# RETENTION STUDY OF PACIFIC GAS AND ELECTRIC COMPANY'S 1996 & 1997 INDUSTRIAL ENERGY EFFICIENCY INCENTIVE PROGRAMS

***PG&E Study ID Numbers:***
***1996 Industrial Process Sixth-Year Retention: 353R2***
***1997 Industrial Process Sixth-Year Retention: 334aR2***
***1996 Industrial Lighting Sixth-Year Retention: 350R2***
***1997 Industrial Lighting Sixth-Year Retention: 334bR2***

***March 1, 2003***


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## 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 selected process and lighting measures for which rebates were paid through Pacific Gas and Electric Company's 1996 & 1997 Industrial Energy Efficiency Incentive Programs. The EUL is the time at which half the units rebated and installed during the program year are no longer in place and operable.

## Methodology

In order to estimate a measure's EUL, this study assumed the number of years a unit of the measure is retained or the time to non-retention of a unit follows some general path. This study considered a variety of paths or distributional assumptions. Per standard methods, this study collected data on the times to non-retention of units of a measure and used these data to estimate the specific path or parameters of each assumed distribution. The estimated path or parameters of an assumed distribution of the time to non-retention of units were then used to estimate the measure's median retention time or EUL under that distributional assumption.

The data necessary for this study were obtained from the Program tracking data and collected via on-site inspections. The on-site inspection data were collected at two points in time, three and six years after installation. A total of 229 projects (a project is a unique site and rebate application combination) provide the data for the retention analysis of lighting measures, and a total of 30 projects provide the data for the retention analysis of process measures.

The parameters of an assumed distribution of the time to non-retention of a unit of a measure were estimated by fitting a general linear regression model to the log of the times to non-retention of units observed in the data. The exponential of the error term of this model followed the standardized form of the assumed distribution. The selection of the most appropriate distribution was then based on several criteria.

To estimate a measure's EUL, the estimated parameters of an assumed distribution of the time to non-retention of a unit of the measure were employed in the survival function. For a given distributional assumption, the survival function gives the probability of retaining a unit of a measure until at least time $t$. Therefore, the estimate of a measure's EUL, under a given distributional assumption, is the time $t^*$ such that the survival probability equals 50 percent.

## Study Results

The results of this study are summarized in the table below. Results are presented for twelve measures: L23, L81, 560, 578, 589A, 589B, 589C, 590, 599A, 599B, 599C, and P2. For two measures, process measures 578 and 599A, the measure's adopted *ex post* EUL equals its *ex post* EUL estimated from this study and its EUL realization rate is less than 1.00. For each of these process measures, the measure's *ex ante* EUL is outside the 80 percent confidence interval and its *ex post* EUL estimated from this study seems reasonable.

**1996 & 1997 Industrial Energy Efficiency Incentive Programs**
**Summary of Effective Useful Life Estimates**

| Program Year | Measure | | End Use | EUL (years) | | | | | | P-value for *ex post* EUL | EUL Realization Rate (adopted *ex post* / *ex ante*) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *ex ante* | *ex post* (estimated from study) | Adopted *ex post* (to be used in claim) | *ex post* Standard Error | 80% Confidence Interval Lower Bound | 80% Confidence Interval Upper Bound | | |
| 1996, 1997 | L23 | | Lighting | 16 | 13.8 | 16.0 | 4.78 | 8.9 | 21.6 | 0.68 | 1.00 |
| 1996 | L81 | | Lighting | 16 | 10.3 | 16.0 | 8.64 | 3.5 | 30.6 | 0.61 | 1.00 |
| 1997 | 560 | | Process | 14 | - | 14.0 | - | - | - | - | 1.00 |
| 1997 | 578 | | Process | 16 | 4.4 | 4.4 | 1.97 | 2.3 | 8.4 | 0.03 | 0.27 |
| | | | | 15 | | | | | | | 0.29 |
| 1996 | 589[a] | A | Process | 18 | 67.7 | 18.0 | 221.40 | 0.5 | 8,459.6 | 0.70 | 1.00 |
| | | B | | 16 | - | 16.0 | - | - | - | - | 1.00 |
| | | | | 15 | | 15.0 | | | | | 1.00 |
| | | C | | 12 | - | 12.0 | - | - | - | - | 1.00 |
| 1997 | 590 | | Process | 20 | 63.3 | 20.0 | 214.42 | 0.8 | 5,141.1 | 0.74 | 1.00 |
| 1996 | 599[b] | A | Process | 20 | 4.0 | 4.0 | 3.02 | 1.0 | 16.7 | 0.17 | 0.20 |
| | | B | | 16 | - | 16.0 | - | - | - | - | 1.00 |
| | | | | 15 | | 15.0 | | | | | 1.00 |
| | | C | | 10 | - | 10.0 | - | - | - | - | 1.00 |
| 1996 | P2 | | Process | 10 | 520.8 | 10.0 | 768.60 | 76.7 | 3,537.1 | 0.01 | 1.00 |

[a] Process measure 589's *ex ante* EULs are sufficiently different that this analysis considers three separate measures: 589A with an *ex ante* EUL of 18 years, 589B with *ex ante* EULs of 16 and 15 years, and 589C with an *ex ante* EUL of 12 years.

[b] Process measure 599's *ex ante* EULs are sufficiently different that this analysis considers three separate measures: 599A with an *ex ante* EUL of 20 years, 599B with *ex ante* EULs of 16 and 15 years, and 599C with an *ex ante* EUL of 10 years.

For the remaining measures, the measure's adopted *ex post* EUL equals its *ex ante* EUL and its EUL realization rate is 1.00. This is the result for process measures 560, 589B, 589C, 599B, and 599C because this study does not provide any basis for changing the measure's EUL from its *ex ante* value. All units of these measures were still retained in the data collected. It is also the result for lighting measures L23 and L81 and process measures 589A and 590 because each measure's *ex ante* EUL is inside the 80 percent confidence interval. Lastly, it is the result for process measure P2 because although its *ex ante* EUL is outside the 80 percent confidence interval, its *ex post* EUL estimated from this study is 520.8 years, which is clearly unreasonable.

## Regulatory Waivers and Filing Variances

None.

# RETENTION STUDY OF PACIFIC GAS AND ELECTRIC COMPANY'S 1996 & 1997 INDUSTRIAL ENERGY EFFICIENCY INCENTIVE PROGRAMS

# FINAL REPORT

**PG&E Study ID Numbers:**

**1996 Industrial Process Sixth-Year Retention: 353R2**
**1997 Industrial Process Sixth-Year Retention: 334aR2**
**1996 Industrial Lighting Sixth-Year Retention: 350R1**
**1997 Industrial Lighting Sixth-Year Retention: 334bR1**

**Prepared for**

**Pacific Gas and Electric Company**
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**March 1, 2003**

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# E EXECUTIVE SUMMARY

This report provides the results of a sixth-year retention study of Pacific Gas and Electric Company's (PG&E) 1996 & 1997 Industrial Energy Efficiency Incentive (IEEI) Programs (Programs), as required by the Measurement and Evaluation Protocols (M&E Protocols) of the California DSM Measurement Advisory Committee (CADMAC).[1]

As given in the M&E Protocols, the goal of a measure retention study is to determine "the length of time the measure(s) installed during the program year are maintained in operable condition." This issue is addressed by estimating a measure's effective useful life (EUL). A measure's EUL is defined as its median retention time; that is, the time at which half the units of the measure installed during a program year are no longer in place and operable.

Each measure has an ex ante EUL, which has been used in the earnings claims to date. A measure's ex post EUL is the EUL estimated by a retention study. If a measure's ex ante EUL is outside the 80 percent confidence interval for the measure's EUL determined by a retention study, the measure's ex post EUL will be used for future earnings claims. Otherwise, a measure's ex post EUL will not replace its ex ante EUL.

For two measures, process measure 578 and process measure 599 with an ex ante EUL of 18 years (599A), this study concludes the measure's ex post EUL should replace its larger ex ante EUL. In the cases of the remaining measures, this study finds the measure's ex ante EUL should continue to be used.

## E.1 SUMMARY OF RESULTS

The results of this study are summarized in Table E-1. Results are presented for 12 measures: L23, L81, 560, 578, 589A, 589B, 589C, 590, 599A, 599B, 599C, and P2. (Measure descriptions are provided in Table E-2.) Process measure 589's ex ante EULs are sufficiently different that this analysis considers three separate measures: 589A with an ex ante EUL of 18 years, 589B with ex ante EULs of 16 and 15 years, and 589C with an ex ante EUL of 12 years. Similarly, for process measure 599, this analysis considers three separate measures: 599A with an ex ante EUL of 20 years, 599B with ex ante EULs of 16 and 15 years, and 599C with an ex ante EUL of 10 years.

[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.

**Table E-1**
**1996 & 1997 Industrial Energy Efficiency Incentive Programs**
**Summary of Effective Useful Life Estimates**

| Program Year | Measure | | End Use | EUL (years) | | | | | | P-value for *ex post* EUL | EUL Realization Rate (adopted *ex post* / *ex ante*) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *ex ante* | *ex post* (estimated from study) | Adopted *ex post* (to be used in claim) | *ex post* Standard Error | 80% Confidence Interval Lower Bound | 80% Confidence Interval Upper Bound | | |
| 1996, 1997 | L23 | | Lighting | 16 | 13.8 | 16.0 | 4.78 | 8.9 | 21.6 | 0.68 | 1.00 |
| 1996 | L81 | | Lighting | 16 | 10.3 | 16.0 | 8.64 | 3.5 | 30.6 | 0.61 | 1.00 |
| 1997 | 560 | | Process | 14 | - | 14.0 | - | - | - | - | 1.00 |
| 1997 | 578 | | Process | 16<br>15 | 4.4 | 4.4 | 1.97 | 2.3 | 8.4 | 0.03 | 0.27<br>0.29 |
| 1996 | 589 | A | Process | 18 | 67.7 | 18.0 | 221.40 | 0.5 | 8,459.6 | 0.70 | 1.00 |
| | | B | | 16<br>15 | - | 16.0<br>15.0 | - | - | - | - | 1.00<br>1.00 |
| | | C | | 12 | - | 12.0 | - | - | - | - | 1.00 |
| 1997 | 590 | | Process | 20 | 63.3 | 20.0 | 214.42 | 0.8 | 5,141.1 | 0.74 | 1.00 |
| 1996 | 599 | A | Process | 20 | 4.0 | 4.0 | 3.02 | 1.0 | 16.7 | 0.17 | 0.20 |
| | | B | | 16<br>15 | - | 16.0<br>15.0 | - | - | - | - | 1.00<br>1.00 |
| | | C | | 10 | - | 10.0 | - | - | - | - | 1.00 |

**Table E-2**
**Measure Descriptions**

| End Use | Measure | Description |
|---|---|---|
| Lighting | L23 | T-8 Lamps and Electronic Ballast, 4-ft Fixture |
| | L81 | HID Fixture: 251-400 Watt Lamp |
| Process | 560 | Heat Recovery |
| | 578 | Adjustable Speed Drive |
| | 589 | Modify Air Compressor System |
| | 590 | Insulation |
| | 599 | Process Other |
| | P2 | Oil Well Pump-Off Controller |

For all measures, Table E-1 presents the ex ante and adopted ex post EULs and the EUL realization rate. Also, for all measures except process measures 560, 589B, 589C, 599B, and 599C, this table presents the selected results of the retention analysis. All units of process measures 560, 589B, 589C, 599B, and 599C were still retained in the data collected; hence, it was not possible to conduct the retention analysis for these measures.

For two measures, process measures 578 and 599A, the measure's adopted ex post EUL equals its ex post EUL estimated from this study and its EUL realization rate is less than 1.00. For each of these process measures, the measure's ex ante EUL is outside the 80-percent confidence interval and its ex post EUL estimated from this study seems reasonable.

For the remaining measures, the measure's adopted ex post EUL equals its ex ante EUL, and its EUL realization rate is 1.00. This is the result for process measures 560, 589B, 589C, 599B, and 599C because this study does not provide any basis for changing the measure's EUL from its ex ante value. All units of these measures were still retained in the data collected. It is also the result for lighting measures L23 and L81 and process measures 589A and 590 because each measure's ex ante EUL is inside the 80-percent confidence interval. Lastly, it is the result for process measure P2 because although its ex ante EUL is outside the 80-percent confidence interval, its ex post EUL estimated from this study is 520.8 years, which is clearly unreasonable.

## E.2 DATA

Two lighting measures and six process measures qualified for inclusion in the study per the M&E Protocols. Under the Programs in 1996, two lighting measures and three process measures, accounting for 58 percent of the Programs' avoided energy costs in 1996, qualified for inclusion in the study. Under the Programs in 1997, one of the same lighting measures and three different process measures, accounting for 54 percent of the Programs' avoided energy costs in 1997, qualified for inclusion in the study.

The projects (a project is a unique site and rebate application combination) identified to provide the retention data for these measures are among the projects included in the first-year impact evaluation of the PG&E IEEI Programs in either 1996 or 1997. The data necessary for this study were obtained from the Program tracking data and collected via on-site inspections. A total of 229 projects provide the data for the retention analysis of lighting measures, and a total of 30 projects provide the data for the retention analysis of process measures.

## E.3 STUDY METHODS

Typically, a retention study is conducted when more than half the units of a measure installed during a program year are still retained. Therefore, it is necessary to employ statistical methods to estimate the measure's EUL. To analyze retention, this study employs a method commonly referred to as survival analysis, which are widely employed to analyze data representing a period of time.

### *E.3.1 Estimating the EUL*

To estimate a measure's EUL, this study assumed the number of years a unit of the measure is retained or the time to non-retention of a unit follows some general path. Technically, this path is referred to as a distribution. Given the variety of reasons a unit of a measure may be not retained, the general path the time to non-retention of a unit follows is unclear. Therefore, this study considered a variety of distributional assumptions:

- Gamma
- Weibull
- Exponential
- Log-normal

- Log-logistic.

These are common distributional assumptions made when conducting survival analysis.

Per standard methods, this study collected data on the times to non-retention of units of a measure and used these data to estimate the specific path or parameters of each assumed distribution. The estimated path or parameters of an assumed distribution of the time to non-retention of units were then used to estimate the measure’s median retention time or EUL under that distributional assumption.

The parameters of an assumed distribution of the time to non-retention of a unit of a measure were estimated by fitting a general linear regression model to the log of the times to non-retention of units observed in the data. The exponential of the error term of this model followed the standardized form of the assumed distribution. The general linear regression model was fitted by maximizing the log-likelihood function for the assumed distribution of the time to non-retention of a unit. The selection of the most appropriate distribution was then based on several criteria:

- Implications for the non-retention rate over time
- Likelihood ratio test
- Analysis of residuals
- Maximum of the log-likelihood function.

To estimate a measure’s EUL, the estimated parameters of an assumed distribution of the time to non-retention of a unit of the measure were employed in the survival function. This function is simply 1 minus the assumed cumulative distribution function of the time to non-retention of a unit. For a given distributional assumption, the survival function gives the probability of retaining a unit of a measure until at least time *t*. Therefore, the estimate of a measure’s EUL, under a given distributional assumption, is the time $t^*$ such that the survival probability equals 50 percent.

