulting estimated median lifetime will be substantially greater than this elapsed lifetime. That is, the EUL estimate entails extrapolating the data far beyond their original range. Such extrapolation is precarious in any modeling exercise. The exception would be if there were a very strong basis for knowing that the model form had been appropriately specified and that its parameters are consistent across the range from the data to the point of extrapolation.

In the present study, there is no such *a priori* basis for specifying the form, and no basis for assuming that the patterns evident so far are retained over extended periods. Consequently, in cases where the estimated EULs are substantially greater than the four years of observed lifetimes, these estimates should be regarded as indicative, not definitive. This issue is discussed further in the context of the results presented in Section 2.

Data Required for the Survival Analysis

The retention data required for the survival analysis are data that indicate for each rebated unit at each participant premise whether the unit was still in place and operable at the time of the survey. A unit not in place and operable is classified as a "failure" for purposes of this analysis. The unit may not have failed physically, but in terms of program savings objectives has failed. Wherever possible, the retention data for failed units also include the date when the failure occurred.

In many cases, the failure is reported but the date when the failure occurred is not known. In this case, the observation is said to be left-censored. That is, the unit is known to have failed by a particular date, but the date of its failure is not known. In other cases, indeed the majority in this study, the unit had still not failed at the time the retention data were collected. In this case, the observation is said to be right-censored. The unit will fail at some future, as yet unknown time. The model forms used in this analysis accept both left- and right-censored data.

1.3 Summary of Results

The results of this study are summarized in Table 1-1. The table shows the estimates for the only distribution for which results were obtained, the exponential distribution. Conceptually, as discussed above, the Weibull distribution would appear to be the most appropriate. However, this distribution failed to converge for the lighting measures studied.

For all lighting measures, the EUL estimated with the Exponential form is not significantly different from the *ex ante* EUL at the 80 percent confidence level. The p-values for a test of whether the *ex post* EUL is significantly different from the *ex ante* EUL are all 0.78 or greater. Rejection of the *ex ante* EUL would require a p-value of 0.20 or less. Thus, retaining the *ex ante* EULs is recommended for all three lighting measures.

Even if the p-values were less extreme, we would not recommend revision of the EUL based on the results of the Exponential model fit. As noted, this was the only model form to converge, but conceptually, the model does not fit the pattern of failures we would expect over the life of the measures. Thus, at this time, we have insufficient failures either to determine the appropriate model form empirically or to estimate the EUL accurately.

Table 1-1
Summary of EUL Findings
(years)

Program Year	Studied Measure Description (Measure Group	End Use	EUL: *ex ante*	EUL: *ex pos* from Study	EUL: To Be Used in Claim	EUL: *ex pos* Standard Error	EUL: 80% Confidence Interval Lower Bound	EUL: 80% Confidence Interval Upper Bound	p-Value for *ex pos* EUL	EUL Realization Rate (*ex pos* / *ex ante*)
1996	CFL	Lighting	10	36.5	10.0	123.1	0.0	194.3	0.83	1
(3rd year	HID	Lighting	16	37.1	16.0	149.3	0.0	228.5	0.89	1
retention)	T-8	Lighting	15	36.9	15.0	78.5	0.0	137.5	0.78	1

1.4 Report Organization

Details on the retention studies for lighting are presented in Section 2. Survey instruments are included in Appendix A. Tables meeting the requirements of Table 6B of the CADMAC Protocols are given in Appendix B. The documentation required by Table 7B of the Protocols is given in Appendix C.

2 DATA AND ANALYSIS

2.1 INTRODUCTION

This section presents the retention analysis of lighting measures for the program years studied. In the RAEI lighting end-use, rebates were provided for CFLs, HIDs, T-8s, and “other.” The other category consisted of exit signs and lighting controls. Table 2-1 shows that CFLs, HIDs, and T-8s combined account for 87 percent of the total kWh impacts in the RAEI lighting tracking system for the 1996 program year.

Table 2-1
RAEI Lighting Measures Included in This Study

Measure Group	Total Percent of Resource Value Covered	*ex ante* EUL (years)
CFL	33	10
HID	6	15
T-8	49	16
TOTAL	87	

2.2 METHODS

2.2.1 Overview

As described in Section 1, the effective useful life of lighting measures was estimated by fitting a set of survival functions to retention data for a sample of customers. The retention data for this program were collected via on-site inspections. The data sources and data collection are described below. The estimation procedures specific to this program are then described.

2.2.2 Data Sources

Data sources used in this study include

- On-site data collected for this study
- Program tracking data.

On-Site Inspection Data

The on-site inspection data constitute the primary data collected for the study. For each sampled site, the inspector determined the number of units currently in place and operable for each of the technology types rebated at that site. Wherever possible, the reason for any shortfall from the rebated number was obtained from a customer respondent. Also obtained, if possible, was the number of years since any missing equipment was removed or failed. A copy of the survey instrument is provided in Appendix A.

