3RD YEAR RETENTION STUDY OF PACIFIC GAS & ELECTRIC COMPANY'S 1996 AND 1997 ENERGY EFFICIENCY INCENTIVES PROGRAM, AGRICULTURAL SECTOR MEASURES:

PG&E Study ID number: 354R1, 385R1, 335AR1, 335BR1, 335CR1

March 1, 2001

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Third Year Measure Retention Study of Pacific Gas & Electric Company's Agricultural Sector
1996 and 1997 Nonresidential Energy Efficiency Incentives Programs
Study IDs: 354R1, 385R1, 335AR1, 335BR1, & 335CR1

Purpose of Study

The purpose of the attached study is to document the level of measure retention in the third year after installation and to estimate the ex post effective useful life (EUL) values for PG&E's 1996 and 1997 Agricultural Energy Efficiency Incentives (AEEI) Programs. As required, the 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" (Protocols), as adopted by California Public Utilities Commission Decision 93-05-063, revised March, 1998, pursuant to Decisions 94-05-063, 94-10-059, 94-12-021, 95-12-054, 96-12-079, and 98-03-063. The study covers measures representing the top 50% of the estimate resource value, as required by the Protocols. These measures include pump repair, micro irrigation conversion, and high intensity discharge lighting measures. The AEEI Program promoted the purchase of energy efficient technologies to the agricultural sector through financial incentives paid to agricultural participants.

Methodology

When PG&E conducted the 1996 and 1997 impact studies, it created retention panels documenting the equipment type and location for approximately 150 sites per program year. These sites were revisited in 1999 and 2000 (respectively three years after installation) to assess whether the measures were still "in place and operable", as required by the Protocols. The resultant data was then analyzed using three basic approaches to estimating EULs. These were the classic survival analysis, the standard ordinary least squares, and the assumed functional form approach.

Study Results

Of the measures studied, the pump retrofit was the only measure that had enough installed measures identified as not "in place and operable" to proceed with analysis. This measure produced a measure life estimate that was statistically indistinguishable from the ex ante EUL estimate. Thus, as is shown below, the EUL values for the third earnings claim for all studied measures will be the same as the ex ante estimated EULs.

Regulatory Waivers and Filing Variances

A waiver concerning earnings calculation methodology is included for completeness. There were no variances from the E-Tables.

PG&E's 1996 Agricultural Sector Energy Efficiency Incentive Programs
Summary of Ex Post Effective Useful Life Estimates from 3rd Year Retention Study

		EUL		**Upper 80% CL**	**Lower 80% CL**	**EUL for Claim**
Measure Description	**Code**	**Ex Ante**	**Ex Post**	**Ex Post**	**Ex Post**	**-**
Pump Retrofit	A1	9.0	12.7	18.3	7.1	9.0
Sprinkler to Micro, Valley/Well/Field Vegetables	A44	20.0	NA	NA	NA	20.0
HID Fixture: Interior, 251-400 Watt Lamp	L81	16.0	NA	NA	NA	16.0
"Like" Measures for HID Fixture: Interior, 251-400 Watt Lamp						
HID Fixture: Interior, 101-175 Watt Lamp	L26	16.0	NA	NA	NA	16.0
HID Fixture: Interior, 176-250 Watt Lamp	L27	16.0	NA	NA	NA	16.0
HID Fixture: Interior, >=176 Watt Lamp	L37	16.0	NA	NA	NA	16.0

If the measure shows NA for the Ex Post EUL, it is because either there were no failures were observed or there were too few failures to analyze.

PG&E's 1997 Agricultural Sector Energy Efficiency Incentive Programs
Summary of Ex Post Effective Useful Life Estimates from 3rd Year Retention Study

		EUL		**Upper 80% CL**	**Lower 80% CL**	**EUL for Claim**
Measure Description	**Code**	**Ex Ante**	**Ex Post**	**Ex Post**	**Ex Post**	**-**
Pump Retrofit	A1	9.0	12.7	18.3	7.1	9.0
Sprinkler to Micro, Valley/Well/Field Vegetables	A44	20.0	NA	NA	NA	20.0
Sprinkler to Micro, Valley/No Well/ Deciduous	A49	20.0	NA	NA	NA	20.0
"Like" Measures for Micro Irrigation Conversion Measure A49						
Sprinkler to Micro, Valley/Well/Deciduous	A45	20.0	NA	NA	NA	20.0
Sprinkler to Micro, Valley/ No Well/Vineyard	A51	20.0	NA	NA	NA	20.0
Sprinkler to Micro, Coast/Well/Vineyard	A55	20.0	NA	NA	NA	20.0
Sprinkler to Micro, Valley/Well/Vineyard	A47	20.0	NA	NA	NA	20.0

If the measure shows NA for the Ex Post EUL, it is because either there were no failures were observed or there were too few failures to analyze.

Equipoise Consulting, Inc.

Energy Analysis

Project Management

Training

Final Report for

3rd Year Retention Study of Pacific Gas & Electric's 1996 and 1997 Energy Efficiency Incentives Programs, Agricultural Sector Measures

Submitted by:

Equipoise Consulting Incorporated

in association with

California AgQuest Consulting Inc.

and

Ridge & Associates

February 21, 2001

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EXECUTIVE SUMMARY

This report presents the results of the 3rd year retention study of Pacific Gas and Electric Company's (PG&E) Paid Year (PY) 1996 and PY 1997 Agricultural Programs. The *Protocols and Procedures for the Verification of Costs, Benefits, and Shareholder Earnings from Demand-Side Management Programs* (Protocols)[1] call for a retention study of the Effective Useful Life (EUL) for the agricultural sector three and six years after the measures are installed.

According to the Protocols, a measure retention study is "to collect data on the fraction of measures or practice remaining in a given year that will be used to produce a revised estimate of its effective useful life."[2] This study uses, where possible, classic survival, ordinary least squares, and assumed functional form analyses of the retention data to assess whether the ex post estimates should replace the ex ante value of EUL. The studies assessed EULs for measures representing 66% of the avoided cost for measures installed in the 1996 and 67% of the measures installed in 1997 in the Agricultural Sector.

Exhibit ES 1 shows the ex ante EULs for the measures assessed, the recommended ex post EUL, and the best estimate of ex post EUL with its 80% confidence interval, for all measures assessed.

ES 1
Ex Ante and Ex Post EUL Estimates for PY 1996/97 (Years)

Measure	Ex Ante Value	Ex Post Recommended	Best Ex Post Model with 80% Confidence Interval
HID Lighting	16	16	Too few failures to analyze.
Micro Irrigation Conversion	20	20	Too few failures to analyze
Pump Repair	9	9	12.7 (7.1 - 18.3)

HID lighting and micro irrigation conversion measures, with 0.4% and 0% failure rates respectively, could not be meaningfully analyzed using existing techniques. Therefore, the ex ante values are retained.

While the pump repair measure had sufficient failures (14% overall), the majority of the analysis results supported retention of the ex ante EUL of nine years.

[1] D.93-05-063 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 99-06-05.
[2] Protocols, Table 8A, footnote 2.

1 OVERVIEW

Energy-efficiency measures installed by Demand-Side Management (DSM) programs all have a predicted time period over which the measures are expected to provide energy savings. This period of time, called the engineering useful life in the *Protocols and Procedures for the Verification of Costs, Benefits, and Shareholder Earnings from Demand-Side Management Programs* (Protocols)[3], is the engineering estimate of the number of years that a piece of equipment will operate if maintained properly. However, equipment is removed from operation for a myriad of reasons. When the engineering useful life is adjusted for early removal, the effective useful life (EUL) is determined. The Protocol definition of EUL is “An estimate of the median number of years that the measures installed under the program are still in place and operable.” The EUL is, then, the median period of time between installation and the point at which 50% of the installed measures remain “in place and operable”. According to the Protocols, a measure retention study is “to collect data on the fraction of measures or practice remaining in a given year that will be used to produce a revised estimate of its effective useful life.”[4]

The Protocols call for a retention study of the EULs for the agricultural sector three and six years after the measures are installed. This report covers the 3rd year retention study of the 1996 and 1997 Agricultural Programs.

For each planned retention study, there are specific measures from each year for which EULs were, if possible, to be updated. These planned measures are shown in Exhibit 1.1 for PY1996 and PY1997 Agricultural measures.