### *E.3.2 Standard Error of a Measure’s EUL Estimate*

To construct a confidence interval for a measure’s EUL or conduct hypothesis tests about the value of a measure’s EUL, the standard errors of both the log of a measure’s EUL estimate and its EUL estimate is required. The confidence intervals and p-values in Table E-1 are based on the adjusted, when necessary, standard errors.

It is not necessary to adjust the standard errors if sampling occurred at the level of a unit of the measure or if all projects that obtained a rebate for the measure are included in the analysis. For none of the measures did sampling occur at the unit level; projects, not units of a measure, were selected for the sample. At the site of a sample project, data were collected on all units of the project measure(s) installed. Therefore, the times to non-retention of units of a measure may be more similar within a project than between projects, which was the case in this study. Consequently, unless all projects that obtained a rebate for a measure are included in the analysis, it is necessary to adjust the standard errors. Specifically, the standard errors are adjusted by the square root of the design effect. In general, the design effect equals the ratio of the variance of the sample calculated consistent with the sample design to the variance of the sample calculated as if it were a simple random sample.

# 1 INTRODUCTION

This report provides the results of a sixth-year retention study of Pacific Gas and Electric Company's (PG&E) 1996 & 1997 Industrial Energy Efficiency Incentive (IEEI) Programs (Programs), as required by the Measurement and Evaluation Protocols (M&E Protocols) of the California DSM Measurement Advisory Committee (CADMAC).[1] In this section, the protocol requirements are discussed and the organization of the report is described.

## 1.1 PROTOCOL REQUIREMENTS

The M&E Protocols require a retention study be performed in the third and sixth years for rebates received through PG&E's IEEI Programs. The CADMAC Persistence Subcommittee directed the retention studies of PG&E's 1996 & 1997 IEEI Programs be combined into a single study.

As given in the M&E Protocols, the goal of a 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 issue is addressed by estimating a measure's effective useful life (EUL). A measure's EUL is defined as its median retention time; that is, the time at which half the units of the measure installed during a program year are no longer in place and operable. We refer to "no longer in place and operable" as "non-retention."

Each measure has an ex ante EUL, which has been used in the earnings claims to date. A measure's ex post EUL is the EUL estimated by a retention study. If a measure's ex ante EUL is outside the 80-percent confidence interval for the measure's EUL determined by a retention study, the measure's ex post EUL will be used for future earnings claims. Otherwise, a measure's ex post EUL will not replace its ex ante EUL.

## 1.2 REPORT ORGANIZATION

The next section of this report, Section 2, describes the data employed in the study. Section 3 discusses the methods employed to estimate a measure's EUL and the standard error of the estimate. The calculation of both the confidence interval for a measure's EUL and hypothesis tests about the value of a measure's EUL are also discussed in Section 3. Sections 4 and 5 present the results for the lighting and process measures, respectively. Appendix A contains the on-site data collection instrument. Appendices B and C provide Tables 6B and 7B, respectively, required by the M&E 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.

# 2 DATA

This section of the report describes the data used in the retention analysis of the PG&E's 1996 & 1997 IEEI Programs. A discussion of both the measures and projects included in this study is presented. These discussions are followed by a description of the sources of the data employed in the analysis. The section concludes with the details of preparing the data for analysis.

## 2.1 MEASURES INCLUDED IN THE STUDY

According to the M&E Protocols (Table 9A), the following measures should be included in the retention study:

> "… the top ten measures, excluding measures that have been identified as miscellaneous (per Table C-9), ranked by net resource value or the number of measures that constitutes the first 50% of the estimated resource value, whichever number of measures is less."

Table 2-1 lists the eight measures included in this study and the Program year under which it qualified for inclusion. Under the Programs in 1996, two lighting measures and three process measures, accounting for 58 percent of the Programs' avoided energy costs in 1996, qualified for inclusion in the study. Under the Programs in 1997, one of the same lighting measures (L23) and three different process measures, accounting for 54 percent of the Programs' avoided energy costs in 1997, qualified for inclusion in the study.

**Table 2-1**
**Measures Included in the Study**

| Measure | Measure Description | % of Total Avoided Cost | |
|---|---|---|---|
| | | 1996 | 1997 |
| | **Lighting** | | |
| L23 | Fixture: T-8 Lamp & Electric Ballast, (Fem or New Fixture), 4 ft Fixture | 8.3% | 8.1% |
| L81 | HID Fixture: Interior, Standard, 251-400 Watt Lamp | 13.4% | |
| | **Process** | | |
| 560 | Heat Recovery | | 27.4% |
| 578 | Adjustable Speed Drive | | 10.7% |
| 589 | Air Compressor System Change/Modify | 10.7% | |
| 590 | Insulate | | 7.5% |
| 599 | Other | 13.4% | |
| P2 | Oil Well Pump-Off Controller | 12.0% | |
| | **Total** | 57.8% | 53.7% |

## 2.2 PROJECTS INCLUDED IN THE STUDY

A project is a unique site (identified by PG&E control number) and rebate application combination. A given rebate application may include a rebate request for more than one measure. Therefore, a project may be included in the analysis of the retention of more than one measure.

The projects eligible for inclusion in this study are projects included in the first-year impact evaluation of either the 1996 or 1997 Programs. Per the projects included in the first-year impact evaluations, for each of the lighting measures, a sample of projects that obtained a rebate is eligible for inclusion in this study and for each of the process measures, the population of projects that obtained a rebate is eligible for inclusion in this study. The population of projects that obtained a rebate for any of the process measures is small, ranging between two and nine, and the first-year impact evaluations included them all.

By Program year and measure, Table 2-2 gives the number of projects in (1) the population, (2) the impact evaluation, and (3) this study. This study includes projects for which an on-site inspection was conducted for the third-year retention study or for this current retention study.

**Table 2-2**
**Projects Included in the Study**

| | | | Number of Projects | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Retention Analysis | | | |
| Measure | End Use | Measure Description | Population | Impact Evaluation | Total | 3rd-year On-site Only | 6th-year On-site Only | 3rd- and 6th-year On sites |
| **Program Year 1996** | | | | | | | | |
| L23 | Lighting | Fixture: T-8 Lamp & Electronic Ballast, 4ft Fixture | 169 | 78 | 65 | 4 | 1 | 60 |
| L81 | Lighting | HID Fixture: Interior, Standard, 251-400 Watt Lamp | 90 | 57 | 54 | 3 | 0 | 51 |
| 589 | Process | Air Compressor System Change/Modify | 6 | 6 | 6 | 0 | 1 | 5 |
| 599 | Process | Process Other | 9 | 9 | 7 | 1 | 1 | 5 |
| P2 | Process | Oil Well Pump-Off Controller | 8 | 8 | 5 | 0 | 2 | 3 |
| | | **Total** | 282 (272 unique) | 158 | 137 | 8 | 5 | 124 |
| **Program Year 1997** | | | | | | | | |
| L23 | Lighting | Fixture: T-8 Lamp & Electronic Ballast, 4ft Fixture | 194 | 120 | 110 | 4 | 2 | 104 |
| 560 | Process | Process Heat Recoveray | 2 | 2 | 2 | 0 | 1 | 1 |
| 578 | Process | Process Adjustable Speed Drive | 6 | 6 | 6 | 0 | 0 | 6 |
| 590 | Process | Process Insulate | 4 | 4 | 4 | 0 | 0 | 4 |
| | | **Total** | 206 | 132 | 122 | 4 | 3 | 115 |
| | | **Grand Total** | 488 (478 unique) | 290 | 259 | 12 | 8 | 239 |

### *2.2.1 Sixth-Year Sample Disposition*

A total of 263 projects were targeted for onsite inspections—255 projects that were part of the third-year retention study and 8 additional process projects that were included in the first-year impact evaluation but were not visited in the third-year retention study. An on-site inspection was completed for 247 of these 263 projects. Table 2-3 presents the sample disposition. The category “Unable to Contact” includes projects for which telephone numbers had changed and a new number could not be found or customers did not return multiple telephone calls and inspectors could not make a walk-up contact. Incomplete on-site data resulted when the inspector could not locate all of the targeted measures but indicated that they could not gain access to the entire facility (due to locked-out areas or insufficient inspection time allotted by the customer).

**Table 2-3**
**Sample Disposition**

| | Number of Projects | Percent of Sample |
|---|---|---|
| Projects in Sample/Panel | 263 | |
| Unable to Contact | 11 | 4% |
| Refusal – No Longer a PG&E Customer | 2 | 1% |
| Incomplete On-Site Data | 3 | 1% |
| Completed On-Site Inspection | 247 | 94% |

## 2.3 DATA SOURCES

The data used in this study were obtained from three sources:

1. The Program tracking data for 1996 and 1997
2. The first-year impact evaluation of the 1996 IEEI Programs and of the 1997 IEEI Programs
3. On-site inspections conducted for the third-year retention study and for this current retention study.

### *2.3.1 Program Tracking Data*

For each project, the Program tracking data provides the following information on each measure for which a rebate was obtained:

- The installation date
- The number of units of the measure for which a rebate was obtained
- The avoided energy costs
- The ex ante EUL.

There are two general types of measures (or end uses), lighting and process. In the cases of all lighting measures, a unit is a lamp, whereas a unit of a process measure is very specific to the process.

### *2.3.2 First-Year Impact Evaluations of the Programs*

The first-year impact evaluation of the 1996 or 1997 Programs provides the following data on each project: contact information, and, on each measure for which a rebate was obtained, the number of units of the measure both rebated and installed (number of expected units when first inspected) and the location of these units.

### 2.3.3 On-Site Inspections

For each project eligible for inclusion in this study, an attempt was made to conduct an on-site inspection in both the third year and the sixth year. An on-site inspection provides the following data on each project: the date of the inspection and, on each measure for which a rebate was obtained, the number of units observed to be in place and the percentage of these units that are working and, in the case of each non-retained unit, any information on when the unit became not retained.

A unit not in place and/or not working at the time of the inspection is classified as not retained for purposes of this analysis. Therefore, a unit is classified as not retained if it is removed and/or if it is not working. When the inspector was able to determine the reason a unit was not retained, this information was recorded as well. A copy of the sixth-year on-site data collection instrument is provided in Appendix A.

## 2.4 DATA PREPARATION

When preparing the data for analysis, the goal was to glean as much as possible from the on-site inspection data about the retention status of each unit of a measure both rebated and installed per the first-year impact evaluations. The main issues in preparing the data for the analysis are discussed briefly here:

- For an observation on a project/measure combination in an on-site inspection data set, if the number of units observed to be in place was larger than the number of units both rebated and installed, the number of units observed to be in place was changed to the smaller, latter number.
- For a project/measure combination, if the total number of units both rebated and installed per the first-year impact evaluation was larger than the total number of units for which a rebate was obtained per the Program tracking, the total number of units both rebated and installed was changed to the smaller, latter number.
- For a project/measure combination, the number of units of not retained between the third and sixth years was calculated as the number of units not retained as of the sixth year less the number of units not retained as of the third year.
- The methods employed in this study (discussed in the next section) allow the time to non-retention of a unit of a measure to be specified inexactly. This is done by specifying for each unit both a lower bound and an upper bound for the time to non-retention. For a unit still retained at the time of the latest on-site inspection, the lower bound of the time to non-retention is the number of years between the installation date and the latest on-site inspection date and the upper bound is infinity.
- The time to non-retention of a unit that has not been retained is specified a variety of ways, depending on what is known about when the unit became not retained. For example:
    - The time to non-retention is known exactly: both the lower and upper bounds of the time to non-retention are set equal to this time (number of years).

- The unit was not retained sometime before the third-year on-site inspection: the lower bound of the time to non-retention is zero years and the upper bound is the number of years between the installation date and the third-year on-site inspection date.
- The unit was not retained sometime between the third-year and sixth-year on-site inspections: the lower bound of the time to non-retention is the number of years between the installation date and the third-year on-site inspection date and the upper bound is the number of years between the installation date and the sixth-year on-site inspection date.

# 3 STUDY METHODS

This section discusses the methods employed to estimate a measure's EUL, the methods employed to estimate the standard error of the estimate, the calculation of the confidence interval for a measure's EUL, and hypothesis tests about the value of a measure's EUL. The results for lighting measures and process measures are presented in Sections 4 and 5, respectively.

The goal of a measure retention study is to determine the length of time a measure installed through a program is retained. This issue is addressed by estimating a measure's EUL. A measure's EUL is defined as its median retention time; that is, the time at which half the units of the measure installed during a program year are not retained. Typically, a retention study is conducted when more than half the units of a measure installed during a program year are still retained. Therefore, it is necessary to employ statistical methods to estimate the measure's EUL.

To analyze retention, this study employs a method commonly referred to as survival analysis. The set of techniques referred to as survival analysis are widely employed to analyze data representing a period of time. The method has several names, depending on the area of application, but was first referred to as survival analysis because it was initially used to analyze death rates. For example, in engineering survival analysis is termed reliability analysis and in economics it is duration analysis. The terminology employed in the analysis may also vary depending on the area of application. In this report, we use the survival analysis terminology, but modify it when appropriate for the application of survival analysis to retention.

## 3.1 SURVIVAL ANALYSIS

### *3.1.1 The Basics*

To estimate a measure's EUL, this study assumes the number of years a unit of the measure is retained or the time to non-retention of a unit follows some general path. Technically, this path is referred to as a distribution. Therefore, the general method of study is to collect data on the times to non-retention of units and use those data to estimate the specific path or parameters of the distribution. The estimated path or parameters of the distribution of the time to non-retention of a unit of a measure are then used to estimate the measure's median retention time or EUL.

The parameters of the distribution of the time to non-retention of a unit of a measure are estimated by fitting a general linear regression model to the log (natural) of the times to non-retention of units observed in the data. This model can be written as

$$\log(T_j) = \mu + \sigma\varepsilon_j,$$

where

$T_j$ = observed time to non-retention of unit $j$,

$\mu$ = location parameter or intercept,

$\sigma$ = scale parameter, and

$\varepsilon_j$ = random error term.

The exponential of the error term of this model ($e^{\varepsilon_j}$) is assumed to follow the standardized form of the distribution of the time to non-retention of a unit. The general linear regression model is fitted by maximizing the log-likelihood function for the assumed distribution.

To estimate a measure's EUL, the estimated parameters of the distribution of the time to non-retention of a unit of the measure are then employed in the survival function. This function is simply 1 minus the cumulative distribution function of the time to non-retention of a unit. The survival function $S(t;\theta)$ gives the probability of retaining a unit of a measure until at least time $t$, given the parameter vector $\theta$. Therefore, the estimate of a measure's EUL is the time $t^*$ such that the survival probability $S(t^*;\hat{\theta}) = 0.50$, where $\hat{\theta}$ is the vector of parameter estimates.

### 3.1.2 Weights

In the retention analysis of a measure, the relative importance of a unit depends on the energy costs avoided by its installation. If the energy costs avoided per unit of a measure varies across units, it is necessary to employ weights that reflect the different levels of energy costs avoided when fitting the general linear regression model. Such weights are employed in the retention analysis of the process measures. Weights are not employed in the retention analysis of the lighting measures because the energy costs avoided per unit of a lighting measure are assumed to be relatively similar across units.

In the retention analysis of a process measure, the weight $w_{ij}$ applied to each unit $j$ of the measure in project $i$ is calculated as

$$\frac{a_i}{\sum_{i=1}^{c} a_i n_i} \times \sum_{i=1}^{c} n_i ,$$

where

$a_i$ = energy costs avoided per unit of the measure for project $i$,

$n_i$ = number of rebated and initially installed units of the measure for project $i$, and

$c$ = number of projects included in the analysis of the measure.