Program Tracking Data

Program tracking data were used in several ways. First, they were used to identify the target customers for the study, the numbers of measures rebated, and the associated savings. Tracking data were then used to provide contact information used to recruit sites for the study. For those sites visited, the number of rebated units of each technology type were provided to the inspectors from the program tracking data.

Data Collection

Sample Design

On-site data were collected in December 1999. As part of the evaluation of first-year impacts for the lighting program (completed in February 1998), a census of sites was targeted for on-site surveys. Ultimately, 71 sites were surveyed for that evaluation. This group of 71 sites became the sample frame for this retention project. The reasons sites were excluded from the impact analysis (inability to identify or locate the customer and customer refusals) indicated that it would not be fruitful to attempt to reincorporate these sites into the sample frame for this retention study. Table 2-2 compares the program year 1996 population to the sample frame.

Table 2-2
Comparison of Population and Sample Frame

	Population			Sample Frame[1]			
Measure Type	**Sites[2]**	**Units**	**kWh**	**Sites[2]**	**% of Pop**	**Units**	**kWh**
CFL	53	2,050	463,980	40	75%	1,264	285,800
HID	17	294	81,192	17	100%	294	81,192
T-8	36	3,498	691,025	28	78%	1,516	287,530
Other	16	663	187,141	10	63%	150	39,419
Total Lighting	**87**	**6,505**	**1,423,338**	**71**	**82%**	**3,224**	**693,941**

[1] Sample frame is the set of sites with completed surveys for the first year impact study of the lighting program.

[2] Sites do not sum to total due to overlap of measures at some sites.

Because of the limited number of sites in the sample frame, a census of sites was attempted.

Sample Disposition

The disposition of the sample contacted and successfully recruited is shown in Table 2-3. Those premises categorized as "not in the retention panel" either could not be contacted or refused to participate in the first year impact study. As shown, on-site visits were completed for 83 percent of the premises attempted. The "unable to contact" category includes three sites where multiple messages were not returned, two sites where the phone number was not current, and one site where no one ever answered the phone.

Table 2-3
Sample Disposition

Reason	Total Frequency	Percent of Population	Percent of Sample Attempted
Population	87	100%	
Not in retention panel	16	18%	
Total attempted for retention stud	71	82%	100%
Wrong premise type	1	1%	1%
Change of ownership	4	5%	6%
Unable to contact	6	7%	8%
Refused	1	1%	1%
Completed survey	**59**	**68%**	**83%**

2.2.3 Estimation

The primary objective of the analysis is the estimation of the EUL or median survival time by fitting a survival function to the collected retention data. The general methodology is described in Section 1. Details specific to multifamily lighting are provided below.

Survival Modeling

The lighting measures studied were rebated under PG&E's 1996 Multifamily Rebate Program. For multifamily properties, it is often difficult to find a respondent knowledgeable about specific equipment. This means that removal dates were not determined with any accuracy. Therefore, all removed units were considered to be left-censored. That is, it was determined whether the unit was still in place and operable at the time of the visit, but the failure time of units that had failed was not known.

A standard survival analysis was conducted on the censored data. This analysis estimated the time when 50 percent of all equipment will fail, with failure defined as final breakdown or disposal or removal from the PG&E service territory.

2.3 RESULTS

2.3.1 Data Attrition

For the 59 sites that were included in the survey, a total of 2, 842 lighting measure units were counted. These units included all observed fixtures that matched the measure descriptions included in the PG&E tracking system for that site. Some data collected for these 59 sites were excluded from the analysis. Two reasons why these data were excluded are:

1. **Types Not for Retention Analysis.** Rebates were provided for various technology types including several not included in the retention study, such as exit sign kits. If rebated equipment of these additional types was found at the premise, the surveyor noted the number observed. Because survival analysis was only to be performed on CFL, HID, and T-8 lamps, these technology type-premise combinations were excluded from the analysis.
2. **Units Not in Tracking System.** Survival analysis was only to be performed on CFL, HID, and T-8 lamps purchased with assistance from PG&E. While at a premise, the surveyor noted the total number of these lamp types observed. If this total was greater than the tracking system number, the additional lamps were not considered in the analysis.

Table 2-4 shows the number of technology type-premise combinations, number of units we excluded from the analysis, and the reason why each was excluded. All sites were used in the analysis.

Table 2-4
Data Attrition

	Technolog Type-Premise	Units
Total With Data Collected	80	2,842
Types Not for Retention Analysis	10	125
Units Not in Tracking Syste	0	102
Total Targeted for Sampled Premises	**70**	**2,615**

Table 2-5 shows the numbers included in the analysis by technology group as compared to the population and sample frame.

Table 2-5
Data Included in Analysis by Technology Group

Measure Type	Population		Sample Frame[1]		Analysis Data	
	Sites[2]	Units	Sites[2]	Units	Sites[2]	Units
CFL	53	2,050	40	1,264	31	961
HID	17	294	17	294	14	271
T-8	36	3,498	28	1,516	25	1,383
Other	16	663	10	150	0	0
Total	87	6,505	71	3,224	59	2,615

[1] Sample frame is the set of sites with completed surveys for the first year impact study of the lighting program.
[2] Sites do not sum to total due to overlap of measures at some sites.