[3] D.93-05-063 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 99-06-05.
[4] Protocols, Table 8A, footnote 2.

Exhibit 1.1
Planned Measures for Retention Study

Program Year	Measure Code	Measure Description	# of Paid Units	Life Cycle Avoided Cost	Project Life	% of Total Avoided Cost
1996	A1	Pump Repair	68	$ 598,123	9	16%
1996	A44	Sprinkler to Micro, Valley, Well, Field/Veg (acres)	1285	$ 603,712	20	16%
1996	L81	HID Fixture: Interior, Standard, 251-400 Watt Lamp (unique apps)	57	$ 1,193,328	16	31%
Total % of Avoided Cost for 1996 Program Year						63%
1997	A1	Pump Repair	111	$ 1,051,755	9	14%
1997	A44	Sprinkler to Micro, Valley, Well, Field/Veg (acres)	1840	$ 1,097,802	20	15%
1997	A49	Sprinkler to Micro, Valley, No Well, Deciduous (acres)	3660	$ 2,225,953	20	31%
Total % of Avoided Cost for 1997 Program Year						60%

There were seven non-studied, or “like,” measures associated with these studied measures. These measure associations are shown in Exhibit 1.2.

Exhibit 1.2
Non-studied Measures Associated to Studied Measures

Studied Measures		Non-Studied Measures		Rationale
PG&E Measure Code	**Measure Description**	**PG&E Measure Code**	**Measure Description**	**Reason Measures are Comparable**
L81	HID Fixture: Interior, 251-400 Watts Lamp	L26	HID Fixture: Interior, 101-175 Watts Lamp	All HID interior applications are similar. The participant to participant (or application) variation is accounted for in the range of applications studied in the retention study.
		L27	HID Fixture: Interior, 176-250 Watts Lamp	
		L37	HID Fixture: Interior, >=176 Watts Lamp	
A49	Sprinkler to Micro, Valley, No Well, Deciduous	A45	Sprinkler to Micro, Valley, Well, Deciduous	Micro irrigation systems are similar in type for perennial crops such as orchards and vineyards. They are used similarly and should have similar effective useful lives.
		A51	Sprinkler to Micro, Valley, No Well, Vineyard	
		A55	Sprinkler to Micro, Coast, Well, Vineyard	
		A47	Sprinkler to Micro, Valley, Well, Vineyard	

When the avoided costs for these “like measures” are added to the values in Exhibit 1.1, 66% of the avoided cost for 1996 and 67% of the avoided cost for 1997 is being assessed. The data collection process, analysis methodology, and analysis results for the 3rd year retention of the 1996 and 1997 Agricultural Program measures are presented next.

2 DATA COLLECTION

The 1996 and 1997 Agricultural Programs Impact Studies created retention databases (also called retention panels) specific to each year. These databases, assembled in the fall of 1997 and 1998, respectively, collected information on measures so that they could be located later and the extent to which they were "in place and operable" could be assessed. As required by the Protocols, the retention database measures were selected to represent "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." The 1996 retention panel collected baseline data on four measures: pump repairs, low-pressure sprinkler nozzles, micro irrigation conversion, and HID lighting. The 1997 retention panel collected baseline data on pump repairs, low-pressure sprinkler nozzles, micro irrigation conversion, greenhouse heat curtains, and refrigeration.

As Exhibit 2.1 indicates, there were 138 total measures installed in the 1996 program for the measure types encompassed by the retention panel. Information for 105 individual measure installations (76% of the total) was gathered for the 1996 retention panel. Similarly, the 1997 program had 172 total measures installed for the measure types covered by the 1997 retention panel. Information for 162 measures (94%) was gathered for the 1997 retention panel.

Exhibit 2.1
1996 and 1997 Program Population and Retention Panel

Measure	***Measure Code***	***PY Population***	***PY Retention Database***
Program Year 1996			
Pump Repair	A1	67	46
Low-Pressure Sprinkler Nozzle	A41, A42, A43	3	2
Micro Irrigation (sites)	A44, A45, A47, A51, A55	11	10
Indoor Lighting (unique applications)	L64 / L66 / L174 / L176 / L6/ L23-L24 / L73-L75 / L160 / L19 / L26 / L81 / L31	57	47
Total for PY1996		***138***	***105***
Program Year 1997			
Pump Repair	A1	111	102
Low-Pressure Sprinkler Nozzle	A40, A41, A42, A43	5	4
Micro Irrigation (sites)	A44, A45, A47, A49, A51, A55	32	32
Greenhouse Heat Curtain (sites)	A10	11	11
Refrigeration	R2, R17, R18, R52	13	13
Total for PY1997		***172***	***162***

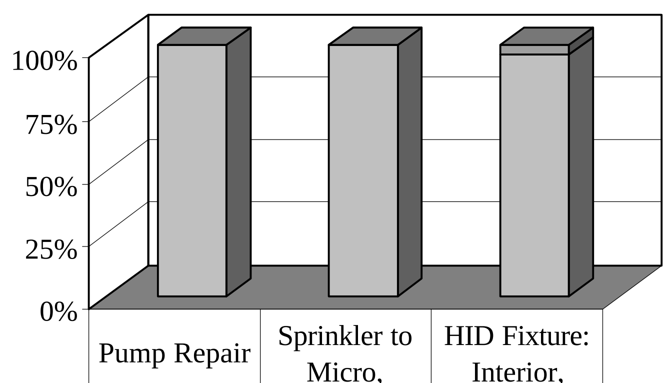
Since the retention study and EUL analysis only needs to include those measures that represented the top 50% of avoided costs for each year, the actual measures and sample for the study are different than those shown in Exhibit 2.1. The sample for this retention study, covering only the measures in the top 50%, is shown Exhibit 2.2.

Exhibit 2.2
Sample Size for Evaluation

Program Year	Measure Code	Measure Description	Sample Size
1996	A1	Pump Repair	46
1996	A44	Sprinkler to Micro, Valley, Well, Field/Veg (sites)	10
1996	L81	HID Fixture: Interior, Standard, 251-400 Watt Lamp (unique apps)	47
Total Sample Size 1996 Program Year			**103**
1997	A1	Pump Repair	102
1997	A44 and A49	Sprinkler to Micro Irrigation (sites)	17
Total Sample Size 1997 Program Year			**119**

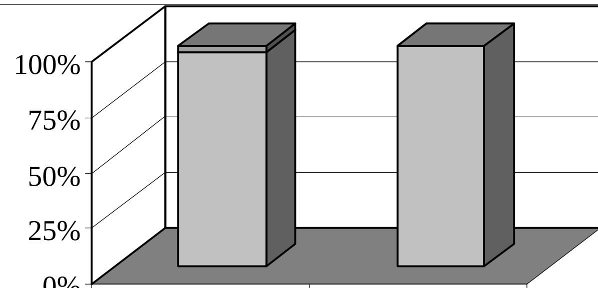
The same firm that gathered data for both the original 1996 and 1997 retention panels also collected the information for this 3rd year retention study. Program year 1996 retention data were collected in the Fall of 1999 and PY1997 retention data were collected in the Fall of 2000. Using the sample sizes from Exhibit 2.2, a census of sites was conducted. As shown in Exhibit 2.3 and Exhibit 2.4, 101 of the PY1996 103 sites (98%) were audited, and 116 of the PY1997 119 sites (97%) were audited.

Exhibit 2.3
1996 Retention Panel Evaluation Audits



	Pump Repair	Sprinkler to Micro,	HID Fixture: Interior,
1996 Retention Database Sites Not Audited	0	0	2
1996 Retention Database Sample	46	10	47

Exhibit 2.4
1997 Retention Panel Evaluation Audits



	Pump Repair	Sprinkler to Micro, Valley,
1997 Retention Database Sites Not Audited	3	0
1997 Retention Database Sample	102	17

Each measure's retention data collection was conducted as follows:

- The pump repair sites had a census performed with at least 75% visited on-site, while the remaining had information collected over the telephone. Each pump was considered a single data point for analysis.
- The HID lights had the percentage of fixtures still in place and operable collected. A census was audited on-site.
- The micro irrigation conversion sites had the acres continuing to have micro irrigation in place collected. A census was audited on-site.