To obtain the correct unadjusted standard error of the EUL estimate, the sum of the weights must equal the number of observations included in the analysis. This is achieved by multiplying the component of the weight that reflects the different levels of energy costs avoided $\left( a_i \Big/ \sum_{i=1}^{c} a_i n_i \right)$ by the number of observations included in the analysis $\left( \sum_{i=1}^{c} n_i \right)$.

### 3.1.3 Distribution Options

Given the variety of reasons a unit of a measure may be not retained, the general path the time to non-retention of a unit follows is unclear. Therefore, this study considers a variety of distributional assumptions:

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

These are common distributional assumptions made when conducting survival analysis.

The Gamma distribution is the most general of the distributions listed above. It has three free parameters, location ($\mu$), scale ($\sigma$), and shape; whereas the other distributions have only one or two free parameters. The Gamma distribution includes the Weibull, Exponential, and Log-normal distributions as special cases. The Weibull distribution includes the Exponential distribution as a special case.

The Weibull, Log-normal, and Log-logistic distributions have two free parameters, location and scale; and the Exponential distribution has one free parameter, location. The Weibull and Log-normal distributions result as special cases of the Gamma distribution when the shape parameter equals 1 and 0, respectively. The Exponential distribution results as a special case of the Gamma distribution when both the shape and scale parameters equal one or as a special case of the Weibull distribution when the scale parameter equals 1.

The Gamma distribution places fewer constraints on the parameters than the Weibull, Exponential, and Log-normal distributions. As a result, the parameter estimates obtained assuming the Gamma distribution will be most based on the data. If one of the other distributions is a good description of the data, its results will be similar to those of the less constrained Gamma distribution.

### 3.1.4 Distribution Adopted

The selection of the most appropriate distribution is based on several criteria:

- Implications for the non-retention rate over time
- Likelihood ratio test
- Analysis of residuals
- Maximum of the log-likelihood function.

### *Non-Retention Rate Over Time*

The distributional assumption has implications for the non-retention rate over time. These implications are seen via the hazard function $h(t;\theta)$. Roughly, the hazard function can be thought of as the probability of not retaining a unit of a measure at time *t,* given the unit has been retained up to that time. Formally, it is the negative ratio of the survival probability density function *dS/dt* to the survival function,

$$h(t;\theta) = -\frac{dS/dt}{S(t;\theta)}.$$

An increasing hazard function means the non-retention rate increases as a unit of a measure ages, whereas a decreasing hazard function means the non-retention rate decreases as a unit of a measure ages. If the hazard function is constant, the non-retention rate remains constant as a unit of a measure ages. The hazard function of the Gamma distribution may have a variety of shapes. However, it is often difficult to determine which possible shape the hazard function of the Gamma distribution actually takes on.

The hazard function of the Weibull distribution may have one of three shapes: always decreasing, always increasing, or constant. If the scale parameter is greater than 1, then the hazard function is decreasing, whereas if the scale parameter is less than 1, then the hazard function is increasing. Recall, a Weibull distribution with scale parameter equal to 1 corresponds to the Exponential distribution. The Exponential distributional results in a constant hazard function.

If the hazard function of the Weibull distribution is increasing (the scale parameter is less than 1), the rate of increase depends on the value of the scale parameter. If the scale parameter is between 0.5 and 1, the hazard function is increasing at a decreasing rate; if the scale parameter equals 0.5, the hazard function is increasing at a constant rate; and if the scale parameter is between 0 and 0.5, the hazard function is increasing at an increasing rate.

The Log-normal distribution produces a hazard function that increases to a peak then decreases. The larger the scale parameter, the sooner the hazard function reaches its peak and begins to decrease. A hazard function that is increasing then decreasing means that for some period of time after a unit of a measure is installed, the non-retention rate increases as the unit of the measure ages then, after some point, the non-retention rate decreases as the unit of the measure ages.

The hazard function of the Log-logistic distribution may increase to a peak then decrease or it may be always decreasing. If the scale parameter is less than 1, then the hazard function is increasing then decreasing, whereas if the scale parameter is greater than or equal to 1, then the hazard function is always decreasing.

### *Likelihood Ratio Test*

If a distribution is a special case of another distribution, the appropriateness of the former versus the latter can be formally tested using the likelihood ratio test. Therefore, likelihood ratio tests comparing the appropriateness of the Weibull, Exponential, and Log-normal distributions versus the Gamma distribution are conducted. A likelihood ratio test comparing the appropriateness of the Exponential distribution versus the Weibull distribution is also conducted.

### *Analysis of Residuals*

According to Allison (1995), Cox-Snell residuals are commonly used in survival analysis and are defined as:

$$e_j = -\log(S(t_j;\hat{\theta})),$$

where

$e_j$ = the residual associated with the observed time to non-retention of unit $j$ $t_j$, and

$S(t_j;\hat{\theta})$ = the estimated survival function at $t_j$.

A Cox-Snell residual is right-censored, interval-censored, left-censored, or uncensored, if the observed time to non-retention of the unit it is associated with is right-censored, interval-censored, left-censored, or uncensored, respectively. The definitions of these various terms for the time to non-retention of a unit are as follows:

- Right-censored: The time to non-retention of a unit still retained is right-censored, the upper bound is unknown (infinity).
- Interval-censored: The time to non-retention of a unit known to be not retained within some time period (e.g., between the third-year and sixth-year on-site inspections) is interval-censored.
- Left-censored: Left-censoring is a special case of interval-censoring, where the lower bound of the time to non-retention of a unit is zero years and the upper bound is known.
- Uncensored: The time to non-retention of a unit is known exactly.

If a fitted general linear regression model is appropriate, Cox-Snell residuals have an approximate exponential distribution with location parameter 0. To determine whether or not this is the case, a general linear regression model is fitted to the log of the Cox-Snell residuals assuming the exponential of the error term follows the standardized form of the exponential distribution. An estimated location parameter not statistically different from 0 at a 10-percent level of significance or better, suggests the general linear regression model fitted to the log of the times to non-retention of units of a measure may be appropriate.

#### *Maximum of the Log-Likelihood Function*

Recall, under each assumed distribution, the general linear regression model is fitted by maximizing the log-likelihood function. A larger maximum value of the log-likelihood function suggests a better model fit.

## 3.2 STANDARD ERROR OF A MEASURE'S EUL ESTIMATE

To construct a confidence interval for a measure's EUL or conduct hypothesis tests about the value of a measure's EUL, the standard error of a measure's EUL estimate is necessary.

### *3.2.1 Calculation of the Standard Error*

The general linear regression model is fitted to the log of the times to non-retention of units of a measure. Therefore, the parameters thus estimated and employed in the survival function directly produce the log of a measure's EUL estimate such that the survival probability is 0.50. A measure's EUL estimate is then obtained by calculating the exponential of this log value ($e^{log(EUL\ estimate)}$). Calculating the standard error of a measure's EUL estimate, however, is not as simple because the logarithmic transformation is nonlinear.

If the distribution of the log of a measure's EUL estimate is known, it may be possible to calculate the exact standard error of the measure's EUL estimate. However, this distribution is unknown in this study, as it is in most studies. Therefore, the approximate standard error is calculated by SAS® using a first-order Taylor expansion of the logarithmic function of the time to non-retention of a unit of a measure around the measure's EUL estimate. This approximation is a function of the log of the measure's EUL estimate and the standard errors of the parameter estimates of the general linear regression model.

### *3.2.2 Adjustment to the Standard Error*

When fitting a general linear regression model to the data for a given measure, an observation is the time to non-retention of a unit of the measure. The calculation of the standard errors of the parameter estimates assumes each observation is independent. This assumption, however, may be incorrect when sampling does not occur at the level of a unit of a measure. For example, as is the case in this study, when sampling occurs at the project level and a project may have obtained a rebate for more than one unit of a measure. In which case, the times to non-retention of units of a measure may not be independent because the times to non-retention of units may be more similar within a project than between projects.

Several factors may cause the times to non-retention of units of a measure to be more similar within a project than between projects. Various reasons a unit may not be retained, remodeling, damage, dissatisfaction, or facility closure, may lead to the simultaneous non-retention of units of a measure installed at a site. Contractor-specific measure installation practices and site-specific operating conditions may affect the times to non-retention of units. Units of a measure installed at the same time are likely to be of a similar quality and, therefore, have similar times to non-retention. In addition, for lighting measures, the times to non-retention of units, lamps, may be more similar within a project than between projects because one fixture may hold more than one lamp.

While the times to non-retention of units of a measure may be more similar within a project than between projects, they are not expected to be identical within a project. Remodeling, damage, dissatisfaction, or facility closure do not necessarily lead to the simultaneous removal of all units of a measure installed at a site. Similar measure installation practices, operating conditions, and measure quality may result in similar but not necessarily identical times to non-retention of units of a measure installed at a site or at the same time.

Because the times to non-retention of units of a measure may be more similar within a project than between projects, the standard errors (of both the log of the measure's EUL estimate and its EUL estimate) are adjusted by the square root of the design effect (Kish 1965). If the times to non-retention of units of a measure are no more similar within a project than between projects, then the design effect equals 1 and the unadjusted and adjusted standard errors are equal. Generally, however, the design effect is greater than 1.

If it is possible to obtain data from all projects that obtained a rebate for a measure, it is not necessary to adjust the standard error of either the log of the measure's EUL estimate or its EUL estimate. If all the units of a measure are included in the analysis, that the data collection occurred at the project level has no consequences and it is not necessary to adjust the standard errors by the square root of the design effect.

### *The Design Effect*

The design effect is used to adjust the standard error of an estimate when the sample that produced the estimate is not a simple random sample. Initially, as is typical, the standard error of an estimate of a measure's EUL is calculated assuming the sample that produced the estimate is a simple random sample, which it is not. In general, the design effect equals the ratio of the variance of the sample calculated consistent with the sample design to the variance of the sample calculated as if it were a simple random sample.

The samples employed in this study are not simple random samples. Rather, the samples employed in this study are unequal cluster samples. In sampling terminology, a project is a cluster. The clusters or projects are "unequal" because they do not necessarily contain the same number of units of a measure.

### *Design Effect for Unequal Clusters*

The design effect for the average time to non-retention of a unit of a measure when the sample consists of unequal clusters is expressed as

$$Deff = \frac{\mathrm{Var}(r)}{(1-f)\dfrac{S^2}{n}},$$

where

$r$ = ratio estimator of the average time to non-retention = $\dfrac{\sum_{i=1}^{c}\sum_{j=1}^{A_i} T_{ij}}{n}$,

$c$ = number of clusters included in the sample,

$A_i$ = number of units in cluster $i$,

$T_{ij}$ = time to non-retention of unit $j$ in cluster $i$,

$n$ = sample size = $\sum_{i=1}^{c} A_i$ ,

$f$ = overall sample rate = $n/N$,

$S^2$ = population variance = $\dfrac{\sum_{k=1}^{N}(T_k - \overline{T})^2}{N-1}$,

$N$ = population size,

$T_k$ = time to non-retention of unit $k$, and

$\overline{T}$ = average time to non-retention of a unit over all clusters.

When the sample for a measure consists of unequal clusters, the sample size $n$ is random because the clusters do not necessarily contain the same number of units of the measure. Therefore, the estimate of the average time to non-retention of a unit of the measure is a ratio estimator.

### *Estimating the Design Effect for Unequal Clusters*

The design effect for the average time to non-retention of a unit of a measure when the sample consists of unequal clusters is estimated as

$$deff = \frac{\text{var}(p)}{(1-f)\frac{s^2}{n}},$$

where

$$\text{var}(p) = (1-f)\frac{c}{c-1}\frac{\sum_{i=1}^{c} A_i^2 (p_i - p)^2}{n^2},$$

$f$ = $n/N$,

$n$ = number of units in the sample,

$N$ = number of units in the population,

$c$ = number of projects included in the sample,

$A_i$ = number of units in project $i$,

$p_i$ = proportion of units not retained to date in project *i*,

$p$ = overall proportion of units not retained to date, and

$$s^2 = \frac{n}{n-1}p(1-p).$$

Var(*r*) and $S^2$ are estimated as var(*p*) and $s^2$, respectively, using the event of not retaining a unit of a measure because the exact time to non-retention of a unit is typically unknown. The expression for var(*p*) is an approximation. It is a reasonable approximation if the coefficient of variation of the sample size *n* (i.e., its standard error divided by the sample size) is less than 20 percent.

### *The Design Effect for Equal Clusters and Rho*

In the cases of lighting measure L81 and process measure 599A, the analysis data did not meet the criterion necessary for the estimate of the design effect for unequal clusters to be valid. For these two measures, the coefficient of variation of the sample size is more than 20 percent. Therefore, for lighting measure L81 and process measure 599A, the design effect is estimated using average cluster size and the design effect for equal clusters, which usually provides a reasonable estimate.

The ratio of the variances involved in the definition of the design effect for equal clusters can be written in terms of a quantity (*Rho*) that provides a measure of the homogeneity of clusters. Thus, for the average time to non-retention of a unit of a measure, the design effect for equal clusters is expressed as

$$Deff = 1 + Rho(A-1),$$

where

*Rho* = the measure's intra-cluster correlation of the time to non-retention of a unit and

*A* = number of units of the measure installed at each cluster through the program.

The equation for a measure's intra-cluster correlation of the time to non-retention of a unit (also known as the rate of homogeneity) *Rho* is

$$Rho = \frac{\sigma_b^2 - \dfrac{\sigma_w^2}{A-1}}{\sigma_o^2},$$

where

$$\sigma_b^2 = \text{between-cluster population variance} = \frac{\sum_{i=1}^{C}(\overline{T}_i - \overline{T})^2}{C},$$

*C* = number of clusters in the population,

$\overline{T}_i$ = average time to non-retention of a unit in cluster *i*,

$\overline{T}$ = average time to non-retention of a unit over all clusters (as defined previously),

$\sigma_w^2$ = within-cluster population variance = $\dfrac{\sum_{i=1}^{C}\sum_{j=1}^{A}(T_{ij}-\overline{T}_i)^2}{A\times C}$,

$A$ = number of units of the measure in each cluster,

$T_{ij}$ = time to non-retention of unit *j* in cluster *i* (as defined previously) and

$\sigma_o^2$ = overall population variance = $\dfrac{\sum_{i=1}^{C}\sum_{j=1}^{A}(T_{ij}-\overline{T})^2}{A\times C}$

= $\sigma_b^2+\sigma_w^2$.

Expressing the design effect as a function of *Rho* has intuitive appeal. Limit values of *Rho* can be determined and interpreted as follows:

- Complete homogeneity within clusters implies $\sigma_w^2$ = 0 and therefore $\sigma_b^2$ = $\sigma_o^2$ which leads to *Rho* = 1. *Rho* = 1 results in the largest design effect possible and, therefore, the largest adjustment to the standard errors.
- Extreme heterogeneity within clusters implies $\sigma_w^2$ takes the largest possible value, $\sigma_o^2$, and, therefore, $\sigma_b^2$ = 0, which leads to *Rho* = $-1/(A-1)$.
- Units of a measure within a cluster no more closely related than units between clusters leads to *Rho* = 0. If this is the case, the design effect is 1 and the standard error obtained directly from the fit of the general linear regression model is correct.