2.3.2 Units Still in Place

Table 2-6 shows the status at the time of inspection of the rebated lamps used in the analysis. All measures had approximately a 7 percent failure rate at the time of the on-site inspections.

Table 2-6
Status of Rebated Lamps

Measure Type	Still in Place	Number Removed	Percent in Place
CFL	892	69	92.8%
HID	252	19	93.0%
T-8	1,284	99	92.8%
Total	**2,428**	**187**	**92.8%**

2.3.3 Standard Error Calculation

A critical part of the model estimation is the calculation of the standard error of the estimated EUL. This standard error determines the confidence bounds for the estimate. On this basis, the *ex ante* EUL may be rejected and replaced by the new *ex post* estimate.

Within- and Between-Site Variance

The standard error provided by SAS treats each fixture observation as independent. They do not recognize that failures may be more similar within the same site than they are across sites. In XENERGY's previous retention report for this program, the standard errors were adjusted as if variation across sites were the only source of variation in failures. Specifically, the reported standard errors reported by SAS were multiplied by a factor of

$$a = \sqrt{\left(n_{fixture} / n_{site}\right)}.$$

Where n_{sites} and $n_{fixtures}$, respectively, denote the number of sites inspected and total number of fixtures originally installed at these sites under the 1996 program.

The correct treatment of the standard error lies somewhere between leaving it unadjusted and the adjustment indicated above. That is, some of the variation in failures is associated with site-specific conditions, and some is independent of the site. The appropriate adjustment factor is given by the square root of the *design effect* d. The design effect indicates the relative contributions of within-site and between-site variance to the total variance of individual observations. This effect can be calculated as

$$deff = 1 + roh\left(\bar{n} - 1\right)$$

where

$$\bar{n} = n_{fixture} / n_{site}$$

is the mean number of fixtures installed per site for the inspected sites, and *roh* is the "rate of homogeneity," also known as the intra-cluster correlation (Kish, 1965). In our study, each site is a cluster.

The maximum possible value of *roh* is +1. This value corresponds to zero variance within a cluster or site. The adjustment factor *a* used in the previous retention study for this program corresponds to *roh* = 1.

If there is no between-cluster variation, the intra-cluster correlation *roh* = 0. In this case, the design effect *d* = 1, and the errors reported from SAS are correct without adjustment. Observations within the same site are no more closely related than observations across different sites.

In the context of this study, some factors that contribute to failures will tend to be more similar within a cluster than between clusters. Removals because of dissatisfaction or renovations will tend to happen in large groups within a site, if not for the entire site. Equipment installation and operating conditions that may contribute to shorter or longer life will also tend to be similar within a site. Batches of equipment delivered to a site may tend to be bad, and fail physically at higher than normal rates. Thus, the intra-cluster correlation *roh* is greater than zero.

On the other hand, there clearly are variations within sites in all of the failure modes. Removals can happen for portions of space rather than an entire space. Operating conditions or product quality may result in higher or lower physical failure rates, but do not cause all units to fail at the same age. Thus, the intra-cluster correlation *roh* is less than 1.

In their study of PG&E's 1994 and 1995 Commercial Energy Incentives programs, Quantum Consulting used the design effect adjustment factor with an assumed value of *roh* = 0.5. Certainly the choice of a value of *roh* somewhere between 0 and 1 is justified. We conducted additional analyses to estimate a plausible value of *roh* for this program.

Estimating Roh

The rate of homogeneity or intra-cluster correlation can be calculated as

$$roh = \left[s_b^2 - s_w^2 \big/ (\bar{n} - 1) \right] \big/ s_o^2$$

where

s_b^2 = between-cluster variance
s_w^2 = within-cluster variance
s_o^2 = overall variance.

Because only a small fraction of measures have failed so far, we have no direct basis for calculating the within- and between-cluster variances of time to failure itself. However, we can calculate these variance components for the proportion of failures over the time period of the study. The design effect should be roughly the same for failure rates as for times to failure.

We therefore calculated the within- and between-cluster variances of the proportion p of failures. First, we calculated the observed proportion of failures p_j for each visited site j. The variance across sites of this estimated proportion is the between-cluster variance s_b^2. For each site, the per-unit variance of the observed proportion itself is estimated by the standard formula for the variance of a single 0/1 observation with probability p. That is,

$$s_j^2 = p_j \left(1 - p_j\right).$$

Averaging the within-site variances s_j^2 over the visited sites gave the within-cluster variance s_w^2. Finally, the overall unit variance is calculated from the observed overall failure rate p_o in the same way as the within-site variances are calculated:

$$s_o^2 = p_o \left(1 - p_o\right),$$

where p_o is the overall ratio of total fixtures missing to total installed across all visited sites.