Once contacted by telephone or in person, the customer was asked a series of questions to determine if the measure was still in place and operable. (See Appendix C) If the measure was no longer in place or was not operable, the customers were asked why not and when the measure had been removed from service. For the micro irrigation conversion sites, the number of acres still in use was determined.

3 METHODOLOGY

Three basic approaches to estimating EULs were explored. The first approach used was a *classic survival analysis* of the data collected in this study. This approach involves the analysis of data that correspond to time from a well-defined time origin until the occurrence of some particular event or end-point (Collett, 1994). This approach is considered to be the most accurate since formal survival models can adjust for right, left, and interval censoring. The other two approaches cannot make any such adjustments. The other two approaches are used (1) when the classic survival model *cannot* be estimated, or (2) as a sanity check, if the classic survival model *can* be estimated. The second approach was the standard *ordinary least squares* (OLS) (Maddala, 1992). This involved regressing the percentage of measures still in place and operable against time (i.e., months since the installation). The third approach is the *assumed functional form* (AFF) approach (Wright, 1999). The AFF assumes a functional form and involves conducting a survey at a given point in time after the installation. The collected data are then used in conjunction with the functional form to estimate the EUL.

Below is a description of the details of the most statistically rigorous approach, classic survival analysis, followed by a description of the OLS and the AFF.

3.1 Classic Survival Analysis

The first part of this section describes the appropriate unit of analysis. This is followed by a description of various issues surrounding survival analysis in the context of this study, including left versus right censoring, the hazard function, precision, covariates, hypothesis testing, and required failures.

3.1.1 Units of Analysis

The unit of analysis for the survival estimation is the survival unit being studied, such as patients or light bulbs. The unit of analysis is always a binary outcome - survival versus failure. For this study, the units of analysis are pumps, HID lighting fixtures, and acres of micro irrigation conversion that are no longer in place and operable.

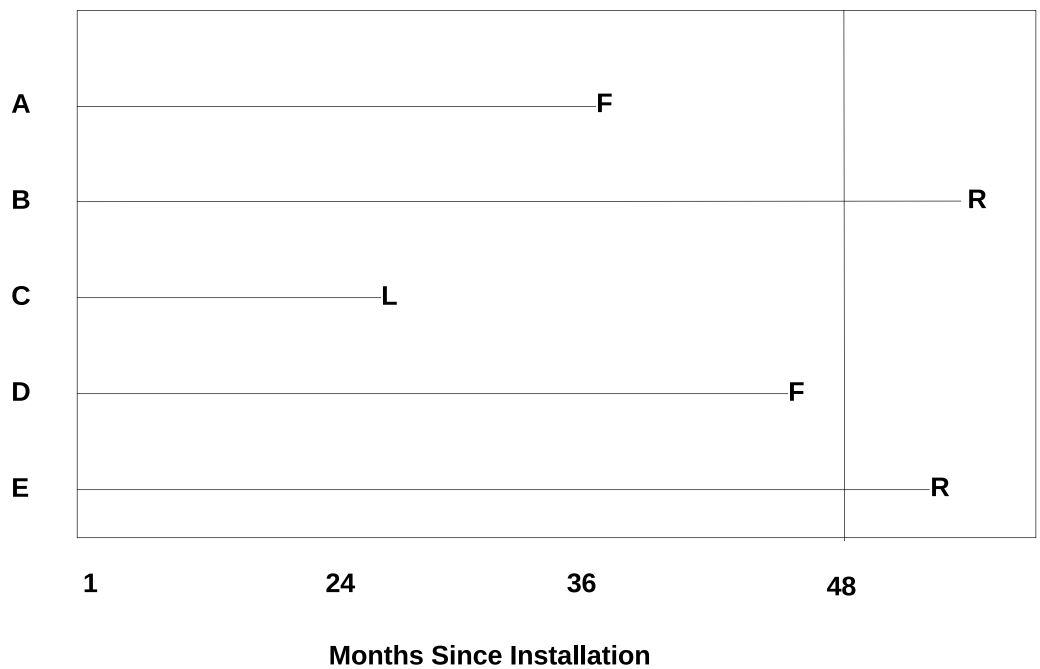
3.1.2 Left Censoring versus Right Censoring

In this survival analysis, a failure event is defined as a point in time at which a particular measure is no longer "in place and operable," hereafter referred to as a "failure." This implies the need to know not only that a given measure has failed but also when it failed.

Two concepts critical to this method are the right censoring and left censoring of the data. Right censoring of the data occurs when a measure is observed before the failure event occurs, i.e., the measure is still "in place and operable." Left censoring occurs when the actual installation or failure date for a measure is unknown. Exhibit 3.1 illustrates the distinction between right and left censoring. The observation followed by an "L" is a case in which the measure did not survive until the 48th month, the month of observation, but the time of failure is still unknown. This is a case of "left" censoring. The observations by an "F" represent those cases in which the measure did not survive until the 48th month but for which the time of failure *is* known. These represent cases of "no" censoring. The observations marked by an "R" represent those cases in which the measure survived until the 48th month and will not fail until some time beyond the 48th month. These represent cases of "right" censoring. Both right censoring and left censoring can have significant impacts on the precision of any survival analysis.

Right censoring is inevitable when one conducts a three- or six-year follow-up on kWh savings associated with measures that have expected useful lives of 15 to 18 years. For example, in a six-year retention study, very few chiller or boiler measures (long life measures) in a small sample will have experienced failure. The problem with right censoring is that more measures that have experienced failure must be brought into the sample in order to produce a robust estimate of the EUL. Of course, right censoring is expected to be somewhat less of a problem in the case of measures that have a shorter EUL.

Exhibit 3.1
Right Versus Left Censoring



The problem of left censoring can be somewhat more easily mitigated by asking participants to report the time of failure. When a site was inspected, the evaluation team asked the customer when the measure failures occurred. The failures were defined as failures at that date. In using such an approach, analysis efforts must guard against the threat of measurement error since customers may not be able to remember the true failure date accurately. This can be handled through use of a hazard function.

3.1.3 Functional Forms

Initially the following general form of the constant hazard function was assumed:

$$h(t) = l \qquad (1.)$$

The corresponding survivor function is:

$$S(t) = e^{-lt} \qquad (2.)$$

This constant hazard implies an exponential distribution for the time until an event occurs.

However, because it was also realized that the probability of a measure not surviving increases with time (i.e., the hazard is not constant over time), the following four accelerated failure time (AFT) models were also explored:

1. Weibull:

   $$S(t) = e^{[-(lt)^K]}$$

   where

   l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

   K = A constant whose value is greater than 0

   Note that when K = 1 (a constant), the exponential model is specified.

2. Gamma

   $$f(t) = \frac{l(lt)^{K-1} e^{-lt}}{\Gamma(K)}$$

   where

   l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

   Γ = The gamma function

   K = $1/d^2$ (the shape parameter)

3. Log-logistic

   $$S(t) = \frac{1}{1 + (lt)^g}$$

   where

   l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

   γ = $1/\sigma$

   σ = Scale parameter

4. Log-normal

Since the log-normal cannot be expressed in closed form, it is presented as a regression model in which the dependent variable is the logarithm of the hazard:

$$\log h(t) = \log h_0(te^{-bx}) - bx$$

where

h_0 (.)= The hazard function for an individual with x = 0

Even if all the models agree on the coefficient estimates, they still have markedly different implications for the shape of the hazard function. The question is how to select the best model. To answer this question, the likelihood ratio statistic was used, which can be used to compare nested models[5]. This statistic is calculated by taking the difference in the likelihood ratios between two nested models and multiplying this difference by 2. This yields a likelihood-ratio chi-square statistic.

The first thing to note is that because the generalized gamma has one more parameter than any of the other models being considered, its hazard function can take on a wide variety of shapes. The exponential, the Weibull, and log-normal models (but not the log-logistic) are all special cases of the generalized gamma model. In addition, the generalized gamma can also take on shapes that are unlike any of these special cases. It also has hazard functions with a U or *bathtub* shapes in which the hazard function declines, reaches a minimum, and then increases. Given the richness of the generalized gamma model, why not always use it instead of the other models? The main reason is that the formula for the generalized gamma model is rather complicated, involving the gamma function and the incomplete gamma function. Consequently, it is often difficult to judge the shape of the hazard function from the estimated parameters. By contrast, the hazard functions for the specific submodels can be rather easily described.