In practice, *Rho* takes on a value somewhere between 0 and 1. Negative values rarely happen. Thus, the design effect is usually larger than 1.

### *Estimating the Design Effect for Equal Clusters*

To estimate the design effect for lighting measure L81 and process measure 599A, the measure's intra-class correlation of the time to non-retention *Rho* is estimated with

$$rho=\frac{\left(\frac{C-1}{C}\right)s_b^2-\frac{s_w^2}{A}}{\left(\frac{N-1}{N}\right)s_o^2},$$

where

$C$ = number of projects in the population,

$s_b^2$ = estimate of the between-clusters population variance = $\frac{\sum_{i=1}^{c}(p_i - p)^2}{c-1}$,

$c$ = number of projects included in the analysis of the measure,

$p_i$ = proportion of units not retained to date in project $i$ (as defined previously),

$p$ = overall proportion of units not retained to date(as defined previously).

$s_w^2$ = estimate of the within-cluster population variance = $\frac{\sum_{i=1}^{c} s_{w_i}^2}{c}$,

$s_{w_i}^2$ = estimate of the within-cluster population variance of project $i$ =

$$\frac{A}{A-1} p_i(1-p_i),$$

$A$ = average number of units of the measure in a project,

$s_o^2$ = estimate of the overall population variance = $\frac{N}{N-1}\left(\frac{C-1}{C}s_b^2 + \frac{A-1}{A}s_w^2\right)$, and

$N$ = number of units of the measure in the population.

Ideally, $s_b^2$, $s_w^2$, and $s_o^2$ would be based on times to non-retention of units of a measure. However, the exact time to non-retention of a unit is typically unknown. Therefore, $s_b^2$, $s_w^2$, and $s_o^2$ are instead based on the proportion of units of the measure not retained.

Given *rho* the design effect is estimated as

$$deff = 1 + rho(A-1).$$

## 3.3 CONFIDENCE INTERVAL FOR A MEASURE'S EUL

Recall, it is only possible to calculate an approximate standard error of a measure's EUL estimate. This is because it is the log of a measure's EUL estimate that is directly obtained and the distribution of the log of a measure's EUL estimate is unknown.

A confidence interval for a measure's EUL can be calculated using the approximate standard error (adjusted or unadjusted, whichever is appropriate) of the measure's EUL estimate. A confidence interval for a measure's EUL can also be obtained from the confidence interval for the log of the measure's EUL. The lower and upper bounds of this later confidence interval for a measure's EUL equal the exponential of the lower and upper bound values of the confidence interval for the log of the measure's EUL, respectively. A confidence interval for the log of a measure's EUL is calculated using the standard error (adjusted or unadjusted, whichever is appropriate) of the log of the measure's EUL estimate.

The confidence interval for a measure's EUL based on the approximate standard error of the measure's EUL estimate is symmetric about the measure's EUL estimate. That is, the lower and upper bounds of this confidence interval are the same distance from the measure's EUL estimate. The confidence interval for the log of a measure's EUL is similarly symmetric about the log of the measure's EUL estimate. However, the confidence interval for a measure's EUL based on the confidence interval for the log of the measure's EUL is not symmetric about the measure's EUL estimate. This is because the logarithmic transformation is nonlinear. Consequently, the confidence interval for a measure's EUL based on the approximate standard error of the measure's EUL estimate is less accurate than the confidence interval for the measure's EUL based on the confidence interval for the log of the measure's EUL.

The larger the approximate standard error of a measure's EUL estimate, the greater the consequences of the nonlinearity of the logarithmic transformation and the less accurate the confidence interval for the measure's EUL based on the approximate standard error of the measure's EUL estimate. The nonlinearity of the logarithmic transformation also explains why the confidence interval for a measure's EUL based on the approximate standard error of the measure's EUL estimate may contain negative values, which are clearly impossible. The confidence interval for a measure's EUL based on the confidence interval for the log of the measure's EUL will never contain negative values.

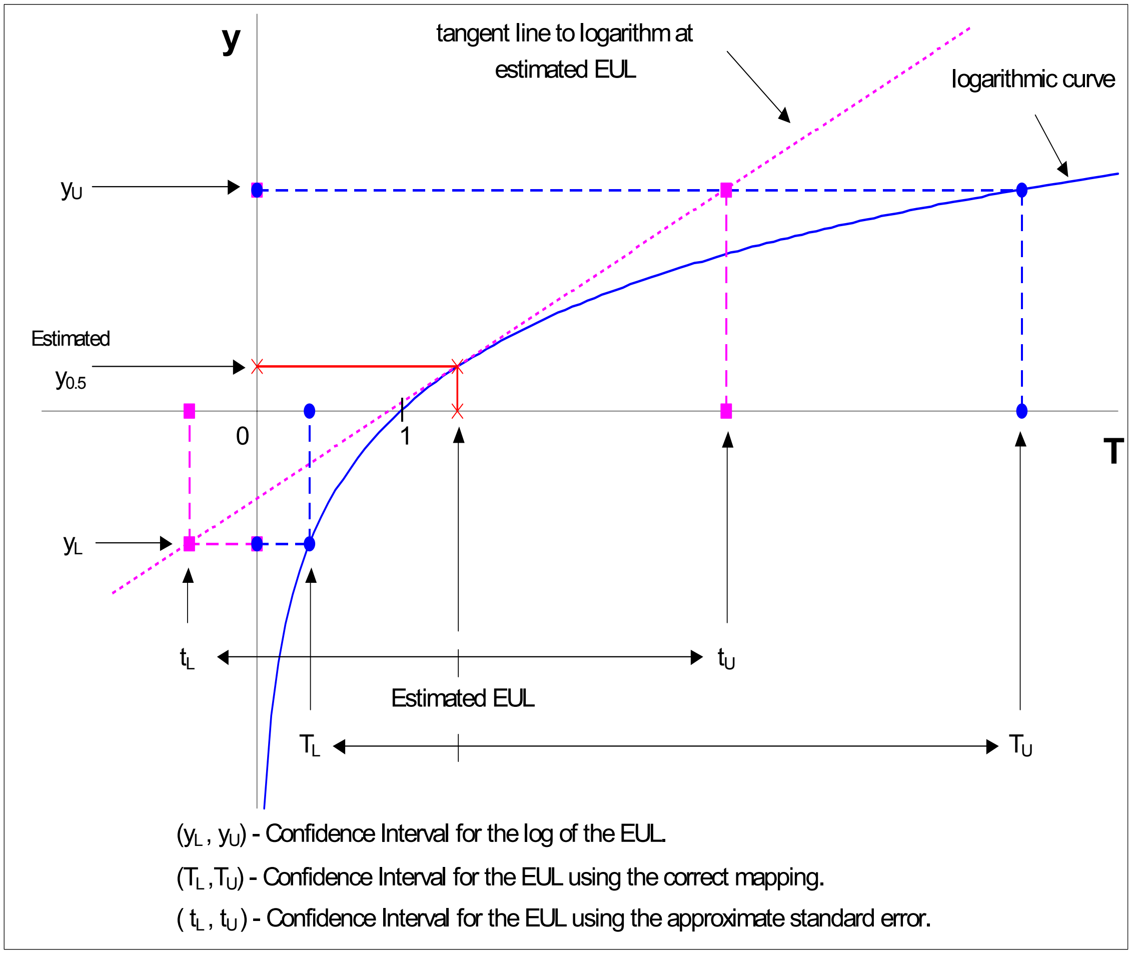
The two methods of calculating a confidence interval for a measure's EUL are illustrated in Figure 3-1. This study calculates and reports the more accurate confidence interval for a measure's EUL obtained from the confidence interval for the log of the measure's EUL.

### *3.3.1 Confidence Interval for the Log of a Measure's EUL*

In general, the bounds of a confidence interval for a parameter are calculated as the parameter estimate plus or minus the standard error of the parameter estimate times the critical value from the appropriate distribution for the desired level of confidence. The standard error of the log of a measure's EUL estimate employed in the calculation of the confidence interval for the log of the measure's EUL is provided by SAS. This standard error is a function of the standard errors of the parameter estimates of the general linear regression model. If necessary, the standard error of the log of a measure's EUL estimate provided by SAS is adjusted by the square root of the design effect.

The log of a measure's EUL estimate is assumed approximately normally distributed. Therefore, the critical value employed in the calculation of a confidence interval for the log of a measure's EUL is approximated using the value from the Student distribution for the appropriate degrees of freedom and desired level of confidence. The degrees of freedom equals the effective sample size $n_{eff}$ minus one, where $n_{eff}$ is the number of units of the measure employed in the analysis divided by the design effect. The value of $n_{eff}$ may be a non-integer.

**Figure 3-1**
**Two Methods of Calculating a Confidence Interval for the EUL**




## 3.4 Hypothesis Tests About the Value of a Measure's EUL

Results are reported for the test of whether a measure's ex ante and ex post EULs are the same or different. Formally, results are reported for the null hypothesis: a measure's ex ante and ex post EULs are equal, and the alternative hypothesis: the two EULs are not equal.

The statistic on which this test is based is:

$$\frac{\left|\log(ex\ post\ EUL) - \log(ex\ ante\ EUL)\right|}{adjusted, if\ necessary, standard\ error\ of\ the\ \log(ex\ post\ EUL)}.$$

The log of a measure's ex post EUL is assumed to have an approximate normal distribution with mean log (EUL) and unknown variance. Therefore, this test statistic has an approximate Student distribution with degrees of freedom equal to the effective sample size $n_{eff}$ minus 1.

The p-value is the probability of obtaining a value of the test statistic greater than or equal to the value calculated if a measure's ex ante and ex post EULs are in fact the same (the null hypothesis is true). In this study, if the p-value is less than or equal 0.20, a measure's ex ante and ex post EULs are concluded to be different (the null hypothesis is rejected).

## 3.5 REFERENCES

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# 4 LIGHTING MEASURES RESULTS

This section presents the retention analysis results for selected lighting measures installed under PG&E's 1996 & 1997 IEEI Programs. Recall, for each measure, the ultimate objective of this study is to estimate the median retention time or effective useful life (EUL). To begin, data descriptive of the lighting measure data employed in the analysis are provided. Next, the adjustment applied to the standard errors of both the log of a measure's EUL estimate and its EUL estimate is reported. Lastly, the results of the survival analysis are discussed.

## 4.1 DESCRIPTIVE STATISTICS

This study analyzes the retention of two lighting measures:

1. L23 - Fixture: T-8 lamp & electric ballast, 4 ft fixture
2. L81 - HID Fixture: interior, standard, 251-400 watt lamp.

Table 4-1 shows the number of projects included in the retention analysis as compared with the number in the population and the impact evaluation by lighting measure. This table also shows the number of units of a lighting measure included in the retention analysis as compared with the number in the impact evaluation. For each lighting measure, a large percentage of units included in the impact evaluation are also included in this study: 79 percent for lighting measure L23 and 98 percent for lighting measure L81.

**Table 4-1**
**Retention Analysis Data**

| Lighting Measure | *ex ante* EUL (years) | Number of Projects | | | Number of Units | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Retention Analysis | | | |
| | | Population | Impact Evaluation | Retention Analysis | Impact Evaluation | Total | 3rd-year On-site Only | 6th-year On-site Only | 3rd- and 6th-year On-sites |
| L23 | 16 | 363 | 198 | 175 | 148,063 | 117,467 | 18,449 | 5,033 | 93,985 |
| L81 | 16 | 90 | 57 | 54 | 2,573 | 2,517 | 171 | 0 | 2,346 |

The third- and sixth-year on-site inspection data provide a limited opportunity to examine at a descriptive level the path that the time to non-retention a unit of the measure follows. The non-retention rate of units of a measure over time determines the measure's EUL, the time at which half the units installed during a program year are not retained. By lighting measure, Table 4-2 presents the retention status of units during two time periods: between installation and the third-year on-site inspection and between the third- and sixth-year on-site inspections. Note that only units for which an on-site inspection was conducted in both the third- and sixth-years are included in the data presented in Table 4-2.

**Table 4-2**
**Retention Status During Two 3-year Time Periods**

| Lighting Measure | *ex ante* EUL (years) | # Initially Installed Units | Installation Thru 3rd-year On-site | | 3rd-year On-site Thru 6th-year On-site | |
|---|---|---|---|---|---|---|
| | | | % Units Not Retained | # Retained Units | % Units Not Retained | # Retained Units |
| L23 | 16 | 93,985 | 3.2% | 91,013 | 9.3% | 82,594 |
| L81 | 16 | 2,346 | 1.1% | 2,321 | 29.3% | 1,642 |

For both lighting measures, the percentage of units not retained is larger during the later 3-year period than during the earlier 3-year period. This pattern is consistent with a unit of a measure being not retained due to failure. However, this pattern is also not necessarily inconsistent with the variety of other reasons units of a measure may be not retained: space remodeled or use of space changed, units damaged due to external factors (such as fire or flooding), dissatisfaction with performance or appearance, and failure.

Table 4-3 presents the retention status of units of a lighting measure between installation and the sixth-year on-site inspection. Units for which an on-site inspection was conducted in either the third or sixth year are included in these data. In Table 4-3, the retention status of units is per the latest on-site inspection data; therefore, the percentages of units not retained are minimums. The percentages are minimums because if the latest on-site inspection data for a unit is from the third year and that unit was counted as retained in the third year, Table 4-3 continues to count that unit as retained in the sixth year. Based on these data, after 6 years, 12 percent of lighting measure L23 units have been not retained, and 28 percent of lighting measure L81 units have been not retained.

**Table 4-3**
**Retention Status After 6 Years**

| Lighting Measure | # Initially Installed Units[a] | % Units Not Retained | # Retained Units |
|---|---|---|---|
| L23 | 117,467 | 11.8% | 103,581 |
| L81 | 2,517 | 28.0% | 1,813 |

[a] For both lighting measures, the number of initially installed units in this table is different from the number in Table 4-2 because this table includes all units included in the analysis (i.e., an on-site inspection was conducted in either the third- or sixth-year), whereas Table 4-2 includes only those units for which an on-site inspection was conducted in both the third and sixth years.

For some units of the lighting measures not retained, the on-site inspection data offers an explanation. Table 4-4 lists the variety of reasons units of the lighting measures were not retained. At the time of the third-year on-site inspection, the largest percentage of units of lighting measure L23 not retained and the largest percentage of units of lighting measure L81 not retained were not retained due to changes in the use of space, 40 percent and 76 percent, respectively. For lighting measure L23, the next most common cause of non-retention of units is remodeling at 30 percent, and for lighting measure L81, it is equipment failure at 12 percent. This is the only time failure is a major cause of non-retention of units of a lighting measure.