Results of the calculation are summarized in Table 2-7 for the measure that had the most observations, compact fluorescent lights. For 22 of the 31 sites visited, there were zero failures ($p_j = 0.00$). For two sites the failure rate was 100 percent ($p_j = 1.00$). The overall failure rate p_o was 7.2 percent. Thus, 24 out of 31 sites either had all units failed or none. This observation suggests a high clustering effect, indicating a value of *roh* close to 1. Confirming this qualitative assessment, the value of *roh* calculated from the within- and between-site variances was

$$
\begin{aligned}
roh &= \left[s_b^2 - s_w^2 \big/ \left(\bar{n} - 1\right)\right] \big/ s_o^2 \\
&= \left[0.066 - 0.032 \big/ \left(\left(961/31\right) - 1\right)\right] \big/ 0.067 \\
&= 0.97 \quad .
\end{aligned}
$$

Table 2-7
Within- and Between-Cluster Variance Calculation

Number of Sites	Number Missing	Number Installed	Fraction Missing p_j	Fraction in Place $(1- p_j)$	Within Site Unit Variance s_j^2
22	0	695	0.000	1.000	0.000
1	1	15	0.067	0.933	0.062
1	2	2	1.000	0.000	0.000
1	2	39	0.051	0.949	0.049
1	3	30	0.100	0.900	0.090
1	3	29	0.103	0.897	0.093
1	3	3	1.000	0.000	0.000
1	7	20	0.350	0.650	0.228
1	17	56	0.304	0.696	0.211
1	31	72	0.431	0.569	0.245
Overall	$N_{missing}$	$N_{fixtures}$	p_o	$1- p_o$	s_o^2
31	**69**	**961**	**0.072**	**0.928**	**0.067**
Average Within Site s_w^2					**0.032**
Variance Between Sites s_b^2			**0.066**		

Calculations of *roh* and the corresponding design effect *deff* for the three technology types are summarized in Table 2-8.

Table 2-8
Intra-Cluster Correlation and Design Effects

Variances	CFL	HID	T-8
Between Sites, s_b^2	0.066	0.056	0.050
Within Site, s_w^2	0.032	0.046	0.039
Overall, s_o^2	0.067	0.065	0.066
roh	0.978	0.822	0.747
deff	31.326	16.905	1.747

Value of ROH *for the Analysis*

The calculation of the intra-cluster correlations *roh* and corresponding design effects *deff* are for estimation of proportions failed over the retention study period. The assumption that these parameters are roughly the same for the calculation of median failure time or EUL is a reasonable but rough approximation. For this reason, we do not rely on the exact values calculated for each technology. Instead, we take the range of values calculated across the three measure types as an indication of a plausible value of *roh* for all three.

Based on the above analysis, we assume an intra-cluster correlation of *roh* = 0.9 to calculate the design effect for all three technologies. Thus, the standard error of the EUL is calculated from the SAS standard error SE_{SAS} as

$$SE = \sqrt{\left(1+0.9\left(\overline{n}-1\right)\right)}\, SE_{SAS}\ .$$

As a sensitivity test, we also calculated standard errors and confidence intervals with assumed values of 0 (no adjustment, no variance due to site effects), 0.5 (within-site and between-site effects equal), and 1.0 (all variance due to site effects).

Degrees of Freedom

For purposes of calculating confidence levels, the degrees of freedom associated with the standard error estimate must also be known, since the *t*-value that multiplies the standard error depends on the degrees of freedom. We adjusted the sample size also by the design effect *deff*. That is, we calculate the effective sample size n_{eff} for the degrees of freedom on the *t*-statistic as

$$\begin{aligned} n_{eff} &= n_{fixtures} \big/ deff \\ &= n_{fixture} \big/ \left(1+roh\left(\overline{n}-1\right)\right) \end{aligned}$$

Thus, the degrees of freedom for the *t*-value used in calculating the confidence interval varied according to the assumed value of *roh.*

2.3.4 Survival Analysis Results

Table 2-9 presents the estimated median lifetime or EUL, and the corresponding standard error for the only form of the survival model to converge, the Exponential model. This table also shows how the various intra-site correlation factors affect the standard error. These correction factors take into account the effect of multiple lamps installed at any given site. Results for the intra-site correlation factor suggested by our analysis, *roh* = 0.9, are shown in bold.

Table 2-9
Estimated EULs and Standard Errors for Converging Hazard Functions
(years)

	CFL		HID		T-8	
***ex ante* EUL:**	**10**		**15**		**16**	
Intra-Site Correlation	**EUL**	**Standard Error**	**EUL**	**Standard Error**	**EUL**	**Standard Error**
0.0	36.5	4.40	37.1	8.52	36.9	3.70
0.5	36.5	70.35	37.1	86.73	36.9	45.27
0.9 *	**36.5**	**123.11**	**37.1**	**149.29**	**36.9**	**78.53**
1.0	36.5	136.30	37.1	164.94	36.9	86.84

* Value of intra-site correlation indicated by the analysis.