As a result, a number of models that are nested within the generalized gamma were estimated. Then any number of formal hypotheses tests were conducted by comparing the performance of each model to the generalized gamma. If the likelihood-ratio chi-square statistic suggests that the difference is not statistically significant, then the model utilizing the more easily interpretable hazard function is adopted. Also note that the exponential is nested in the Weibull which can serve as another way of testing whether the hazard is constant or accelerated. Finally, recall that the log-logistic, because it is not nested within any other model does not fit into the formal test of significance. It must be compared with the other models on the basis of the likelihood ratios alone and not on the basis of the likelihood-ratios chi square statistics.

3.1.4 Precision

The precision that one can achieve is in large part a function of the number of failures that one can expect to see in a study. The number of failures that one can expect to see is largely a function of the expected EULs. For example, in the hazard function (Equation 1), the median survival time is given by

[5] A model is said to be nested within another if the first model is a special case of the second

$$\hat{t}(50) = \hat{l}^{-1} \log 2 \qquad (3.)$$

with a standard error of

$$\text{s.e.}\{\hat{t}(50)\} = \frac{\hat{t}(50)}{\sqrt{r}} \qquad (4.)$$

where r is the number of failures within a sample. The more failures there are, the smaller the standard error and the greater the precision of the estimate. That is, the number of failures is directly related to the power of any survival analysis to determine whether any differences between re-estimated EULs and the ex ante EULs are statistically different at some predetermined level of confidence. Of course, in a third year retention study, the number of failures for longer-EUL measures will be very small, while the numbers of failures associated with shorter-EUL measures will be more numerous. While the problem of right censoring may be somewhat serious for all measures, it may be particularly acute for the measures with longer EULs.

3.1.5 Covariates

In some retention studies, other factors that may affect the life distribution were investigated. If there are sufficient failures, one can determine whether some equipment experiences different rates of failure than others. In such a study, one can attempt to control for the heterogeneity of the determinants of measure survival. Also, note that the characteristics of each area that do not change over time can be controlled for by including an area/building-specific intercept in the model, i.e., each measure associated with a given area or building could have a common intercept. However, for this study, it was not possible to collect information on such variables.

3.1.6 Software

The Statistical Analysis System (SAS) software was used to estimate all survival functions. SAS has a wide range of procedures (e.g., LIFETEST, LIFEREG, and PHREG) that can handle right censoring and provide standard errors for each point on the survival curve, including the median.

3.1.7 Hypothesis Testing

The Protocols consider effective useful life to be that median number of years in which half of the units associated with a given measure (e.g., HID fixtures) installed in a given program year are still in place and operable. It turns out that in survival analysis, the median value is of greatest importance because the mean value is biased downward when there is right censoring, as may be the case in this study. Thus, the evaluation team's hypothesis test will focus on the ex ante and ex post median values.

The null hypothesis established for this phase of the analysis is that the measure-level EUL (a median value) estimated as a part of this research project is not statistically different from the ex ante EUL (a median value) at the 80% percent level of confidence, i.e.,

$$EUL_{ex\ post} = EUL_{ex\ ante}$$

For measures with relatively long expected useful lives, the hypothesis test is perhaps the most difficult task, since the model will be extrapolated to times that are beyond those that are actually observed. In such cases, the standard errors of the estimated medians will be substantial.

Along with the predicted medians, the standard errors of the medians were also produced. The 80% confidence intervals were calculated by multiplying 1.28 (the t value associated with the 80% level of confidence) times the standard error. If the 80% confidence interval did include the ex ante EUL, then the newly estimated ex post EUL was adopted. If the interval does include the ex ante EUL, then the ex ante was retained.

3.1.8 Required Failures

Normally, for a classic survival analysis, one must attempt to estimate the number of failures needed to achieve the required level of precision and then determine the required sample size to produce the number of required failures. Prior to conducting any analysis of any particular measure, one should estimate the number of failures needed to achieve the required level of precision. This estimate requires that one make a number of other assumptions in addition to the confidence level. For example, how big a difference between the ex ante and the ex post EULs (the so-called effect size) should the statistical test be able to detect as significant? This is a particularly critical factor since the sample size is, to a large extent, a function of the effect size. As the expected size of the effect increases, the required size of the sample decreases.

Having said this, it is noted that the sizes of the samples for this retention study were not designed with the expected number of required failures in mind. Also note that because PG&E's approach relies on retention panel data collected during the first-year impact evaluation, there is no possibility of increasing the sample sizes in the event that the number of failures is insufficient. In subsequent retention studies, we recommend that, whenever possible, a power analysis be conducted so that the required number of failures and the sample size needed to obtain these failures can be determined.

The example below illustrates how one can estimate the required number of failures. For this calculation, the exponential functional form could be assumed to produce a range of required sample sizes. The following assumptions could be made:

- a power of 0.8 or 0.7
- an alpha of 0.20 (i.e., 80% confidence level)
- an ex ante EUL of 9 years for pumps
- a range of possible effect sizes, Δ

The calculation of the effect size requires some further explanation. If one assumes that the survival curves have an exponential distribution, then:

$$p_{\mathrm{T}} = \mathrm{S}(t) \exp(-l_{\mathrm{T}} t) \qquad (5.)$$

where p_T is the proportion of measures surviving at some fixed time t and l_T is the constant hazard for a given measure. Equation 5 can be rewritten as

$$l_{\mathrm{T}} = \frac{-\log p_{\mathrm{T}}}{t} \qquad (6.)$$

In a similar way, one can obtain for the ex ante EUL at the same time t

$$l_{\mathrm{C}} = \frac{-\log p_{\mathrm{C}}}{t} \qquad (7.)$$

Thus, the effect, Δ, is defined as

$$\frac{l_T}{l_C} \qquad (8.)$$

Specifically for the median, the following equation holds

$$\Delta = \frac{l_{\mathrm{T}}}{l_C} = \frac{\mathrm{M_C}}{\mathrm{M_T}} \qquad (9.)$$

where M_C is the estimated median survival time based on the sample in this study, while M_T is the estimated median survival time for the ex ante EUL.

It can be shown that if an equal number of subjects are allocated to each treatment, the total number of events, E, that need to be observed in a study comparing two treatment groups is given approximately by:

$$\mathrm{E} = [(\mathrm{Z}_{1\text{-}a} + Z_{1-b})(1+\Delta)/(1-\Delta)]^2 \qquad (10.)$$

where $\mathrm{Z}_{1\text{-}a/2}$ is the upper point of the standard normal distribution and $\mathrm{Z}_{1\text{-}b}$ is the power of the test.

Using Equation 10 and the assumptions listed earlier, the number of required failures could be calculated. However, an adjustment must be made to these numbers that accounts for the fact that there is only one group that has a known distribution, the sample of sites and their associated measures in this study. The ex ante EUL has no distribution; it is just an *a priori* engineering assumption. Such an adjustment should be done in order to account for the fact that only half of the sampling error is present. For example, an adjustment factor of 0.50 could be used to determine the number of required failures for the required precision.

3.1.9 Tied Survival Times

The survival models described above assume that the hazard function is continuous and, under this assumption, tied survival times are not possible. While some ties were present in the pump data, it was not considered serious.

3.2 Ordinary Least Squares

The first alternative approach used was the familiar ordinary least squares (OLS) regression that estimates the relationship between time and the percentage of measures remaining that are still present and operable (Maddala, 1992). The following model was estimated for each measure where there was an adequate number of observations.

$$\mathrm{PR} = a + bt + e \qquad (11.)$$

where

PR = Percentage remaining

b = The change in the Percentage Remaining due to a one unit change in t (months)

a = A constant that captures the Percentage Remaining through an unspecified set of variables

e = The error term that capture changes in Percentage Remaining that are not explained by the model

Once this model was estimated, it was evaluated at values of t until the percentage remaining equaled 50%. The value of t that produced 50% was the chosen estimate of the EUL.