**Table 4-4**
**Why Units Were Not Retained**

| | Units of L23 Not Retained | | | | Units of L81 Not Retained | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | At 3rd-year On-site | | At 6th-year On-site | | At 3rd-year On-site | | At 6th-year On-site | | | |
| Reason Not Retained | # | % | # | % | # | % | # | % | # | % |
| Equipment failed | 10 | <1% | 198 | 2% | 3 | 12% | 1 | <1% | 212 | 1% |
| Equipment upgraded | | | 3,138 | 30% | | | | | 3,138 | 22% |
| Remodel | 973 | 30% | 2,304 | 22% | | | | | 3,277 | 22% |
| Change of use | 1,297 | 40% | 368 | 3% | 19 | 76% | | | 1,684 | 12% |
| Facility/Part-of-facility closed down | | | 4,344 | 41% | | | 671 | 99% | 5,015 | 34% |
| Other | 127 | 4% | 22 | <1% | | | | | 149 | 1% |
| Total possible | 3,263 | | 10,623 | | 25 | | 679 | | 14,590 | |

At the time of the sixth-year on-site inspection, the most common cause of non-retention of units is again the same for both lighting measures, facility closures. Facility closures affected 41 percent of units of lighting measure L23 not retained and 99 percent of units of lighting measure L81 not retained. For lighting measure L23, other major causes of non-retention of units were upgrading equipment and remodeling, at 30 percent and 22 percent, respectively. Remodeling was also identified as a major cause of non-retention of units of lighting measure L23 at the time of the third-year on-site inspection. Clearly, at the 6-year point in the lives of the studied measures, equipment failure is but a small contributor to non-retention, explaining only about 1 percent of all removals. The other factors, which are more a function of business decisions and outcomes, are the predominant drivers in measure retention at this stage of the studied measures lives. These factors are mainly a function of the business climate and are difficult to predict.

## 4.2 ADJUSTMENT TO THE STANDARD ERROR

For each lighting measure, it is necessary to correct the standard errors of both the log of the measure's EUL estimates and its EUL estimates. As discussed in detail earlier in this report (Section 3 Study Methods, Subsection 3.2.2, Adjustment to the Standard Error), it is necessary because the standard errors are initially calculated assuming the sample that produced the estimates is a simple random sample, which it is not. The adjustment applied to the standard errors is reported in Table 4-5. The adjustment equals the square root of the design effect.

**Table 4-5**
**Adjustment to the Standard Errors**

| Lighting Measure | Adjustment |
|---|---|
| L23 | 37.48 |
| L81 | 6.73 |

For lighting measure L23, the adjustment applied to the standard errors is based on the design effect for unequal clusters and for lighting measure L81, this adjustment is based on the design effect for equal clusters. Projects (clusters) do not contain the same number of units of lighting measure L23 nor do they contain the same number of units of lighting measure L81. However, in the case of lighting measure L81, the analysis data do not meet the criterion necessary for the estimate of the design effect for unequal clusters to be valid. Therefore, for lighting measure L81, the design effect is estimated using average cluster size and the design effect for equal clusters, which usually provides a reasonable estimate.

It is necessary to correct the standard errors to the extent that the times to non-retention of units of a measure are more similar within a project than between projects. Estimates of a measure's within-project variance ($s_w^2$) and between-projects variance ($s_b^2$) provide some indication of the extent to which this is the case. For each lighting measure, Table 4-6 gives the estimates of these variances. For both lighting measures, the within-project variance estimate is smaller than the between-project variance estimate.

**Table 4-6**
**Variance Estimates**

| Variance Component | Lighting Measure | | | | | |
|---|---|---|---|---|---|---|
| | L23 | | | L81 | | |
| Within-project variance ($s_w^2$) | 0.020 | Min. | 0.000 | 0.004 | Min. | 0.000 |
| | | Max. | 0.244 | | Max. | 0.088 |
| Between-project variance ($s_b^2$) | 0.102 | | | 0.128 | | |

## 4.3 SURVIVAL ANALYSIS RESULTS

For each lighting measure, Table 4-7 presents the results of the survival analysis. Results are presented for each distribution for which it was possible to fit a general linear regression model. The more parameters a distribution has, the more observations there must be on units of a measure not retained in order to fit the general linear regression model. Therefore, it is easiest to fit a model assuming the time to non-retention of a unit of a measure follows an Exponential distribution, with only one free parameter, and it is hardest to fit a model assuming a Gamma distribution, with its three free parameters. The remaining distributions each have two free parameters. The confidence intervals reported in Table 4-7 are based on the corrected standard errors of the log of EUL estimates. Similarly, the standard errors reported in the table are the corrected standard errors.

**Table 4-7**
**Survival Analysis Results**

| Lighting Measure | *ex ante* EUL (years) | Distribution | Maximum of Log Likelihood | Selected Parameter Estimates: Scale | Selected Parameter Estimates: Shape | *ex post* EUL (years) | 80% Confidence Interval (EUL in years) | Standard Error (years) |
|---|---|---|---|---|---|---|---|---|
| L23 ($n_{eff}$ = 84) | 16 | Exponential | -67,153 | 1.00 [a] | - | 29.8 | ( 19.7, 44.9 ) | 9.47 |
| | | Log-logistic | -63,598 | 0.40 | - | 11.9 | ( 8.2, 17.4 ) | 3.51 |
| | | Log-normal | -63,335 | 0.80 | - | 13.8 | ( 8.9, 21.6 ) | 4.78 |
| | | Weibull | -63,663 | 0.41 | - | 11.0 | ( 7.8, 15.4 ) | 2.90 |
| L81 ($n_{eff}$ = 56) (*rho* =0.97) | 16 | Exponential | -2,213 | 1.00 [a] | - | 14.1 | ( 10.2, 19.6 ) | 3.59 |
| | | Gamma | -1,616 | 0.41 | -3.5 | 10.3 | ( 3.5, 30.6 ) | 8.64 |
| | | Log-logistic | -1,740 | 0.22 | - | 7.6 | ( 6.8, 8.5 ) | 0.67 |
| | | Log-normal | -1,704 | 0.39 | - | 7.7 | ( 6.8, 8.8 ) | 0.76 |
| | | Weibull | -1,762 | 0.25 | - | 7.5 | ( 6.8, 8.3 ) | 0.59 |

[a] The value of the scale parameter for the Exponential distribution is always 1, it is not estimated.

For each of the lighting measures, it was possible to estimate the measure's EUL employing different distributional assumptions regarding the time to non-retention of a unit of the measure. The selection of which distributional assumption is most appropriate is based on several criteria:

- Analysis of residuals
- Likelihood ratio test
- Implications for the non-retention rate over time
- Maximum of the log-likelihood function.

### *4.3.1 Lighting Measure L23*

In the case of lighting measure L23, depending on the distribution, the measure's ex ante EUL may be inside or outside the 80-percent confidence interval. And depending on the distribution, its ex ante EUL may be outside the 80-percent confidence interval and smaller than or larger than its ex post EUL. Lighting measure L23's ex post EULs range between 11.0 and 29.8 years, compared with its ex ante EUL of 16 years. The endpoints of this range of ex post EULs correspond to the Weibull and Exponential distributions, respectively. As explained below, it appears most appropriate to assume the time to non-retention of a unit of lighting measure L23 follows a Log-normal distribution, which produces an ex post EUL of 13.8 years.

The residual analysis does not suggest any distribution is more appropriate than another. However, a likelihood ratio test rules out the Exponential distribution. Based on the likelihood ratio test, the Weibull distribution is more appropriate than the Exponential distribution at a better than 1-percent significance level.

Considering all but the Exponential distribution, the survival analysis results suggest the non-retention rate over time of units of lighting measure L23 is initially increasing then decreasing or always increasing. The estimated scale parameter of both the Log-logistic and Weibull distributions is less than 1. In the case of the Log-logistic distribution, this means the non-retention rate over time increases then decreases. In the case of the Weibull distribution, a scale parameter less than 1 means the non-retention rate over time is always increasing. The Log-normal distribution always results in a non-retention rate over time that increases then decreases.

Again, considering all but the Exponential distribution, the Log-normal distribution has the largest maximum value of the log-likelihood function, followed by the Log-logistic distribution and then the Weibull distribution. On the surface, a non-retention rate over time that is always increasing rather than increasing then decreasing seems more consistent with the earlier observation that the percentage of units of lighting measure L23 not retained is larger during the later 3-year period than during the earlier 3-year period. However, such broad times to non-retention appear to be masking more refined times to non-retention consistent with a non-retention rate over time that is increasing then decreasing.

It is worth noting that, although it appears most appropriate to assume the time to non-retention of a unit of lighting measure L23 follows a Log-normal distribution, the Log-logistic and Weibull distributions produce very similar results. In the cases of the Log-normal and Log-logistic distributions, lighting measure L23's ex ante EUL is inside the 80-percent confidence interval. In the case of the Weibull distribution, its ex ante EUL is outside the 80-percent confidence interval, but it is just outside. Lighting measure L23's ex ante EUL is 16 and the upper bound of the confidence interval when a Weibull distribution is assumed is 15.4 years. In addition, the three distributions produce very similar ex post EULs, ranging between 11.0 and 13.8 years.

### *4.3.2 Lighting Measure L81*

In the case of lighting measure L81, depending on the distribution, the measure's ex ante EUL may be inside or outside of the 80-percent confidence interval. If lighting measure L81's ex ante EUL is outside the 80-percent confidence interval, it is larger than its ex post EUL. Lighting measure L81's ex post EULs range between 7.5 and 14.1 years, compared with its ex ante EUL of 16 years. The end points of this range of ex post EULs correspond to the Weibull and Exponential distributions, respectively. As explained below, it appears most appropriate to assume the time to non-retention of a unit of lighting measure L81 follows a Gamma distribution, which produces an ex post EUL of 10.3 years.

The residual analysis does not suggest any distribution is more appropriate than another. However, likelihood ratio tests rule out the Weibull, Exponential, and Log-normal distributions. Based on the likelihood ratio test, at a better than 1-percent level of significance, the Gamma distribution is more appropriate than the Weibull, Exponential, and Log-normal distributions.

The survival analysis results for the Log-logistic distribution suggest the non-retention rate over time of units of lighting measure L81 is increasing then decreasing (the estimated scale parameter is less than 1). The survival analysis results for the Gamma distribution, the only other distribution that has not been ruled out based on a likelihood ratio test, does not have clear descriptive implications for the non-retention rate over time of units of lighting measure L81.

The Gamma distribution allows the non-retention rate over time of units to look a variety of ways.

Of the Gamma and Log-logistic distributions, the Gamma distribution has the largest maximum value of the log-likelihood function. In addition, with an additional parameter the Gamma distribution can better fit the available data on the times to non-retention of units of lighting measure L81. The selection of the Gamma distribution over the Log-logistic distribution does have consequences. Lighting measure L81's ex ante EUL is inside the 80-percent confidence interval when a Gamma distribution is assumed; whereas it is outside the 80-percent confidence interval and larger than the ex post EUL when a Log-logistic distribution is assumed. These two confidence intervals are (3.5, 30.6) and (6.8 and 8.5), respectively.

Recall that 1 percent of units of lighting measure L81 were not retained during the earlier 3-year period, in contrast to the 29 percent of units not retained during the later 3-year period. The Gamma and Log-logistic distributions both appear to be picking up this increasing non-retention rate of units of lighting measure L81 over time, as they produce ex post EULs of 10.3 and 7.6 years, respectively. However, given the available data on the times to non-retention of units of lighting measure L81, the Gamma distribution associates a much larger error with its estimate of lighting measure L81's EUL than does the Log-logistic distribution. The Log-logistic distribution appears to put lighting measure L81's EUL in the increasing portion of a non-retention rate of units over time rather than the decreasing portion. If the Log-logistic distribution were less constrained, it may have put lighting measure L81's EUL in the decreasing portion of the non-retention rate of unit over time and also associated a larger error with its estimate of the measure's EUL.

## 4.4 SUMMARY

For each lighting measure, Table 4-8 provides a summary of the results for what appears to be the most appropriate distribution. A measure's EUL realization rate is its adopted EUL divided by its ex ante EUL.

**Table 4-8**
**Summary of Results**

| Lighting Measure | *ex ante* EUL (years) | Results Selected | | | | | Adopted *ex post* EUL (years) | EUL Realizatn Rate |
|---|---|---|---|---|---|---|---|---|
| | | Distributn | Non-ret Rate Over T | *ex post* EUL (years) | 80% Conf Interval (EUL in years) | P-value | | |
| L23 | 16 | Log-normal | Increases then decreases | 13.8 | ( 8.9 , 21.6 ) | 0.68 | 16.0 | 1.00 |
| L81 | 16 | Gamma | Not possible to specify | 10.3 | ( 3.5 , 30.6 ) | 0.61 | 16.0 | 1.00 |

Several points should be emphasized regarding these results:

- Although it appears most appropriate to assume the time to non-retention of a unit of lighting measure L23 follows a Log-normal distribution, the Log-logistic and Weibull distributions produce very similar results. A likelihood ratio test rules out the

Exponential distribution. Of the three considered distributions, two indicate that the ex ante EUL is within the 80-percent confidence interval of the ex post EUL estimate.

- In the case of lighting measure L81, a Gamma distribution was selected over a Log-logistic distribution as most appropriate. Likelihood ratio tests rule out the Weibull, Exponential, and Log-normal distributions. The Gamma distribution was selected over a Log-logistic distribution because it has the largest maximum value of the log-likelihood function and with an additional parameter can better fit the available data on the times to non-retention of units of lighting measure L81. The Gamma and Log-logistic distributions produce similar ex post EULs for lighting measure L81, 10.3 and 7.6 years, respectively. However, the Gamma distribution associates a much larger error with its estimate of lighting measure L81's EUL than does the Log-logistic distribution. The smaller error associated with the Log-logistic distribution may be largely due to constraints placed on this distribution that are not placed on the Gamma distribution.

# 5 PROCESS MEASURES RESULTS

This section presents the retention analysis results for selected process measures installed under PG&E's 1996 & 1997 IEEI Programs. Recall, for each measure, the ultimate objective of this study is to estimate the median retention time or effective useful life (EUL). To begin, data descriptive of the process measure data employed in the analysis are provided. Next, the adjustment applied to the standard errors of both the log of a measure's EUL estimate and its EUL estimate is reported. Lastly, the results of the survival analysis are discussed.

## 5.1 DESCRIPTIVE STATISTICS

This study analyzes the retention of six process measures:

1. 560 - Heat recovery
2. 578 - Adjustable speed drive
3. 589 - Air compressor system change/modify
4. 590 - Insulate
5. 599 - Other
6. P2 - Oil well pump-off controller.

As Table 5-1 shows, three of these six process measures, 578, 589, and 599, have at least two different ex ante EULs. Process measure 578 adjustable speed drive's ex ante EULs are similar enough, 16 and 15 years, and this analysis does not differentiate between them. Process measure 589 air compressor system change/modify's ex ante EULs are sufficiently different that this analysis considers three separate measures: 589A with an ex ante EUL of 18 years, 589B with ex ante EULs of 16 and 15 years, and 589C with an ex ante EUL of 12 years. Similarly, for process measure 599, this analysis considers three separate measures: 599A with an ex ante EUL of 20 years, 599B with ex ante EULs of 16 and 15 years, and 599C with an ex ante EUL of 10 years. Therefore, there are effectively 10 process measures when the ex ante EUL is taken into account.

Table 5-2 shows the number of projects included in the retention analysis compared with the number in the population and the impact evaluation by process measure. This table also compares the number of units of a process measure included in the retention analysis with the number in the impact evaluation. For all but two of the process measures, all units included in the impact evaluation are also included in this study. For process measures 599A and P2, 59 percent and 94 percent, respectively, of units included in the impact evaluation are also included in this study.