Table 2-10 shows the corresponding 80 percent confidence intervals. Also indicated in the table are the estimates that are statistically significantly different from the *ex ante* EUL at this confidence level. As shown, only for the uncorrected standard errors are the *ex ante* EULs outside the confidence interval. Our analysis suggests that the 0.9 intra-cluster correlation factor, with results indicated in bold, is more appropriate. Even with the 0.5 factor we find the *ex ante* EUL inside the confidence interval.

Table 2-10
Estimated EULs and Confidence Intervals for Various Hazard Functions
(years)

	CFL		HID		T-8	
***ex ante* EUL:**	**10**		**15**		**16**	
Intra-Site Correlation	**EUL**	**80% Confidence Interval**	**EUL**	**80% Confidence Interval**	**EUL**	**80% Confidence Interval**
0	36.5	(32.5, 42.2)*	37.1	(26.2, 48.1)*	36.9	(32.1, 41.6)*
0.5	36.5	(0.0, 126.7)	37.1	(0.0, 148.3)	36.9	(0.0, 94.9)
0.9 **	**36.5**	**(0.0, 194.3)**	**37.1**	**(0.0, 228.5)**	**36.9**	**(0.0, 137.5)**
1	36.5	(0.0, 211.2)	37.1	(0.0, 248.6)	36.9	(0.0, 148.2)
EUL for Claim	**10**		**15**		**16**	

* 80 percent confidence interval does not include the *ex ante* estimate. Formally, the *ex ante* EUL would be rejected if this value of the intra-site correlation *roh* were assumed to be correct. The *ex ante* EUL is not rejected based on these results because this value of the intra-site correlation is both implausible on theoretical grounds and inconsistent with the empirical analysis.

**Value of intra-site correlation indicated by the analysis.

Interpretation of the Results

With the Gamma hazard function, the survival model did not converge for any of the three technology types. Failure to converge means that there is not enough information in the available data to determine the parameters of this most general form. As noted in Section 1, the Weibull form is conceptually the most appropriate, as it allows an increasing hazard function—that is, a failure rate increasing with age. This form also did not converge for any of the measure groups. The Log-normal and Log-logistic forms also did not converge for any of the measure types.

The Exponential form, with its assumption of a constant hazard function, is a questionable model, but it was the only one that converged for any of the measure groups. In most cases, the constant hazard function would be expected to give longer EULs than a form that allows for an increasing hazard. For all corrections to the standard error for this model, the *ex ante* EUL fell within the 80 percent confidence interval. Only the uncorrected standard error created a confidence interval where the *ex ante* EUL fell outside the 80 percent confidence interval.

Because only the Exponential model converged, and this model does not fit the failure pattern we would expect over the life of the measures, revision of the *ex ante* EULs based on the retention study results is not recommended. With any plausible value of the intra-cluster correlation, the *ex ante* EUL falls within the 80 percent confidence interval for the *ex post* estimate for all measures. Moreover, all these estimates are based on the Exponential hazard function. This was the only model form to converge, but is not conceptually the most appropriate form. At this time, we have insufficient failures either to determine the appropriate model form or to estimate the EUL accurately. Table 2-10 above indicates that all *ex ante* EULs are retained at this time.

2.4 REFERENCES

Kish, Leslie. 1965. *Survey Sampling*. John Wiley & Sons, Inc., New York. 643 p.

Quantum Consulting Inc. 1999. “Lessons Learned in Retention Analysis: Recipes for Success.” Pages 719–734 *in Proceedings of the Ninth International Evaluation Conference, Evaluation in Transition: Working in a Competitive Energy Industry Environment*, August 18–20, 1999, Denver, Colorado.

XENERGY Consulting Inc. 1999. *1994 Residential Refrigeration Fourth Year Retention. PG&E Study ID 384aR1*. Madison, Wisconsin.

A

ON-SITE DATA COLLECTION INSTRUMENT

A.1 MULTIFAMILY LIGHTING ON-SITE RETENTION STUDY

[This page intentionally left blank.]

PG&E Residential Appliance Efficiency Incentive Lighting Program
Multifamily Measure Retention Study

PG&E Account Number	*Name of Owner / Checkname*	***Tracking #***
XXX9999999	**JOHN DOE PROPERTIES**	**9999999**
Name of Contact Person	*Contact Phone*	*Segment*
JOHN DOE	**(999) 999-9999**	**1-96-CEN**

Name of Complex/Customer:	**JOHN DOE PROPERTIES**	*PG&E Division:*	**XXX**
Address:	**9999 ANYSTREET**	*PG&E Local Office:*	**Anycity**
City/State/Zip:	**ANYCITY, CA 99999**	*Billing System Phone:*	**(999) 999-9999**