3.3 Assumed Functional Form

The assumed functional form (AFF) approach was explored next. The AFF first assumes a functional form, such as the logistic or exponential. Next, a survey is conducted at a given point in time after the installation. The results of the survey are entered into an equation that describes the functional form that has been manipulated algebraically to derive the EUL associated with 50% survival. This method has most recently been developed by Wright (1999). Wright begins with the exponential survival function:

$$S(t) = e^{-lt} \qquad (12.)$$

Here the mean survival time is equal to $1/l$. The EUL is defined as the value of t that satisfies the equation $S(t) = e^{-lt}$ = 0.5. Solving for t=EUL, one obtains

$$EUL = -\frac{\ln(0.5)}{l} \qquad (13.)$$

If one observes $\hat{S}$ in a sample with average measure age t, then one can solve the survival function for

$$\hat{l} = -\frac{\ln(\hat{S})}{t} \qquad (14.)$$

If one substitutes this equation in the preceding one, one obtains

$$E\hat{U}L = \frac{t \ln(0.5)}{\ln(\hat{S})} \qquad (15.)$$

Thus, for example, if one finds that, in a sample of 100, 90% survive and that the average age of the surviving units is three years, then the estimated EUL is 19.7 years.

3.4 Confidence Intervals

3.4.1 Classic Survival Analysis

Standard errors around the estimated median EUL are automatically produced by SAS for a classic survival analysis. However, these standard errors may be less precise than they appear and thus can affect the testing of the null hypotheses that the ex ante EUL is equal to the ex post EUL. This problem and the solution used are described below.

Using a simple random sampling (SRS), the assumption is that the observations are independent and identically distributed (IID). However, when sampling units within sampled sites, i.e., a cluster sample, this assumption may be violated. For example, when a pump fails or is removed for some other reason, it is likely that other pumps also fail or are removed for some other reason. The effect of such intra-cluster correlation is to inflate the standard errors. SAS makes no such correction for intra-class correlation and thus underestimates the size of the standard error, making the estimates seem more precise than they really are. This of course affects hypotheses testing, making it easier to reject the null hypothesis, which, in this case, is that the ex ante EUL is equal to the ex post EUL.

Skinner (1989) provides a way to adjust the standard errors to correct for such inflation. Skinner estimated the design effect as:

$$\text{deff} = 1 + (\text{N} - 1)t \qquad (16.)$$

where

N= The average number of sample points per site

t = The intra-cluster correlation

The standard error is adjusted by the design effect factor, which equals $\sqrt{deff}$. Unfortunately, with so few failures/removals, only the intra-cluster correlation can be estimated. For this analysis, it was assumed that the intra-cluster correlation is 0.50. This is based on an assumption that removals are perfectly correlated and removals for other reasons are perfectly uncorrelated.

3.4.2 Ordinary Least Squares

The pump repair measure was the only measure found to have enough failures for this type of analysis. The 80% confidence intervals shown in the tables in Section 5 were calculated using the approach shown below.

The variance of the model error (the residuals) is first estimated using Equation 17 (Pindyck and Rubinfeld, 1981).

$$s^2 = \frac{1}{\text{T} - 2} \Sigma(\text{Y}_t - \hat{\text{Y}}_t)^2 \qquad (17.)$$

The variance of the forecast error is then estimated using Equation 18.

$$s_f^2 = s^2\left[1 + \frac{1}{T} + \frac{\left(X_{T+1} - \overline{X}\right)^2}{\sum\left(X_t - \overline{X}\right)^2}\right] \qquad (18.)$$

Finally, the calculation of the confidence interval around each forecasted point was then done using Equation 19.

$$\hat{Y}_{T+1} \;+/-\; \text{t}_{.20}s_f \qquad (19.)$$

However, the percentage of pump repairs surviving is not an EUL. The EUL is derived as follows. First the estimated model is evaluated at future values of time to determine when the forecasted percentage reaches 50%. The number of months associated with this 50% value is then divided by 12 to derive the EUL. To calculate the 80% confidence interval around this EUL, the upper and lower bounds surrounding the forecasted value of 50% were first determined. Then, forecasted values that are near to the upper and lower bounds are identified. The number of months associated with the upper and lower bounds are then divided by 12 to derive the upper and lower bounds of the EUL.

3.4.3 Assumed Functional Form

Once the EUL was estimated using Equation 15, the standard error for $\hat{S}$, the estimated proportion of the measures surviving was calculated. The upper and lower bounds of the estimated proportion at the 80% confidence level were then calculated. These upper and lower bounds used Equation 19 to calculate the upper and lower bounds of the EUL.

4 RESULTS

The results are presented in two ways. First, the data are tabulated to see how many measures continued to be in place and operable in 1999 or 2000. Second, if there are sites with measures removed, the EUL is determined (when possible) using the three analysis methods described in Section 3.

4.1 Survival of Measures

Exhibit 4.1 shows those measures for the PY1996 program that are still in place and operable as of 1999.

Exhibit 4.1
1996 Program Measures In Place and Operable as of 1999

		In Place and Operable		
Measure	Measure Code	Yes	No	Total
Pump Repair	A1	43	3	46
Sprinkler to Micro, Valley, Well, Field/Veg (acres)	A44	1,638	0	1,638
HID Fixture: Interior, Standard, 251-400 Watt Lamp (fixtures)	L81	4,907	20	4,927
Total		6,588	23	6,611

As shown above, 7% of the 1996 retention panel pump repair measures had been removed. There were no removals of the micro irrigation conversion sites. The failures for the HID lighting represented 0.4% of the installed HID fixtures

Exhibit 4.2 shows the measures audited during the evaluation of the 1997 program. Just over 17% of the pump repair measures are not in place and operable. Again, there were no removals of the micro irrigation conversion sites.

Exhibit 4.2
1997 Program Measures In Place and Operable as of 2000

		In Place and Operable		
Measure	Measure Code	Yes	No	Total
Pump Repair	A1	82	17	99
Sprinkler to Micro, Valley, Well, Field/Veg (acres) and No Well, Deciduous (acres)	A44 and A49	5,500	0	5,500
Total		5,582	17	5,599

4.2 Effective Useful Life of Measures

Where possible, an EUL was to be determined for the measures indicated in Exhibit 1.1. The pump repair measure had enough failures to support an EUL analysis, while the HID lighting and micro irrigation conversion measures did not. Each measure is discussed separately below.

4.2.1 HID Lighting – Default Value Retained

Because there were only 0.4% failures observed in the 1996 data, estimating time to the 50% measure failure point (i.e., the EUL) from this point would be futile. Thus the ex ante HID measure EUL of 16 years (Exhibit 1.1) was retained as the best estimate of effective useful life for the 1996 program year.

4.2.2 Micro Irrigation Conversion – Default Value Retained

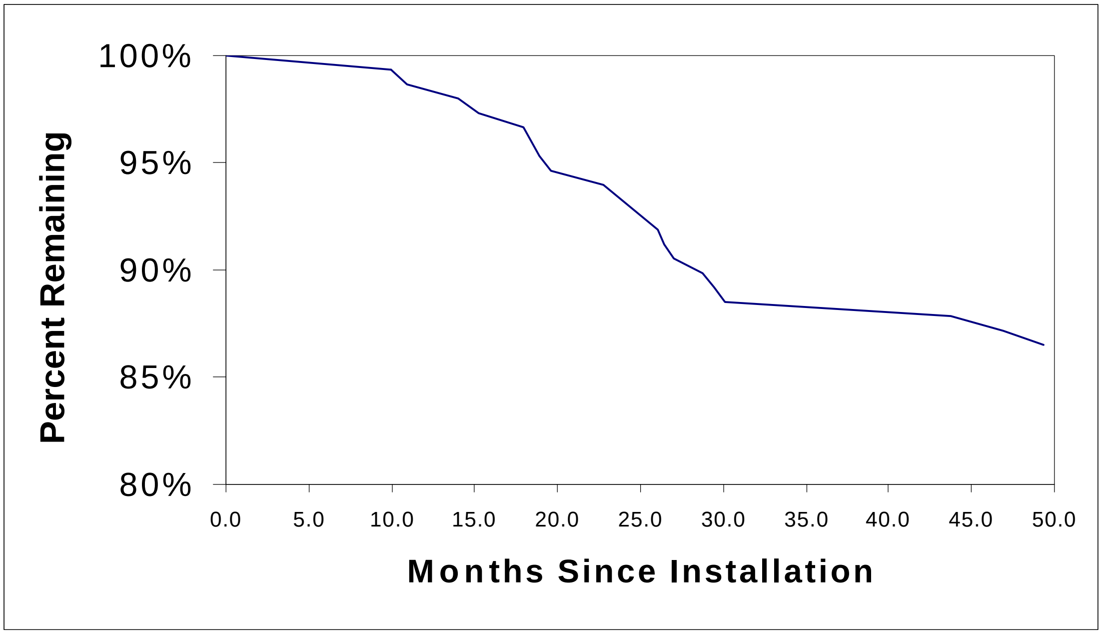
There were no failures seen in this measure. Clearly, with an estimated EUL of 20 years, a three-year retention study is early. The ex ante EUL of 20 years is retained as the best estimate of effective useful life for both the 1996 and 1997 program years.