**Table 5-1**
**Process Measure and Ex Ante EUL Combinations**

| Process Measure | | *ex ante* EUL (years) |
|---|---|---|
| 560 | | 14 |
| 578 | | 16, 15 |
| 589 | A | 18 |
| | B | 16, 15 |
| | C | 12 |
| 590 | | 20 |
| 599 | A | 20 |
| | B | 16, 15 |
| | C | 10 |
| P2 | | 10 |

**Table 5-2**
**Retention Analysis Data**

| Process Measure | | *ex ante* EUL (years) | Number of Projects | | | Number of Units | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Retention Analysis | | | |
| | | | Population | Impact Evaluation | Retention Analysis | Impact Evaluation | Total | 3rd-year On-site Only | 6th-year On-site Only | 3rd- and 6th-year On-sites |
| 560 | | 14 | 2 | 2 | 2 | 2 | 2 | 0 | 1 | 1 |
| 578 | | 16, 15 | 6 | 6 | 6 | 7 | 7 | 0 | 0 | 7 |
| 589 | A | 18 | 3 | 3 | 3 | 6 | 6 | 0 | 0 | 6 |
| | B | 16, 15 | 2 | 2 | 2 | 3 | 3 | 0 | 1 | 2 |
| | C | 12 | 1 | 1 | 1 | 6 | 6 | 0 | 0 | 6 |
| 590 | | 20 | 4 | 4 | 4 | 53 | 53 | 0 | 0 | 53 |
| 599 | A | 20 | 5 | 5 | 3 | 496 | 291 | 17 | 268 | 6 |
| | B | 16, 15 | 3 | 3 | 3 | 6 | 6 | 0 | 0 | 6 |
| | C | 10 | 1 | 1 | 1 | 5 | 5 | 0 | 0 | 5 |
| P2 | | 10 | 8 | 8 | 5 | 433 | 405 | 0 | 202 | 203 |

For 5 of the 10 process measures, all units of the measure continue to be retained based on the third- and sixth-year on-site inspections. Table 5-3 lists these five process measures.

**Table 5-3**
**Process Measures with Zero Non-Retention**

| Process Measure | | *ex ante* EUL (years) |
|---|---|---|
| 560 | | 14 |
| 589 | B | 16, 15 |
| | C | 12 |
| 599 | B | 16, 15 |
| | C | 10 |

For the five remaining process measures, the third- and sixth-year on-site inspection data provide a limited opportunity to examine at a descriptive level the path the time to non-retention a unit of the measure follows. The non-retention rate of units of a measure over time determines the measure's EUL, the time at which half the units installed during a program year are not retained. For the five process measures for which units have not been retained, Table 5-4 presents the retention status of units during two time periods: between installation and the third-year on-site inspection and between the third- and sixth-year on-site inspections. Note that only units for which an on-site inspection was conducted in both the third- and sixth-years are included in the data presented in Table 5-4.

**Table 5-4**
**Retention Status During Two 3-year Time Periods**

| | | | Installation Thru 3rd-year On-site Inspection | | | 3rd-year On-site Inspection Thru 6th-year On-site Inspection | | |
|---|---|---|---|---|---|---|---|---|
| | | | % Units Not Retained | | | % Units Not Retained | | |
| Process Measure | *ex ante* EUL (years) | # Initially Installed Units | Simple % | Weighted %, Weight = Energy Costs Avoided | # Retained Units | Simple % | Weighted %, Weight = Energy Costs Avoided | # Retained Units |
| 578 | 16, 15 | 7 | 0.0% | 0.0% | 7 | 14.3% | 64.2% | 6 |
| 589A | 18 | 6 | 33.3% | 11.8% | 4 | 0.0% | 0.0% | 4 |
| 590 | 20 | 53 | 0.0% | 0.0% | 53 | 3.8% | 1.4% | 51 |
| 599A[a] | 20 | 6 | 0.0% | 0.0% | 6 | 0.0% | 0.0% | 6 |
| P2 | 10 | 203 | 3.0% | 0.9% | 197 | 0.0% | 0.0% | 197 |

[a] All of the units of process measure 599A for which an on-site inspection was conducted in both the third- and sixth-years continue to be retained; these are the data included in this table. However, as Table 5-5 shows below, some units of process measure 599A for which an on-site inspection was conducted in only the third- or sixth-year have not been retained.

According to Table 5-4, for process measures 578 and 590, both the simple and weighted percentage of units not retained is larger during the later 3-year period than during the earlier 3-year period. This is the pattern we would expect if failure is the primary reason a unit of a measure may be not retained. On the other hand, for process measures 589A and P2, both the simple and weighted percentage of units not retained is larger during the earlier 3-year period than during the later 3-year period. This pattern serves as a reminder that units of a measure may be not retained for a variety of reasons: space remodeled or use of space changed, equipment damaged due to external forces, dissatisfaction with performance or appearance, and failure.

Table 5-5 presents the retention status of units of a measure between installation and the sixth-year on-site inspection. Units for which an on-site inspection was conducted in either the third- or sixth-year are included in these data. In Table 5-5, the retention status of units is per the latest on-site inspection data and, therefore, the percentages of units not retained are minimums. The percentages are minimums because if the latest on-site inspection data for a unit is from the third year and that unit was counted as retained in the third year, Table 5-5 continues to count that unit as retained in the sixth year. Both process measures 578 and 599A appear to have an EUL of less than 6 years. For each of these measures, more than 50 percent of the energy costs avoided have been not retained within 6 years of installation.

**Table 5-5**
**Retention Status After Six Years**

| Process Measure | # Initially Installed Units[a] | % Units Not Retained | | # Retained Units |
|---|---|---|---|---|
| | | Simple % | Weighted %, Weight = Energy Costs Avoided | |
| 578 | 7 | 14.3% | 64.2% | 6 |
| 589A | 6 | 33.3% | 11.8% | 4 |
| 590 | 53 | 3.8% | 1.4% | 51 |
| 599A | 291 | 92.1% | 97.4% | 23 |
| P2 | 405 | 1.5% | 0.4% | 399 |

[a] For process measure 599A and P2, the number of initially installed units in this table is different from the number in Table 5-4 because this table includes all units included in the analysis (i.e., an on-site inspection was conducted in either the third or sixth year), whereas Table 5-4 includes only those units for which an on-site inspection was conducted in both the third and sixth years.

For some units of the process measures not retained, the on-site inspection data offers an explanation. The single unit of process measure 578 not retained and all the units of process measure 599A not retained were not retained due to facility closures. Also, both units of process measure 589A not retained were not retained due to remodeling/change of use.

## 5.2 ADJUSTMENT TO THE STANDARD ERROR

In the cases of process measures 599A and P2, it is necessary to correct the standard errors of both the log of the measure's EUL estimates and its EUL estimates. As discussed in detail earlier in this report (Section 3 Study Methods, Subsection 3.2.2, Adjustment to the Standard Error), it is necessary because the standard errors are initially calculated assuming the sample that produced the estimates is a simple random sample, which it is not. In the cases of process measures 578, 589A, and 590, it is not necessary to correct the standard errors because all projects that obtained a rebate for the measure are included in the analysis.

For process measures 599A and P2, the adjustment applied to the standard errors is reported in Table 5-6. The adjustment equals the square root of the design effect. For process measure 599A, the adjustment applied to the standard errors is based on the design effect for equal clusters and for process measure P2, this adjustment is based on the design effect for unequal clusters. Projects (clusters) do not contain the same number of units of process measure 599A nor do they contain the same number of units of process measure P2. However, in the case of process measure 599A, the analysis data do not meet the criterion necessary for the estimate of the design effect for unequal clusters to be valid. Therefore, for process measure 599A, the design effect is estimated using average cluster size and the design effect for equal clusters, which usually provides a reasonable estimate.

**Table 5-6**
**Adjustment to the Standard Errors**

| Process Measure | Adjustment |
|---|---|
| 599A | 9.85 |
| P2 | 2.77 |

It is necessary to correct the standard errors to the extent that the times to non-retention of units of a measure are more similar within a project than between projects. Estimates of a measure's within-project variance ($s_w^2$) and between-projects variance ($s_b^2$) provide some indication of the extent to which this is the case. For process measures 599A and P2 Table 5-7 gives the estimates of these variances.

**Table 5-7**
**Variance Estimates**

| Variance Component | Process Measure | | | | | |
|---|---|---|---|---|---|---|
| | 599A | | | P2 | | |
| Within-project variance ($s_w^2$) | 0.000 | Min. | 0.000 | 0.025 | Min. | 0.000 |
| | | Max. | 0.000 | | Max. | 0.123 |
| Between-project variance ($s_b^2$) | 0.333 | | | 0.004 | | |

For process measure 599A, the within-project variance estimate is smaller than the between-project variance estimate. For process measure P2, with less than 2 percent of units not retained, the within-project variance estimate is actually larger than the between-projects variance estimate.

## 5.3 Survival Analysis Results

It is only possible to produce survival analysis results for a measure if at least one unit of the measure has not been retained. Consequently, survival analysis results were produced only for process measures 578, 589A, 590, 599A, and P2. For each measure, Table 5-8 presents results of the survival analysis.

Results are presented for each distribution for which it was possible to fit a general linear regression model. The more parameters a distribution has, the more observations there must be on units of a measure not retained in order to fit the general linear regression model. Therefore, it is easiest to fit a model assuming the time to non-retention of a unit of a measure follows an Exponential distribution, with only one free parameter, and it is hardest to fit a model assuming a Gamma distribution, with its three free parameters. The remaining distributions each have two free parameters.

**Table 5-8**
**Survival Analysis Results**

| Process Measure | *ex ante* EUL (years) | Distribution | Maximum of Log Likelihood | Selected Parameter Estimate: Scale | *ex post* EUL (years) | 80% Confidence Interval (EUL in years) | Standard Error (years) |
|---|---|---|---|---|---|---|---|
| 578 ($n_{eff}$ = 7) | 16, 15 | Exponential | -9.966 | 1.00 [a] | 4.4 | ( 2.3, 8.4 ) | 1.97 |
| 589A ($n_{eff}$ = 6) | 18 | Exponential | -3.103 | 1.00 [a] | 32.7 | ( 5.6, 188.7 ) | 38.81 |
| | | Log-logistic | -3.066 | 1.22 | 67.7 | ( 0.5, 8,459.6 ) | 221.40 |
| | | Log-normal | -3.008 | 2.32 | 90.1 | ( 0.4, 18,963.1 ) | 326.56 |
| | | Weibull | -3.079 | 1.28 | 52.9 | ( 0.6, 4,399.5 ) | 158.40 |
| 590 ($n_{eff}$ = 53) | 20 | Exponential | -3.878 | 1.00 [a] | 328.5 | ( 62.9, 1,716.7 ) | 418.48 |
| | | Log-logistic | -3.701 | 0.39 | 31.8 | ( 1.2, 849.7 ) | 80.51 |
| | | Log-normal | -3.674 | 1.07 | 63.3 | ( 0.8, 5,141.0 ) | 214.42 |
| | | Weibull | -3.701 | 0.40 | 27.8 | ( 1.3, 582.7 ) | 65.15 |
| 599A ($n_{eff}$ = 3) (*rho* =1.00) | 20 | Exponential | -163.439 | 1.00 [a] | 4.0 | ( 1.0, 16.7 ) | 3.02 |
| P2 ($n_{eff}$ = 53) | 10 | Exponential | -21.265 | 1.00 [a] | 520.8 | ( 76.7, 3,537.0 ) | 768.60 |

[a] The value of the scale parameter for the Exponential distribution is always 1, it is not estimated.

For process measures 599A and P2, the confidence intervals reported in Table 5-8 are based on the corrected standard errors of the log of EUL estimates. Similarly, for these process measures, the standard errors reported in the table are the corrected standard errors. In the cases of process measures 578, 589A, and 590, it was not necessary to correct the standard errors because all projects that obtained a rebate for the measure are included in the analysis.

### *5.3.1 Process Measures 578, 599A, and P2*

In the cases of process measures 578, 599A, and P2, it is only possible to fit a general linear regression model when the time to non-retention of a unit is assumed to follow an Exponential distribution.

#### *Process Measures 578 and 599A*

For process measures 578 and 599A, the measure's ex ante EUL is outside the 80-percent confidence interval and larger than its ex post EUL. These results are not surprising because each of these measures has an ex ante EUL of 15 or more years and more than 50 percent of the measure's energy costs avoided have been not retained within 6 years of installation.

Process measure 578's ex post EUL is 4.4 years, compared with its ex ante EUL of about 15 years. Although it was possible to estimate process measure 578's EUL under only one distributional assumption, given 64 percent of the measure's energy costs avoided were not retained sometime between 3 and 6 years after installation, the estimate obtained, 4.4 years, seems reasonable.

Process measure 599A's ex post EUL is 4.0 years, compared with its ex ante EUL of 20 years. Although it was possible to estimate process measure 599A's EUL under only one distributional assumption, given 97 percent of the measure's energy costs avoided were not retained sometime within 6 years of installation, the estimate obtained, 4.0 years, seems reasonable.

### 5.3.2 Process Measure P2

Process measure P2's ex ante EUL is outside the 80-percent confidence interval and smaller than its ex post EUL. However, process measure P2's ex post EUL is 520.8 years, which is clearly not reasonable. This estimate is based on the times to non-retention of less than 1 percent of energy costs avoided not retained.

### 5.3.3 Process Measures 589A and 590

For process measures 589A and 590, it was possible to estimate the measure's EUL employing different distributional assumptions regarding the time to non-retention of a unit of the measure. The selection of which distributional assumption is most appropriate is based on several criteria:

- Analysis of residuals
- Likelihood ratio test
- Implications for the non-retention rate over time
- Maximum of the log-likelihood function.

#### Process Measure 589A

In the case of process measure 589A, for all distributions, the measure's ex ante EUL is inside the 80-percent confidence interval. Consequently, for process measure 589A, which distribution is adopted is of little consequence.

Process measure 589A's ex post EULs range between 32.7 and 90.1 years, compared with its ex ante EUL of 18 years. The endpoints of this range of ex post EULs correspond to the Exponential and Log-normal distributions, respectively. As explained below, it appears most appropriate to assume the time to non-retention of a unit of process measure 589A follows a Log-logistic distribution, which produces an ex post EUL of 67.7 years.

The residual analysis does not suggest any distribution is more appropriate than another. However, a likelihood ratio test rules out the Weibull distribution. Based on the likelihood ratio test, at a 10-percent level of significance, the Weibull distribution is not more appropriate than the Exponential distribution.

Considering all but the Weibull distribution, the survival analysis results suggest the non-retention rate over time of units of process measure 589A is constant or decreasing. The Exponential distribution always results in a constant non-retention rate over time. The estimated scale parameter of the Log-logistic distribution is greater than 1, which means the non-retention rate over time is always decreasing. Consequently, the Log-normal distribution, which always results in a non-retention rate over time that increases then decreases, does not appear to be appropriate. The Log-logistic distribution will also produce a non-retention rate over time with this same shape if its scale parameter is less than one; however, its estimated scale parameter is greater than 1.

Of the Exponential and Log-logistic distributions, the Log-logistic distribution has the largest maximum value of the log-likelihood function. In addition, a non-retention rate over time that is always decreasing rather than constant is consistent with the earlier observation that the percentage of units of process measure 589A not retained is larger during the earlier 3-year period than during the later 3-year period.

### *5.3.4 Process Measure 590*

In the case of process measure 590, for all but the Exponential distribution, the measure's ex ante EUL is inside the 80-percent confidence interval. Process measure 590's ex post EULs range between 27.8 and 328.5 years, compared with its ex ante EUL of 20 years. The endpoints of this range of ex post EULs correspond to the Weibull and Exponential distributions, respectively. As explained below, it appears most appropriate to assume the time to non-retention of a unit of process measure 590 follows a Log-normal distribution, which produces an ex post EUL of 63.3 years.