	Area Code	*Application Code*	*Check Date*	*Measure Code*	*Measure Description*	*Number Purchased*	*Number Expected*	*Number Observed*	*Control Code*	*Discrep Code*	*Removal Code*	*Yrs Since Removal*
1	7	XXX9999	9/9/99	L86	COMPACT FLUORESCENT: HARDWIRE FIXTURE, 5-13 WATTS (RES. LIGHTING)	13	**10**					
2	5	XXX9999	9/9/99	L101	FIXTURE: T-8 FIXTURE & BALLAST, 4 FT, 2-LAMP	15	**15**					
3	10	XXX9999	9/9/99	L89	HID FIXTURE: 0-70 WATTS	11	**11**					
4												
5												
6												

Notes:

Table 1-Area Codes

Code		Description
A	1	Hallway
	2	Storage/utility
	3	Office
	4	Recreation area
	5	Parking lot
	6	Laundry room
	7	Exterior walkway
	8	Exit
	9	Kitchen
	10	Other

Table 2-Control Codes

Code		Description
C	1	Manual switch
	2	Photosensor
	3	Occupancy sensor
	4	Timer

Table 3-Observed/Expected Discrepancy Codes

Code		Description
D	1	Removed, not replaced
	2	Removed, replaced with different (describe)
	3	Never installed, stockpiled
	4	Temporarily taken out of operation
	5	Could not locate
	6	Other (describe)

Table 4-Removal Codes

Code		Description
R	1	Equip failed, not replaced
	2	Remodeled/Equipment replaced
	3	Unable to locate equivalent replacement
	4	Change of use
	5	Other (describe)

B

TABLE 6B

B.1 1996 LIGHTING

[This page intentionally left blank.]

Protocol Table 6B
Results of Retention Study
PG&E 1996 Residential Sector
Study Name
Study ID 372R1

Item 1		Item 2		Item 3	Item 4	Item 5	Item 6		Item 7	Item 8
Studied Measure Description	End Use	*ex ante* EUL	Source of *ex ante* EUL (ref. Ftnote)	*ex post* EUL from Study	*ex post* EUL to be used in Claim	*ex post* EUL Standard Error	80 Conf. Interval Lower Bound	80 Conf. Interval Upper Bound	p-Value for *ex post* EUL	EUL Realizat'n Rate (*ex post* / *ex ante*)
CFL										
COMPACT FLUORESCENT: HARDWIRE FIXTURE, 5-13 WATTS (RES. LIGHTING)	LIGHTING	10	1	36.5	10.0	123.1	0.0	194.3	0.83	1.0
COMPACT FLUORESCENT: HARDWIRE FIXTURE, 14-26 WATTS (RES. LIGHTING)	"	10	1	36.5	10.0	123.1	0.0	194.3	0.83	1.0
COMPACT FLUORESCENT: HARDWIRE FIXTURE, 27-50 WATTS (RES. LIGHTING)	"	10	1	36.5	10.0	123.1	0.0	194.3	0.83	1.0
HID										
HID FIXTURE: 0-70 WATTS	LIGHTING	16	1	37.1	16.0	149.3	0.0	228.5	0.89	1.0
HID FIXTURE: >= 71 WATTS	"	16	1	37.1	16.0	149.3	0.0	228.5	0.89	1.0
T-8										
FIXTURE: REPLACE LAMP & BLST, 3 FT, T-8 & ELEC BLST	LIGHTING	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0
FIXTURE: REPLACE LAMP & BLST, 4 FT, T-8 & ELEC BLST	"	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0
FIXTURE: T-8 FIXTURE & BALLAST, 2 FT, 2-LAMP	"	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0
FIXTURE: T-8 FIXTURE & BALLAST, 2 FT, 4-LAMP	"	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0
FIXTURE: T-8 FIXTURE & BALLAST, 4 FT, 1-LAMP	"	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0
FIXTURE: T-8 FIXTURE & BALLAST, 4 FT, 2-LAMP	"	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0
FIXTURE: T-8 FIXTURE & BALLAST, 8 FT, 2-LAMP	"	15	1	36.9	15.0	78.5	0.0	137.5	0.78	1.0

ex ante Source References: 1 — PG&E Advice Letter 1867-G/1481-E. 1995 DSM Program Activity and Expected Earnings. As approved by the California Public Utilities Commission, May 8, 1995.

C

TABLE 7B

C.1 1996 LIGHTING

C.1.1 Overview Information

a. Study Title and Study ID Number

Study Title: 1996 Residential Lighting Third Year Retention Study,

Study ID No: PG&E Study ID 372R1: Multifamily Lighting.

b. Program Years and Program Description

Program year: 1996

This report presents the retention analysis of lighting measures rebated in 1996. CFL, HID, and T-8 lamps offered through the Multifamily Property Rebate Program account for 87 percent of the total resource value of the RAEI High Efficiency Lighting end-use in the 1996 program year.

c. End Uses and Measures Covered

Lighting:

Compact fluorescent bulbs
HID lamps
T-8 lamps and ballasts.

d. Methods and Models Used

EUL Estimation

Survival analysis was performed using data collected during on-site surveys. The survival analysis utilized the SAS procedure LIFEREG, and considered the following hazard distributions:

- Log-normal,
- Exponential,
- Log-logistic,
- Weibull, and
- Gamma.