4.2.3 Pump Repairs

The pump repair measure had enough data for an EUL analysis. The data from the two program years were combined and the three different analysis methods were applied to the data gathered on this measure.

First, the empirical survival function is presented in Exhibit 4.3. This is the function that the various approaches attempt to fit.

Exhibit 4.3
Empirical Survival Function for Pump Repairs



The average hazard rate is simply defined as the total number of failures (20) divided by the total number of observations (145). Thus, the average hazard rate is 0.138. The percentage of observations that are right censored is 0.862 (i.e., 1 - 0.138). Each technique will now be explored, beginning with the classic survival analysis.

Classic Survival Analysis

The exponential functional form, which assumes that hazard is constant, was tried first. Then the four other functional forms that assumed that the probability of failure increased over time were tried. These so-called accelerated failure time (AFT) models include the Weibull, the log-logistic, the log-normal, and the generalized gamma. The results of these analyses are presented in Exhibit 4.4.

Exhibit 4.4
Estimated Pump Repair EULs and 80% Confidence Interval, by Functional Form

Functional Forms	EUL	80% Confidence	Log-Likelihood
Log-logistic	10.5	6.5 - 14.4	-68.61
Weibull	9.3	6.1 - 12.4	-68.78
Log-normal	12.7	7.1 - 18.3	-67.76
Generalized Gamma	N/A	N/A	N/A
Exponential	17.3	11.9 - 22.6	-71.05

The first thing to note is that the generalized gamma model failed (i.e., it did not converge), making it impossible to estimate a reliable log-likelihood and to estimate a median EUL and standard error. Of the models that could be estimated, all, except the exponential, produced 80% confidence intervals that include the ex ante value of 9 years.

Another side effect of the failure of the generalized gamma model is that it also makes it impossible to conduct many of the formal hypotheses tests. This is because all but one of the formal hypothesis tests uses the generalized gamma as the point of comparison. Thus, the only hypothesis test that could be conducted is presented in Exhibit 4.5.

Exhibit 4.5
Pump Repair Model Comparison

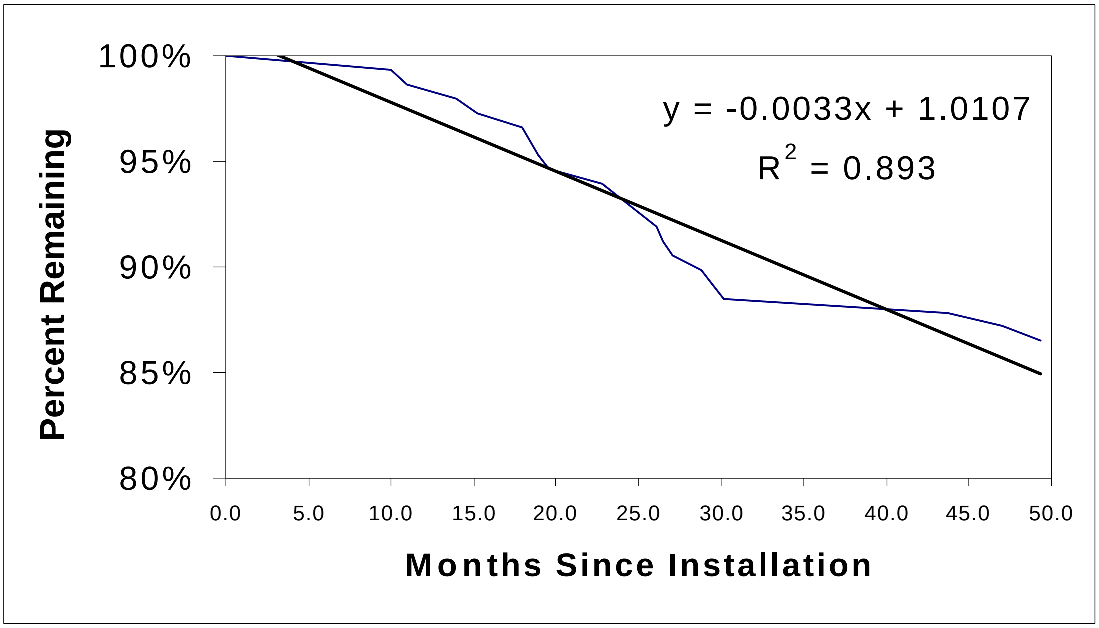
Comparison	Likelihood-Ratio Chi-Square
Exponential vs. Weibull	4.54

That the exponential model should be eliminated seems clear given that it produces an implausibly high EUL estimate (17.3 years) and a large chi-square that indicates that it is significantly different than the Weibull model ($p < .05$). Except for the exponential model, these results strongly support the conclusion to accept the ex ante value of 9 years. Because of the failure of the generalized gamma to converge, one can only select the model with the highest log-likelihood statistic, which is the log-normal model. Thus, for reporting purposes, the results from the log-normal model (EUL=12.7 years) is recommended.

Ordinary Least Squares

Next, linear and exponential trend lines were fitted to the empirical survival function. The result for the linear model, which had the higher R^2, is presented in Exhibit 4.6.

Exhibit 4.6
Empirical Survival Function Versus Fitted Trend Line for Pump Repairs



The percentage remaining was forecasted until the median, 50%, was reached. The forecast error surrounding the 50% was four percentage points at the 80% level of confidence.

The 80% confidence interval for the percentage of pump repairs surviving is very small. There are two primary reasons for this. First, the pump forecast is unconditional, since the explanatory variable, *time*, is known with certainty for the entire forecast period. This absence of error around future explanatory values removes a large source of forecasting error. Second, the model has a very high R^2 of 0.893, leading to a very small model error, which has a direct effect on the forecast error.

However, the percentage of pump repairs surviving is not an EUL. The EUL is derived as follows. First, the estimated model is evaluated at future values of time to determine when the forecasted percentage reaches 50%. The number of months associated with this 50% value is then divided by 12 to derive the EUL. To calculate the 80% confidence interval around this EUL, the upper and lower bounds surrounding the forecasted value of 50% were first determined. Then, forecasted values that were near to the upper and lower bounds were identified and the number of months associated with each are divided by 12 to derive the upper and lower bounds of the EUL.

Thus, estimate of the EUL is 12.9 years, plus or minus 0.75 years, making the upper and lower bounds of the EUL 10.75 and 12.25, respectively. Because this confidence interval does not include 9, the ex ante EUL of 9 years is rejected using this method.

Assumed Functional Form

Next, the assumed functional form approach was used to estimate the EUL for pump repairs. The resulting EUL was 16.1 years. The 80% confidence interval was plus/minus 6.2 years. Because this interval excludes the ex ante value of 9 years, the ex ante value is rejected using this method. However, this estimate is 79% greater than the ex ante, which is implausibly large. It is interesting to note that, not surprisingly, the estimate of 16.1 years is reasonably close to the 17.3 years estimated by the exponential model using classic survival analysis. However, as noted above, the formal hypotheses testing described above rejected, rather convincingly, the functional form as being exponential.

Conclusions

Based on the more robust classic survival analysis, the main conclusion is that the ex ante value of 9 years should be retained.

5 PROTOCOL TABLES

5.1 Protocol Table 6.B – 1996 Agricultural Sector

Refer to Section 3.4 for the method used to determine the confidence intervals shown in this table.