The residual analysis does not suggest any distribution is more appropriate than another. However, a likelihood ratio tests rules out the Weibull distribution. Based on the likelihood ratio test, at a 10-percent level of significance, the Weibull distribution is not more appropriate than the Exponential distribution.

Considering all but the Weibull distribution, the survival analysis results suggest the non-retention rate over time of units of process measure 590 is constant or, after initially increasing, is decreasing. The Exponential distribution always results in a constant non-retention rate over time. The estimated scale parameter of the Log-logistic distribution is less than 1, which means the non-retention rate over time increases then decreases. The Log-normal distribution always results in a non-retention rate over time that increases then decreases.

Again, considering all but the Weibull distribution, the Log-normal distribution has the largest maximum value of the log-likelihood function.

## 5.4 SUMMARY

For each process measure, Table 5-9 provides a summary of the results for what appears to be the most appropriate distribution. A measure's EUL realization rate is its adopted EUL divided by its ex ante EUL.

**Table 5-9**
**Summary of Results**

| Process Measure | *ex ante* EUL (years) | Results Selected: Distributn | Non-ret Rate Over T | *ex post* EUL (years) | 80% Conf Interval (EUL in years) | P-value | Adopted *ex post* EUL (years) | EUL Realizatn Rate |
|---|---|---|---|---|---|---|---|---|
| 578 | 16<br>15 | Exponential | Constant | 4.4 | ( 2.3 , 8.4 ) | 0.03 | 4.4 | 0.28<br>0.29 |
| 589A | 18 | Log-logistic | Decreases | 67.7 | ( 0.5 , 8,459.6 ) | 0.70 | 18.0 | 1.00 |
| 590 | 20 | Log-normal | Increases then decreases | 63.3 | ( 0.8 , 5,141.0 ) | 0.74 | 20.0 | 1.00 |
| 599A | 20 | Exponential | Constant | 4.0 | ( 1.0 , 16.7 ) | 0.17 | 4.0 | 0.20 |
| P2 | 10 | Exponential | Constant | 520.8 | ( 76.7 , 3,537.0 ) | 0.01 | 10.0 | 1.00 |

Several points should be emphasized regarding these results:

- Although it was possible to estimate process measure 578's EUL under only one distributional assumption, given 64 percent of the measure's energy costs avoided were not retained sometime between 3 and 6 years after installation, the estimate obtained, 4.4 years, seems reasonable.
- In the case of process measure 589A, for all distributions, the measure's ex ante EUL is inside the 80-percent confidence interval.
- In the case of process measure 590, for all but the Exponential distribution, the measure's ex ante EUL is inside the 80-percent confidence interval. When an Exponential distribution is assumed the measure's ex post EUL is 328.5 years; whereas when one of the other distributions is assumed, its ex post EUL ranges between 27.8 and 63.3 years. The Log-normal distribution was selected as the most appropriate distributional assumption based on several criteria.
- Although it was possible to estimate process measure 599A's EUL under only one distributional assumption, given 97 percent of the measure's energy costs avoided were not retained sometime within 6 years of installation, the estimate obtained, 4.0 years, seems reasonable.
- For process measure P2, it is only possible to fit a general linear regression model when the time to non-retention of a unit is assumed to follow an Exponential distribution. Although process measure P2's ex ante EUL is outside the 80-percent confidence interval, its ex post EUL is 520.8 years, which is clearly not reasonable. Therefore, process measure P2's adopted ex post EUL equals its ex ante EUL.

A

# On-Site Data Collection Instrument

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| Control Num | Application Num | Check Num | Check Date | Check paid to |
|---|---|---|---|---|
| «CNTL» | «CODE» | «CHECKNO» | «CHKIS_DT» | «Payable» |
| Complex | | | | |
| «Custname», «Seradd», «Sercity», CA «SERZIP» | | | | |

**Project Description:** «Prjdesc» «Prjdesc2»

**Measure Description:** «Measdesc»

**Item Description:** «ITEMDSC»

**Location:** «LOCATION»

**Other notes:** «PRJNOTES»

**Measure Level Data:** Number of units originally purchased: **«P_NUMPUR»**
Paid Savings: **«P_KWH»** kWh **«P_KW»** kW **«P_THM»** therms
Rebate: «P_REBATE»

| **Measure Attribute** Measure Number → | | |
|---|---|---|
| Measure Code | «P_MEASUR» | **Corrections (If Any)** |
| Install Date | «INSTDATE» | |
| Customer Equipment Name | «CUSTEQP» | |
| Manufacturer | «EQPMFR» | |
| Model Number | «MODELNUM» | |
| Serial Number | SERIALNM | |
| Rated Output Capacity / Size | «EQPSIZE» | |
| Rated Input Volts / RL Amps / therms | «EQPPOWER» | |
| Lamps per fixture | «LAMPFIXT» | |
| Observed in Eval = # Expected $3^{rd}$-Yr. | «EXPECT3» | |
| Observed $3^{rd}$-Yr. = **Number Expected** $6^{th}$-Yr. | «EXPECT6» | |
| **Number Observed** | «OBSERV» | |
| **Percent in Working Condition** | «WORKING» | |
| **Discrepancy Code** ***see table below*** | «DISCREP» | |
| **Removal Code** ***see table below*** | «REMOVE» | |
| **Removal Date** | «REMOVEDT» | |

## Table 1-Observed/Expected Discrepancy Codes

| Code | | Description |
|---|---|---|
| D | 1 | Removed, not replaced |
| D | 2 | Removed, replaced with similar |
| D | 3 | Removed, replaced with different (describe) |
| D | 4 | Never installed |
| D | 5 | Temporarily taken out of operation |
| D | 6 | Could not locate |
| D | 7 | Other (describe) |

## Table 2-Removal Codes

| Code | | Description |
|---|---|---|
| R | 1 | Equipment failed |
| R | 2 | Unsatisfactory Performance |
| R | 3 | Equipment Upgraded |
| R | 4 | Remodel |
| R | 5 | Change of use |
| R | 6 | Facility/Part-of-Facility Closed Down |
| R | 7 | Other (describe) |

# B

# TABLE 6B

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# Protocol Table 6B
## Results of Sixth-Year Retention Study
## Pacific Gas and Electric Company's 1996 & 1997 Industrial Energy Efficiency Incentive Programs

### PG&E Study ID Numbers:

**1996 Industrial Process: 353R2**
**1997 Industrial Process: 334aR2**
**1996 Industrial Lighting: 350R2**
**1997 Industrial Lighting: 334bR2**

| Item1 | | | Item 2 | | Item 3 | Item 4 | Item 5 | Item 6 | | Item 7 | Item 8 | Item 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | EUL (years) | | | | | | | | | |
| | | | | | | | | 80% Confidence Interval | | | | |
| Measure | End Use | Measure Description | *ex ante* | Source of *ex ante* | *ex post* (estimated from study) | Adopted *ex post* (to be used in claim) | *ex post* Standard Error | Lower Bound | Upper Bound | P-value for *ex post* | EUL Realization Rate (adopted *ex post* / *ex ante*) | "Like" Measures Associated with Studied Measures |
| L23 | Lighting | Fixture: T-8 Lamp & Electronic Ballast, 4ft Fixture | 16 | a | 13.8 | 16.0 | 4.78 | 8.9 | 21.6 | 0.68 | 1.00 | None |
| L81 | Lighting | HID Fixture: Interior, Standard, 251-400 Watt Lamp | 16 | a | 10.3 | 16.0 | 8.64 | 3.5 | 30.6 | 0.61 | 1.00 | None |
| 560 | Process | Heat Recovery | 14 | a | - | 14.0 | - | - | - | - | 1.00 | None |
| 578 | Process | Adjustable Speed Drive | 16<br>15 | a<br>a | 4.4 | 4.4 | 1.97 | 2.3 | 8.4 | 0.03 | 0.27<br>0.29 | None |
| 589 A | Process | Air Compressor System Change/ Modify | 18 | a | 67.7 | 18.0 | 221.40 | 0.5 | 8,459.6 | 0.70 | 1.00 | None |
| 589 B | Process | Air Compressor System Change/ Modify | 16<br>15 | a<br>a | - | 16.0<br>15.0 | - | - | - | - | 1.00<br>1.00 | None |
| 589 C | Process | Air Compressor System Change/ Modify | 12 | a | - | 12.0 | - | - | - | - | 1.00 | None |
| 590 | Process | Insulate | 20 | a | 63.3 | 20.0 | 214.42 | 0.8 | 5,141.1 | 0.74 | 1.00 | None |
| 599 A | Process | Other | 20 | a | 4.0 | 4.0 | 3.02 | 1.0 | 16.7 | 0.17 | 0.20 | None |
| 599 B | Process | Other | 16<br>15 | a<br>a | - | 16.0<br>15.0 | - | - | - | - | 1.00<br>1.00 | None |
| 599 C | Process | Other | 10 | a | - | 10.0 | - | - | - | - | 1.00 | None |
| P2 | Process | Oil Well Pump-Off Controller | 10 | a | 520.8 | 10.0 | 768.60 | 76.7 | 3,537.1 | 0.01 | 1.00 | None |

[a] *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 OVERVIEW INFORMATION

### *a. Study Title and Study ID Number*

Study Title: 1996 &1997 Industrial Energy Efficiency Incentive Programs Sixth-Year Retention Study.

Study ID Number:

- 1996 Industrial Process: 353R2
- 1997 Industrial Process: 334aR2
- 1996 Industrial Lighting: 350R2
- 1997 Industrial Lighting: 334bR2

### *b. Program, Program Years, and Program Description*

Program: Industrial Energy Efficiency Incentive (IEEI).

Program years: 1996 and 1997.

Program description: The Programs provided incentives to industrial customers to install energy-efficiency measures. The Programs included the Retrofit Express Program (RE), the Retrofit Efficiency Options Program (REO), the Advanced Performance Options Program (APO), and the Customer Efficiency Options Program (CEO).

### *c. End Uses and Measures Covered*

This study covers lighting and process end uses. Table C-1 lists the measures covered by end use.

**Table C-1**
**Measures Included in the Study**

| Measure | Measure Description |
|---|---|
| | **Lighting** |
| L23 | Fixture: T-8 Lamp & Electric Ballast, (Fem or New Fixture), 4 ft Fixture |
| L81 | HID Fixture: Interior, Standard, 251-400 Watt Lamp |
| | **Process** |
| 560 | Heat Recovery |
| 578 | Adjustable Speed Drive |
| 589 | Air Compressor System Change/Modify |
| 590 | Insulate |
| 599 | Other |
| P2 | Oil Well Pump-Off Controller |

### *d. Method and Models Used*

Typically, a retention study is conducted when more than half the units of a measure installed during a program year are still retained. Therefore, it is necessary to employ statistical methods to estimate the measure's EUL. To analyze retention, this study employs a method commonly referred to as Survival Analysis. The set of techniques referred to as Survival Analysis are widely employed to analyze data representing a period of time.

#### Estimating the EUL

In order to estimate a measure's EUL, this study assumed the number of years a unit of the measure is retained or the time to non-retention of a unit follows some general path. Technically, this path is referred to as a distribution. Given the variety of reasons a unit of a measure may be not retained, the general path the time to non-retention of a unit follows is unclear. Therefore, this study considered a variety of distributional assumptions:

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

These are common distributional assumptions made when conducting Survival Analysis.

Per standard methods, this study collected data on the times to non-retention of units of a measure and used these data to estimate the specific path or parameters of each assumed distribution. The estimated path or parameters of an assumed distribution of the time to non-retention of units were then used to estimate the measure's median retention time or EUL under that distributional assumption.

The parameters of an assumed distribution of the time to non-retention of a unit of a measure were estimated by fitting a general linear regression model to the log of the times to non-retention of units observed in the data. The exponential of the error term of this model followed the standardized form of the assumed distribution. The general linear regression model was fitted by maximizing the log-likelihood function for the assumed distribution of the time to non-retention of a unit. The selection of the most appropriate distribution was then based on several criteria:

- implications for the non-retention rate over time;
- likelihood ratio test;
- analysis of residuals; and
- maximum of the log-likelihood function.

To estimate a measure's EUL, the estimated parameters of an assumed distribution of the time to non-retention of a unit of the measure were employed in the survival function. This function is simply one minus the assumed cumulative distribution function of the time to non-retention of a unit. For a given distributional assumption, the survival function gives the probability of retaining a unit of a measure until at least time $t$. Therefore, the estimate of a measure's EUL, under a given distributional assumption, is the time $t^*$ such that the survival probability equals 50 percent.

**Standard Error of a Measure's EUL Estimate**

In order to construct a confidence interval for a measure's EUL or conduct hypothesis tests about the value of a measure's EUL, the standard errors of both the log of a measure's EUL estimate and its EUL estimate is required. The confidence intervals and p-values are based on the adjusted, when necessary, standard errors.

It is not necessary to adjust the standard errors if sampling occurred at the level of a unit of the measure or if all projects that obtained a rebate for the measure are included in the analysis. For none of the measures did sampling occur at the unit level; projects, not units of a measure, were selected for the sample. At the site of a sample project, data were collected on all units of the project measure(s) installed. Therefore, the times to non-retention of units of a measure may be more similar within a project than between projects, which was the case in this study. Consequently, unless all projects that obtained a rebate for a measure are included in the analysis, it is necessary to adjust the standard errors. Specifically, the standard errors are adjusted by the square root of the design effect.

### *e. Analysis Sample Size*

Table C-2 and Table C-3 show the analysis sample sizes by measure for lighting and process end uses, respectively. These tables show both the number of projects and the number of units of a measure included in a measure's analysis data set. Projects were selected for data collection and a unit of a measure is the level at which the data are analyzed. Third-year on-site inspections were conducted April through October 2000, and sixth-year on-site inspections were conducted

October through November 2002. In the cases of all lighting measures, a unit is a lamp; whereas a unit of a process measure is very specific to the process.

**Table C-2**
**Analysis Sample Sizes by Lighting Measure**

| Lighting Measure | # Projects | # Units |
|---|---|---|
| L23 | 175 | 117,467 |
| L81 | 54 | 2,517 |

**Table C-3**
**Analysis Sample Sizes by Process Measure**

| Process Measure | | *ex ante* EUL (years) | # Projects | # Units |
|---|---|---|---|---|
| 560 | | 14 | 2 | 2 |
| 578 | | 16, 15 | 6 | 7 |
| 589 | A | 18 | 3 | 6 |
| | B | 16, 15 | 2 | 3 |
| | C | 12 | 1 | 6 |
| 590 | | 20 | 4 | 53 |
| 599 | A | 20 | 3 | 291 |
| | B | 16, 15 | 3 | 6 |
| | C | 10 | 1 | 5 |
| P2 | | 10 | 5 | 405 |

## C.2 DATABASE MANAGEMENT

### *a. Data Sources and Elements*

The data used in this study were obtained from three sources:

1. the Program tracking data for the 1996 and 1997 Programs: SAS data sets track96.sas7bdat and track97.sas7bdat, respectively;
2. the first-year impact evaluation of the 1996 Programs and of the 1997 Programs: SAS data set eval9697.sasbdat; and
3. on-site inspections conducted for the third-year retention study and for this current retention study: SAS data sets surv3yr.sas7bdat and survdata.sas7bdat, respectively.