Only the Exponential form of the model converged for all measures studied.

Standard Errors and Precision

Standard errors from SAS were adjusted for intra-site correlation of failures using a design effect calculation. The same design effect was used to adjust the degrees of freedom for *t*-statistics for calculating confidence intervals. Details are described under Section C.1.4.i.

e. Analysis Sample Size

Number of customers: 59 sites.
Number of measures: 2,615 units.

C.1.2 Database Management

a. Specific Data Sources

Tracking Data:

TRACK.SD2	SAS dataset - item (measure) level data

On-site survey data:

LIGHTS3.SD2	SAS dataset - retention data

b. Data Attrition

Table C-1 shows the data collected and used in the analysis, and the reasons for exclusion. Data were originally collected at 59 sites for a total of 80 technology type-premise combinations, and a total of 2,842 lighting measure units were counted. These units included all observed fixtures that matched the measure descriptions included in the PG&E tracking system for that site. Some data collected for these 59 sites were excluded from the analysis for two reasons:

1. **Types Not for Retention Analysis.** Rebates were provided for various technology types including several not included in the retention study, such as exit sign kits. If rebated equipment of these additional types was located at the premise, the surveyor noted the number observed. Because survival analysis was only to be performed on CFL, HID, and T-8 lamps, these technology type-premise combinations were excluded from the analysis.
2. **Units Not in Tracking System.** Survival analysis was only to be performed on CFL, HID, and T-8 lamps purchased with assistance from PG&E. While at a premise, the surveyor noted the total number of these lamp types observed. If this total was greater than the tracking system number, the additional lamps were not considered in the analysis.

Table C-1
Data Attrition

	Technolog Type-Premise	Units
Total With Data Collected	80	2,842
Types Not for Retention Analysis	10	125
Units Not in Tracking Syste	0	102
Total Targeted for Sampled Premises	**70**	**2,615**

Table C-2 shows the numbers included in the analysis by technology group as compared to the program population and sample frame.

Table C-2
Data Included in Analysis by Technology Group

Measure Type	Population		Sample Frame[1]		Analysis Data	
	Sites[2]	Units	Sites[2]	Units	Sites[2]	Units
CFL	53	2,050	40	1,264	31	961
HID	17	294	17	294	14	271
T-8	36	3,498	28	1,516	25	1,383
Other	16	663	10	150	0	0
Total	87	6,505	71	3,224	59	2,615

[1] Sample frame is the set of sites with completed surveys for the first year impact study of the lighting program.
[2] Sites do not sum to total due to overlap of measures at some sites.

c. Data Quality

The PG&E control application code number was used to link tracking data and survey data.

d. Data Collected Specifically for the Analysis but not Used

The years since removal were reported for some measures at some sites. Most respondents were not able to provide this information. Thus, these data were available for a limited number of sites only. Even these sites did not have dates specific enough to be used in the analysis. Thus, the removal date data collected were not used.

C.1.3 Sampling

a. Procedures and Protocols

On-site data were collected in December 1999. As part of the evaluation of first year impacts for the lighting program (completed in February 1998), a census of sites was targeted for on-site surveys. Ultimately, 71 sites were surveyed. This group of 71 sites became the sample frame for this retention project. Factors causing the exclusion of sites in the impact analysis (inability to identify or locate the customer and customer refusals) led to the decision not to attempt to reincorporate these sites into the sample frame for this retention study. The following table compares the program year 1996 population to the sample frame.

Table C-3
Comparison of Population and Sample Frame

	Population			Sample Frame[1]			
Measure Type	**Sites[2]**	**Units**	**kWh**	**Sites[2]**	**% of Pop**	**Units**	**kWh**
CFL	53	2,050	463,980	40	75%	1,264	285,800
HID	17	294	81,192	17	100%	294	81,192
T-8	36	3,498	691,025	28	78%	1,516	287,530
Other	16	663	187,141	10	63%	150	39,419
Total Lighting	**87**	**6,505**	**1,423,338**	**71**	**82%**	**3,224**	**693,941**

[1] Sample frame is the set of sites with completed surveys for the first year impact study of the lighting program.

[2.] Sites do not sum to total due to overlap of measures at some sites.

Because of the limited number of sites in the sample frame, a census of sites was attempted.

b. Survey Information

A copy of the survey instrument is provided in Appendix A. The disposition of the sample contacted and successfully recruited is shown in the table below. Those premises categorized as “not in the retention panel” either could not be contacted or refused to participate in the first year impact study. The “unable to contact” category includes three sites where multiple messages were not returned, two sites where the phone number was not current, and one site where no one ever answered the phone.