Protocol Table 6.B
Results of 3rdYear Retention Study
PG&E 1996 Agricultural Sector
Study ID 354R1 and 385R1

Item 1			**Item 2**		**Item 3**	**Item 4**	**Item 5**	**Item 6**		**Item 7**	**Item 8**	**Item 9**
PG&E Measure Code	**Studied Measure Description**	**End Use**	**Ex Ante EUL**	**Source of Ex Ante EUL (ref. Ftnote)**	**Ex post EUL from Study**	**Ex Post EUL to be used in Claim**	**Ex Post EUL Standard Error**	**80% Conf. Interval Lower Bound**	**80% Conf. Interval Upper Bound**	**p-Value for Ex Post EUL**	**EUL Realizat'n Rate (ex post/ex ante)**	**"Like" Measures Associated with Studied Measure (by measure code)**
A1	Pump Repair	Pumping and Related	9.0	1	12.7	9.0	4.01	7.1	18.3	0.80	1.00	-
A44	Sprinkler to Micro, Valley, Well, Field/Veg	Pumping and Related	20	1	NA*	20.0	NA	NA	NA	NA	NA	-
L81	HID Fixture: Interior, Standard, 251-400 Watts Lamp	Ag Indoor Lighting	16.0	1	NA*	16.0	NA	NA	NA	NA	NA	-

*Not enough failures were found during the retention study for an EUL to be calculated

Ex Ante Source References: 1 PG&E Advice Filing 1921-G-A/1540-E October 1995

5.2 Protocol Table 6.B – 1997 Agricultural Sector

Refer to Section 3.4 for the method used to determine the confidence intervals shown in this table for the pump retrofit measure.

Protocol Table 6.B
Results of 3rd Year Retention Study
PG&E 1997 Agricultural Sector
Study ID 335AR1

Item 1			**Item 2**		**Item 3**	**Item 4**	**Item 5**	**Item 6**		**Item 7**	**Item 8**	**Item 9**
PG&E Measure Code	**Studied Measure Description**	**End Use**	**Ex Ante EUL**	**Source of Ex Ante EUL (ref. Ftnote)**	**Ex post EUL from Study**	**Ex Post EUL to be used in Claim**	**Ex Post EUL Standard Error**	**80% Conf. Interval Lower Bound**	**80% Conf. Interval Upper Bound**	**p-Value for Ex Post EUL**	**EUL Realizat'n Rate (ex post/ex ante)**	**"Like" Measures Associated with Studied Measure (by measure code)**
A1	Pump Retrofit	Pumping and Related	9.0	1	12.7	9.0	4.01	7.1	18.3	0.80	1.00	-
A44	Sprinkler to Micro, Valley, Well, Field/Veg	Pumping and Related	20.0	1	NA*	20.0	NA	NA	NA	NA	NA	-
A49	Sprinkler to Micro, Valley, No Well, Deciduous	Pumping and Related	20.0	1	NA*	20.0	NA	NA	NA	NA	NA	-

*Not enough failures were found during the retention study for an EUL to be calculated

Ex Ante Source References: 1 PG&E Advice Filing 1978-G/1608-E October 1, 1996

5.3 Protocol Table 7 – 1996 Retention Study (Study # 354R1 and 385R1)

1996 Agricultural EEI Program
3rd Year Retention Study
PG&E Study ID #354R1 and 385R1

The purpose of this section is to provide the documentation for data quality and processing as required in Table 7 of the California Public Utility Commission (CPUC) Evaluation and Measurement Protocols (the Protocols). Major topics are organized and presented in the same order as they are listed in Table 7 for ease of reference and review. When responses to the items are discussed in detail elsewhere in the report, only a brief summary will be given in this section to avoid redundancy.

5.3.1 Overview Information

5.3.1.1 Study Title and Study ID Number

Study Title: 3rd Year Evaluation of Retention in Pacific Gas &Electric Company's 1996 Agricultural Energy Efficiency Incentives (AEEI) Program

Study ID Number: 354R1 and 385R1

5.3.1.2 Program, Program Year and Program Description

Program: PG&E Agricultural EEI Program, Agricultural Sector

Program Year: Rebates Received in the 1996 Calendar Year.

Program Description: The 1996 Agricultural Program rebated technologies covered by the Retrofit Express (RE), Retrofit Efficiency Options (REO), Customized Incentives (CI) Programs, and Advanced Performance Options (APO).

5.3.1.3 End Uses and/or Measures Covered

End Uses Covered: Agricultural Pumping and Related Technologies
Agricultural Indoor Lighting Technologies

Measures Covered: Pump Repair
Micro Irrigation Conversion
HID Interior 251-400 W Lamps

5.3.1.4 Methods and Models Use

The PG&E AEEI Program retention study evaluated three methods: 1) classic survival analysis 2) ordinary least squares (OLS), and 3) assumed functional form (AFF).

Classic Survival Analysis: Pump Repair

In additional to the exponential model, which assumes a constant hazard, also estimated were a number of accelerated time failure (AFT) models, including:

1. Weibull:

$$S(t) = e^{\left[-(l t)^{K}\right]}$$

where

l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

K = A constant whose value is greater than 0

Note that when K = 1 (a constant), the exponential model is specified.

2. Gamma

$$f(t) = \frac{l\,(l\,t)^{K-1} e^{-l t}}{\Gamma(K)}$$

where

l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

Γ = The gamma function

K = $1/d^2$ (the shape parameter)

3. Log-logistic

$$S(t) = \frac{1}{1 + (l\,t)^{g}}$$

where

l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

γ = $1/\sigma$

σ = Scale parameter

4. Log-normal

Since the log-normal cannot be expressed in closed form, it is presented as a regression model in which the dependent variable is the logarithm of the hazard:

$$\log h(t) = \log h_0(te^{-bx}) - bx$$

where

h_0 (.)= The hazard function for an individual with x = 0

Ordinary Least Squares: Pump Repair

The first alternative approach used was the familiar ordinary least squares (OLS) regression that estimates the relationship between time and the percentage of measures remaining that are still present and operable (Maddala, 1992). The following model was estimated for each measure where there were an adequate number of observations.

$$\text{PR} = a + bt + e$$

where

PR = Percentage remaining

b = The change in the Percentage Remaining due to a one unit change in t (months)

a = A constant that captures the Percentage Remaining through an unspecified set of variables

e = The error term that capture changes in Percentage Remaining that are not explained by the model

Once this model was estimated, it was evaluated at values of t until the percentage remaining equaled 50%. The value of t that produced 50% was the estimate of the EUL.

Assumed Functional Form: Pump Repairs

$$\hat{\text{EUL}} = \frac{t \ln(0.5)}{\ln(\hat{S})}$$

where $\hat{S}$ = equal to survey-based estimate of the proportion of measures surviving

t = average measure age in the survey

The key inputs come from the site survey that provides the percentage surviving ($\hat{S}$) and the average age of the pumps (t). These two values are inserted into the equation above to derive the estimated EUL.

5.3.1.5 Analysis Sample Size

The analysis sample size is shown below in Exhibit 5.1.

Exhibit 5.1
Sample Summary – 1996 Agricultural Sector

Measure	Measure Code	1996 and 1997 Program Year		Total
		1996	1997	
Pump Repair	A1	46	102	148
Micro Conversion	A44 or A49	10	17	27
HID lighting	L81	47	0	47
Total		103	119	222

5.3.2 Database Management

5.3.2.1 Specific Data Sources

On-site survey data were collected for a census of specific measures from the 1996 retention panel. All data came directly from the retention panel.

5.3.2.2 Data Attrition

All data elements mentioned above were first validated and then merged together to form the final analysis data set. All data points collected during the on-site audits were kept.

5.3.2.3 Internal Data Quality Procedures

The data quality procedures are consistent with PG&E's internal guidelines and the guidelines established in the Protocols. The on-site audits were validated by an agricultural engineer prior to data entry.

5.3.2.4 Unused Data Elements

All data collected specifically for the Evaluation were utilized.

5.3.3 Sampling

5.3.3.1 Sampling Procedures and Protocols

The limited participant population necessitated an attempted census of retention panel participants. The number of completed participant surveys as mentioned above in section 5.3.1.5, reflects such an attempted census.

5.3.3.2 Survey Information

On-site audit instruments are presented in Appendix C.

5.3.3.3 Statistical Descriptions

The only variables in the model were whether the measure had failed and time. No covariates were available. Descriptive statistics for variables in the models are shown in Exhibit 5.2.

Exhibit 5.2
Descriptive Statistics

End Use	Average Age (Years)	Standard Deviation	Percent Surviving
Pumping	3.36	0.78	86.5

5.3.4 Data Screening and Analysis

5.3.4.1 Outliers and Missing Data

When the failure date was unavailable, the date of removal was set for 1.5 years before the 3rd year retention evaluation completed its on-site audits. There were no outliers in the analysis.