Each of the on-site inspection data sets also includes the relevant first-year impact evaluation data for the projects for which an on-site inspection was conducted.

### Program Tracking Data

For each project, the Program tracking data provides the following information on each measure for which a rebate was obtained:

- the installation date;
- the number of units of the measure for which a rebate was obtained;
- the avoided energy costs; and
- the *ex ante* EUL.

There are two general types of measures (or end uses), lighting and process. In the cases of all lighting measures, a unit is a lamp; whereas a unit of a process measure is very specific to the process.

### First-Year Impact Evaluations of the Programs

The first-year impact evaluation of the 1996 or 1997 Programs provides the following data on each project:

- contact information; and

on each measure for which a rebate was obtained:

- the number of units of the measure both rebated and installed (number of expected units when first inspected) and
- the location of these units.

### On-Site Inspections

For each project eligible for inclusion in this study, an attempt was made to conduct an on-site inspection in both the third year and the sixth year. An on-site inspection provides the following data on each project:

- the date of the inspection; and

  on each measure for which a rebate was obtained:

  - the number of units observed to be in place and the percentage of these units that are working and
  - in the case of each non-retained unit, any information on when the unit became not retained.

When the inspector was able to determine the reason a unit was not retained, this information was recorded as well.

### *b. Data Attrition*

Table C-4 and Table C-5 show the number of projects included in the retention analysis as compared with the number in the population and the impact evaluation by lighting measure and process measure, respectively. These tables also report the number of units of a measure included in the retention analysis as compared with the number in the impact evaluation. For each lighting measure, a large percentage of units included in the impact evaluation are also included in this study: lighting measure L23, 79 percent and lighting measure L81, 98 percent. For all but two of the process measures, all units included in the impact evaluation are also included in this study. For process measures 599A and P2, 59 and 94 percent, respectively, of units included in the impact evaluation are also included in this study.

**Table C-4**
**Analysis Data by Lighting Measure**

| Lighting Measure | Number of Projects | | | Number of Units | |
|---|---|---|---|---|---|
| | Population | Impact Evaluation | Retention Analysis | Impact Evaluation | Retention Analysis |
| L23 | 363 | 198 | 175 | 148,063 | 117,467 |
| L81 | 90 | 57 | 54 | 2,573 | 2,517 |

**Table C-5**
**Analysis Data by Process Measure**

| Process Measure | | *ex ante* EUL (years) | Number of Projects | | | Number of Units | |
|---|---|---|---|---|---|---|---|
| | | | Population | Impact Evaluation | Retention Analysis | Impact Evaluation | Retention Analysis |
| 560 | | 14 | 2 | 2 | 2 | 2 | 2 |
| 578 | | 16, 15 | 6 | 6 | 6 | 7 | 7 |
| 589 | A | 18 | 3 | 3 | 3 | 6 | 6 |
| | B | 16, 15 | 2 | 2 | 2 | 3 | 3 |
| | C | 12 | 1 | 1 | 1 | 6 | 6 |
| 590 | | 20 | 4 | 4 | 4 | 53 | 53 |
| 599 | A | 20 | 5 | 5 | 3 | 496 | 291 |
| | B | 16, 15 | 3 | 3 | 3 | 6 | 6 |
| | C | 10 | 1 | 1 | 1 | 5 | 5 |
| P2 | | 10 | 8 | 8 | 5 | 433 | 405 |

Units of a measure included in the impact evaluation but not included in the retention analysis are units for which it was not possible to conduct an on-site inspection in either the third- or sixth-year.

A total of 263 projects were targeted for onsite inspections – 255 projects that were part of the third-year retention study and 8 additional process projects that were included in the first-year impact evaluation but were not visited in the third-year retention study. An on-site inspection was completed for 247 of these 263 projects. Table C-6 presents the sample disposition.

**Table C-6**
**Sample Disposition**

| | Number of Projects | Percent of Sample |
|---|---|---|
| Projects in Sample/Panel | 263 | |
| Unable to Contact | 11 | 4% |
| Refusal – No Longer a PG&E Customer | 2 | 1% |
| Incomplete On-Site Data | 3 | 1% |
| Completed On-Site Inspection | 247 | 94% |

### *c. Data Used to Merge Data Sets*

Data sets were merged using project and measure. A project is a unique site—identified by PG&E control number--and rebate application combination. All the data sets employed the same measure codes.

### *d. Data Collected Specifically for the analysis but not Used*

All data collected specifically for the analysis were used.

## C.3 SAMPLING

### *a. Sampling Procedures and Protocols*

The projects eligible for inclusion in this study are projects included in the first-year impact evaluation of either the 1996 or 1997 Programs. Per the projects included in the first-year impact evaluations, for each of the lighting measures, a sample of projects that obtained a rebate is eligible for inclusion in this study and for each of the process measures, the population of projects that obtained a rebate is eligible for inclusion in this study.

### *b. Survey Information*

The on-site data collection instrument is provided in Appendix A. For this current retention study, an on-site inspection was at least partially completed for 94% of the projects eligible for inclusion in this study. Therefore, no effort was made to test or correct for non-response bias.

### *c. Statistical Descriptions*

Only units of a measure for which an on-site inspection was conducted in both the third- and sixth-years are included in Table C-7 and Table C-10. Units of a measure for which an on-site inspection was conducted in either the third-or sixth-year are included in Table C-8 and Table C-11.

**Table C-7**
**Retention Status During Two Three-year Time Periods by Lighting Measure**

| Lighting Measure | *ex ante* EUL (years) | # Initially Installed Units | Installation Thru 3rd-year On-site | | 3rd-year On-site Thru 6th-year On-site | |
|---|---|---|---|---|---|---|
| | | | % Units Not Retained | # Retained Units | % Units Not Retained | # Retained Units |
| L23 | 16 | 93,985 | 3.2% | 91,013 | 9.3% | 82,594 |
| L81 | 16 | 2,346 | 1.1% | 2,321 | 29.3% | 1,642 |

**Table C-8**
**Retention Status After Six Years by Lighting Measure**

| Lighting Measure | # Initially Installed Units | % Units Not Retained | # Retained Units |
|---|---|---|---|
| L23 | 117,467 | 11.8% | 103,581 |
| L81 | 2,517 | 28.0% | 1,813 |

**Table C-9**
**Process Measures with Zero Non-Retention**

| Process Measure | | *ex ante* EUL (years) |
|---|---|---|
| 560 | | 14 |
| 589 | B | 16, 15 |
| | C | 12 |
| 599 | B | 16, 15 |
| | C | 10 |

**Table C-10**
**Retention Status During Two Three-year Time Periods by Process Measure**

| Process Measure | *ex ante* EUL (years) | # Initially Installed Units | Installation Thru 3rd-year On-site Inspection | | | 3rd-year On-site Inspection Thru 6th-year On-site Inspection | | |
|---|---|---|---|---|---|---|---|---|
| | | | % Units Not Retained | | | % Units Not Retained | | |
| | | | Simple % | Weighted %, Weight = Energy Costs Avoided | # Retained Units | Simple % | Weighted %, Weight = Energy Costs Avoided | # Retained Units |
| 578 | 16, 15 | 7 | 0.0% | 0.0% | 7 | 14.3% | 64.2% | 6 |
| 589A | 18 | 6 | 33.3% | 11.8% | 4 | 0.0% | 0.0% | 4 |
| 590 | 20 | 53 | 0.0% | 0.0% | 53 | 3.8% | 1.4% | 51 |
| 599A[a] | 20 | 6 | 0.0% | 0.0% | 6 | 0.0% | 0.0% | 6 |
| P2 | 10 | 203 | 3.0% | 0.9% | 197 | 0.0% | 0.0% | 197 |

**Table C-11**
**Retention Status After Six Years by Process Measure**

| Process Measure | # Initially Installed Units | % Units Not Retained: Simple % | % Units Not Retained: Weighted %, Weight = Energy Costs Avoided | # Retained Units |
|---|---|---|---|---|
| 578 | 7 | 14.3% | 64.2% | 6 |
| 589A | 6 | 33.3% | 11.8% | 4 |
| 590 | 53 | 3.8% | 1.4% | 51 |
| 599A | 291 | 92.1% | 97.4% | 23 |
| P2 | 405 | 1.5% | 0.4% | 399 |

## C.4 DATA SCREENING AND ANALYSIS

### *a. Treatment of Outliers and Missing Data Points*

Typically, the residuals of a fitted model are examined for the presence of any outliers. However, in Survival Analysis, residuals do not have the typical definition and, therefore, we do not attempt to use the residuals to determine outliers. For each measure, the survival analysis results appear to be consistent with what is known regarding non-retention of units over time as well as to date. Missing data are discussed in a later section.

### *b. Background Variables*

See the discussion of Omitted Factors below (C.4.e.2).

### *c. Data Screens*

A unit of a measure is included in the retention analysis if an on-site inspection was conducted in either the third-year or sixth-year.

### *d. Model Statistics*

The standard model statistics for the selected final general linear regression models are provided in Table C-12. The table provides the corrected standard errors and the approximate p-value associated with the corrected standard errors. The p-value for the intercept corresponds to a test of the hypothesis that the intercept equals 0. SAS does not provide a p-value for the scale or shape parameters.

**Table C-12**
**Selected General Linear Regression Model Statistics**

| Measure | Distribution | Intercept Estimate (*ln* (years)) | Intercept Standard Error (*ln* (years)) | Intercept P-value | Scale[a] (dimensionless) Estimate | Scale[a] (dimensionless) Standard Error | Shape (dimensionless) Estimate | Shape (dimensionless) Standard Error |
|---|---|---|---|---|---|---|---|---|
| **Lighting** | | | | | | | | |
| L23 | Log-normal | 2.63 | 0.01 | <0.01 | 0.80 | 0.01 | - | - |
| L81 | Gamma | 1.57 | 0.03 | <0.01 | 0.41 | 0.02 | -3.50 | 0.23 |
| **Process** | | | | | | | | |
| 578 | Exponential | 1.84 | 0.45 | <0.01 | 1.00 | - | - | - |
| 589A | Log-logistic | 4.21 | 3.27 | 0.20 | 1.22 | 1.39 | - | - |
| 590 | Log-normal | 4.15 | 3.39 | 0.22 | 1.07 | 1.45 | - | - |
| 599A | Exponential | 1.75 | 0.08 | <0.01 | 1.00 | - | - | - |
| P2 | Exponential | 6.62 | 0.53 | <0.01 | 1.00 | - | - | - |

[a]The value of the scale parameter for the Exponential distribution is always one, it is not estimated.

The parameter estimates in Table C-12 produce the EUL estimates in Table C-13.

**Table C-13**
**Summary of EUL Estimates**

| Measure | EUL (years) *ex ante* | EUL (years) *ex post* (estimated from study) | EUL (years) *ex post* Standard Error | 80% Confidence Interval Lower Bound | 80% Confidence Interval Upper Bound | P-value for *ex post* EUL |
|---|---|---|---|---|---|---|
| **Lighting** | | | | | | |
| L23 | 16 | 13.8 | 4.78 | 8.9 | 21.6 | 0.68 |
| L81 | 16 | 10.3 | 8.64 | 3.5 | 30.6 | 0.61 |
| **Process** | | | | | | |
| 578 | 16, 15 | 4.4 | 1.97 | 2.3 | 8.4 | 0.03 |
| 589A | 18 | 67.7 | 221.40 | 0.5 | 8,459.6 | 0.70 |
| 590 | 20 | 63.3 | 214.42 | 0.8 | 5,141.1 | 0.74 |
| 599A | 20 | 4.0 | 3.02 | 1.0 | 16.7 | 0.17 |
| P2 | 10 | 520.8 | 768.60 | 76.7 | 3,537.1 | 0.01 |

### *e. Specification*

For each measure, this study assumes the time to non-retention of a unit of a measure follows some parametric distribution. The time to non-retention of a unit is then modeled as function of only the parameters of this distribution. Given the variety of reasons a unit of a measure may be not retained, the general path the time to non-retention of a unit follows is unclear. Therefore, this study considered a variety of distributional assumptions:

- Gamma;

- Weibull;
- Exponential;
- Log-normal; and
- Log-logistic.

These are common distributional assumptions made when conducting Survival Analysis.

### 1. Heterogeneity

The heterogeneity of projects is recognized and addressed in the model specification and estimation procedures in at least two ways.

i. The number of units of a measure may vary across projects. In this analysis, an observation is a unit of a measure. Therefore, the number of observations on a project included in the analysis is equal to the number of units in the project.

ii. If the energy costs avoided per unit of a measure varies across projects, when estimating the general linear regression model, weights that reflect the different levels of energy costs avoided are employed.

### 2. Omitted Factors

It is possible to include in the model of the time to non-retention of a unit of a measure the parameters of the assumed distribution as well as other independent variables. The additional independent variables may be background variables such as economic and political activity and/or variables that vary by project or even by unit of a measure within a project. Two categorical variables that are likely to vary by project and may affect the time to non-retention of a unit are

- whether or not the same firm occupies the space and
- whether the space is being used for the same or a different purpose.

Modeling the time to non-retention of a unit of a measure as a function of the parameters of the assumed distribution as well as other independent variables will provide insight into the effect of these other independent variables on the time to non-retention of a unit. However, it is unclear whether additional independent variables will result in a better estimate of a measure's EUL.

The value of modeling the time to non-retention of a unit as a function of background variables and/or variables that vary by project depends on at least three factors:

1. the magnitude of their effect on the time to non-retention;
2. how accurately their future values can be estimated; and
3. if the result is more than one estimate of the EUL (e.g., if a variable is categorical), whether or not the various EUL estimates and their standard errors can be meaningful combined.

The future values of background variables and/or variables that vary by project may not be able to accurately estimated. In addition, the ultimate objective of this study is to estimate a single EUL for the population of a measure, not to estimate different EULs for different subpopulations of a measure. Therefore, we model the time to non-retention of a unit of a measure as a function of only the parameters of the assumed distribution.

### *f. Error in Measuring Variables*

There are no particular concerns regarding error in measuring variables. The methods employed are well suited to handle imprecise measures of the time to non-retention of a unit of a measure.

### *g. Influential Data Points*

Influential data points are not a concern. For each measure, the survival analysis results appear to be consistent with what is known regarding non-retention of units over time as well as to date.

### *h. Missing Data*

The only “missing data” are the times to non-retention of units of a measure included in the impact evaluation but not included in the retention analysis because it was not possible to conduct an on-site inspection in either the third- or sixth-year.

### *i. Precision*

In order to construct a confidence interval for a measure’s EUL or conduct hypothesis tests about the value of a measure’s EUL, the standard errors of both the log of a measure’s EUL estimate and its EUL estimate is required. The confidence intervals and p-values are based on the adjusted, when necessary, standard errors.

It is not necessary to adjust the standard errors if sampling occurred at the level of a unit of the measure or if all projects that obtained a rebate for the measure are included in the analysis. For none of the measures did sampling occur at the unit level; projects, not units of a measure, were selected for the sample. At the site of a sample project, data were collected on all units of the project measure(s) installed. Therefore, the times to non-retention of units of a measure may be more similar within a project than between projects, which was the case in this study. Consequently, unless all projects that obtained a rebate for a measure are included in the analysis, it is necessary to adjust the standard errors. Specifically, the standard errors are adjusted by the square root of the design effect.