Reason	**Total Frequency**	**Percent of Population**	**Percent of Sample Attempted**
Population	87	100%	
Not in retention panel	16	18%	
Total attempted for retention stud	71	82%	100%
Wrong premise type	1	1%	1%
Change of ownership	4	5%	6%
Unable to contact	6	7%	8%
Refused	1	1%	1%
Completed survey	**59**	**68%**	**83%**

c. Statistical Descriptions

Measure Type	Still in Place	Number Removed	Percent in Place
CFL	892	69	92.8%
HID	252	19	93.0%
T-8	1,284	99	92.8%
Total	**2,428**	**187**	**92.8%**

C.1.4 Data Screening and Analysis

a. Procedures

Potential extremely influential points were examined, but none turned out to be extremely influential. Removal dates could not be determined with any accuracy; therefore, any removals were considered censored with the on-site survey date as the left-censoring endpoint.

b. Background Variables

n/a

c. Data Screening

See Section C.1.2.b above regarding data attrition and screening.

d. Model Statistics

Studied Measure Description (Measure Group)	Distribution	*ex post* EUL from Study (Years)	SE	Lower Confidence Level	Upper Confidence Level	Intercept	SE	Number of Units	Number of Premises
CFL	Exponential	36.5	123.1	0.0	194.3	6.45	123.1	961	31
HID	Exponential	37.1	149.3	0.0	228.5	6.47	149.3	271	14
T-8	Exponential	36.9	78.5	0.0	137.5	6.46	78.5	1,383	25

e. Specification

Several hazard function distributions were explored for the survival analysis: Gamma, Weibull, Exponential, Log-normal, and Log-logistic. Of these, the Weibull was considered the most appropriate, since it allows for an increasing failure rate over time. However, this model form did not converge. That is, the failure incidence at this date is sufficiently low that with the available sample sizes there was not enough information to fit this most general model form.

The Exponential result was taken as the next most plausible form. However, the assumption of a constant failure rate implicit in this form is questionable.

The Log-normal and Log-logistic forms both have an initially high failure rate followed by a declining rate. Initially, this pattern makes sense. A certain fraction of customers find out in the early period after measure installation that they are dissatisfied with the measure and remove it. After that early period, removals are more sporadic. In later years, however, failure rates due to physical measure failure would be expected to increase. Thus, with either of these forms, the fitted model may be a reasonable description of the loss rates within the period studied, but its projection to a time period twice as long as what was studied is of unknown validity. As it turned out, neither of these models converged for any of the measure groups. Because of these uncertainties in the model specification, none of the results is considered reliable as a basis for rejecting the *ex ante* EUL, regardless of nominal significance level.

1) Heterogeneity

Customer heterogeneity was addressed by attempting a census of sites.

2) Omitted Factors

No covariates were included in the model. With the limited instances of measure failure, estimation of effects of covariates was considered impractical.

f. Error in Measuring Variables

Uncertain removal dates were treated as left-censored with the on-site survey date as the left-censoring endpoint.

g. Influential Data Points

No sites were considered extremely influential.

h. Missing Data Points

All recidivism dates were considered left-censored with the on-site survey date as the left-censoring endpoint.

i. Precision

Standard Error Calculation

Standard errors reported by the SAS estimation procedure are calculated as if all the observed units are independent. To account for within-site correlation of failures, the standard errors generated by SAS were adjusted by the factor

$$\sqrt{deff}$$

where the design effect *deff* is calculated as

$$deff = 1 + roh(\bar{n} - 1)$$
$$\bar{n} = n_{fixture} / n_{site}$$

and the rate of homogeneity *roh* is calculated from the within- and between-site and overall variances s_w^2, s_b^2, and s_o^2, respectively, as

$$roh = \left[s_b^2 + s_w^2 / (\bar{n} - 1)\right] / s_o^2 \; .$$

Because too few failures have yet occurred to calculate the variances of failure times directly, the design effect was instead calculated for the observed proportions that failed over the time period of the study. The variance components s_w^2, s_b^2, and s_o^2 were calculated directly for the proportions failed, and the design effect was evaluated using these values The same design effect was assumed to apply to failure times.

The rate of homogeneity *roh* was calculated for each of the measure types studied, resulting in estimates ranging from 0.75 to 0.98. Because of the approximations required and the limited number of sites available for this analysis, a single value of 0.9 was assumed for *roh* for all measures.

Degrees of Freedom for *t*-Statistic

The degrees of freedom for the *t*-statistic used to construct confidence intervals were calculated using the design effect adjustment. That is, the effective sample size was calculated as

$$n_{eff} = n_{fixtures}/deff.$$

The *t*-statistic for 80 percent confidence was determined for degrees of freedom = n_{eff} - 1.

Confidence Intervals

Confidence intervals were calculated using the standard errors and *t*-statistics calculated as indicated above. As a sensitivity test, confidence intervals were calculated not only with our assumed rate of homogeneity of *roh* = 0.9, but also with values of 0, 0.5, and 1.0 for *roh.*