5.3.4.2 Background Variables

There were no background variables modeled.

5.3.4.3 Data Screening Process

No data were screened from the retention analysis.

5.3.4.4 Model Statistics

Classic Survival Analysis: Pump Repairs

The following tables provide the basic model results for pump repairs using classic survival analysis.

Exhibit 5.3
Estimated Pump Repair EULs and 80 Percent Confidence Interval, by Functional Form

Functional Forms	EUL	80% Confidence	Log-Likelihood
Log-logistic	10.5	6.5 - 14.4	68.61
Weibull	9.3	6.1 - 12.4	68.78
Log-normal	12.7	7.1 - 18.3	67.76
Generalized Gamma	N/A	N/A	N/A
Exponential	17.3	11.9 - 22.6	71.05

The first thing to note is that the generalized gamma model failed (i.e., it did not converge), making it impossible to estimate a reliable log-likelihood and to estimate a median EUL and standard error. Of the models that could be estimated, all, except the exponential, produced 80% confidence intervals that include the ex ante value of 9 years.

Another side effect of the failure of the generalized gamma model is that it also makes it impossible to conduct many of the formal hypotheses tests. This is because all but one of the formal hypothesis tests uses the generalized gamma model as the point of comparison. The only hypothesis test that could be conducted is presented in Exhibit 4.5 and is presented again below.

Exhibit 5.4
Model Comparison

Comparison	Likelihood-Ratio Chi-Square
Exponential vs. Weibull	4.54

That the exponential model should be eliminated seems clear cut given that it produces an implausibly high EUL estimate (17.3 years) and a large chi-square that indicates that it is significantly different than the Weibull model ($p < .05$). All three of the remaining models have 80% confidence intervals that include the ex ante value of 9 years.

Except for the exponential model, these results strongly support the conclusion to accept the ex ante value of 9 years. Because of the failure of the generalized gamma model, one can only select the model with the highest log-likelihood statistic, which is the log-normal model. Thus, for reporting purposes, the results from the log-normal model (EUL=12.7 years) are recommended.

Ordinary Least Squares (OLS): Pump Repairs

The final model used for the pump repair measure only was an OLS model with time as the independent variable and percentage surviving as the dependent variable. The final model equation was:

Y = 1.0107 -.0033X

where:

Y = percentage surviving
X = months

The equation had an R^2 of 0.893.

Assumed Functional Form: Pump Repair

The key inputs come from the site survey that provides the percentage surviving ($\hat{S}$) and the average age of the pumps (t).

Percentage Surviving	86.5%
Average Age of Pumps	3.36 years

These two values are inserted into the equation below to derive the estimated EUL.

$$E\hat{U}L = \frac{t\ln(0.5)}{\ln(\hat{S})}$$

5.3.4.5 Model Specification

Classical Survival Analysis – Specification was not an issue since there were no other variables other than whether the measure had survived up to the time of the field survey and the date of installation. There were no covariates.

OLS Analysis – Specification is not an issue since there was only one independent variable available, time. There were no covariates. The chosen model had the highest R^2 and, therefore, the best predictive power.

Assumed Functional Form Analysis – Specification is not an issue since the functional form is assumed.

5.3.4.6 Measurement Errors

The main source of measurement errors is the on-site survey. Our approach has been to proactively stop the problem before it happens so that statistical corrections are kept to a minimum.

Measurement errors are a combination of random and non-random error components that plague all survey data. The non-random error frequently takes the form of systematic bias, which includes, but is not limited to, ill-formed or misleading questions and miscoded study variables. In this project, controls were implemented to reduce the systematic bias in the data. These steps included auditor training and instrument pre-test.

The random measurement error, such as data entry error, has no impact on estimating mean values because the errors are typically unbiased.

5.3.4.7 Influential Data Points

Since the analysis consisted of a simple regression of the percentage of surviving pumps by time, there were no influential data points in the OLS analysis. There were no outliers in the analysis.

5.3.4.8 Missing Data

When the failure date was unavailable, the date of removal was set for 1.5 years before the 3rd year retention evaluation completed its on-site audits.

5.3.4.9 Precision

The precision was determined as specified in Section 3.4..

5.4 Protocol Table 7 – 1997 Retention Study (Study # 335AR1)

1997 Agricultural EEI Program
3rd Year Retention Study
PG&E Study ID #335AR1

The purpose of this section is to provide the documentation for data quality and processing as required in Table 7 of the California Public Utility Commission (CPUC) Evaluation and Measurement Protocols (the Protocols). Major topics are organized and presented in the same order as they are listed in Table 7 for ease of reference and review. When responses to the items are discussed in detail elsewhere in the report, only a brief summary will be given in this section to avoid redundancy.

5.4.1 Overview Information

5.4.1.1 Study Title and Study ID Number

Study Title: 3rd Year Evaluation of Retention in Pacific Gas &Electric Company's 1997 Agricultural Energy Efficiency Incentives (AEEI) Program

Study ID Number: 335AR1

5.4.1.2 Program, Program Year and Program Description

Program: PG&E Agricultural EEI Program, Agricultural Sector

Program Year: Rebates Received in the 1997 Calendar Year.

Program Description: The 1997 Agricultural Program rebated technologies covered by the Retrofit Express (RE) and Retrofit Efficiency Options (REO) Programs

5.4.1.3 End Uses and/or Measures Covered

End Uses Covered: Agricultural Pumping and Related Technologies

Measures Covered: Pump Repair
Micro Irrigation Conversion

5.4.1.4 Methods and Models Use

The PG&E AEEI Program retention study evaluated three methods: 1) classic survival analysis 2) ordinary least squares (OLS), and 3) assumed functional form (AFF).

Classic Survival Analysis: Pump Repair

In additional to the exponential model, which assumes a constant hazard, also estimated were a number of accelerated time failure (AFT) models, including:

1. Weibull:

   $$S(t) = e^{\left[-(l t)^{K}\right]}$$

   where

l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

K = A constant whose value is greater than 0

Note that when K = 1 (a constant), the exponential model is specified.

2. Gamma

$$f(t) = \frac{l(lt)^{K-1} e^{-lt}}{\Gamma(K)}$$

where

l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

Γ = The gamma function

K = $1/d^2$ (the shape parameter)

3. Log-logistic

$$S(t) = \frac{1}{1 + (lt)^g}$$

where

l = $\exp\{-[\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k]\}$

γ = $1/\sigma$

σ = Scale parameter

4. Log-normal

Since the log-normal cannot be expressed in closed form, we present it as a regression model in which the dependent variable is the logarithm of the hazard:

$$\log h(t) = \log h_0(te^{-bx}) - bx$$

where

h_0 (.)= The hazard function for an individual with x = 0

Ordinary Least Squares: Pump Repair

The first alternative approach used was the familiar ordinary least squares (OLS) regression that estimates the relationship between time and the percentage of measures remaining that are still present and operable (Maddala, 1992). The following model was estimated for each measure where there were an adequate number of observations.

$$PR = a + bt + e$$

where

PR = Percentage remaining

b = The change in the Percentage Remaining due to a one unit change in t (months)

a = A constant that captures the Percentage Remaining through an unspecified set of variables

e = The error term that capture changes in Percentage Remaining that are not explained by the model

Once this model was estimated, it was evaluated at values of t until the percentage remaining equaled 50%. The value of t that produced 50% was the chosen estimate of the EUL.

Assumed Functional Form: Pump Repairs

$$\hat{EUL} = \frac{t \ln(0.5)}{\ln(\hat{S})}$$

where $\hat{S}$ = equal to survey-based estimate of the proportion of measures surviving

t = average measure age in the survey

The key inputs come from the site survey which provides the percentage surviving ($\hat{S}$) and the average age of the pumps (t). These two values are inserted into the equation above to derive the estimated EUL.

5.4.1.5 Analysis Sample Size

The analysis sample size is shown below in Exhibit 5.5.

Exhibit 5.5
Sample Summary – 1997 Agricultural Sector

Measure	Measure Code	1996 and 1997 Program Year		Total
		1996	1997	
Pump Repair	A1	46	102	148
Micro Conversion	A44 or A49	10	17	27
HID lighting	L81	47	0	47
Total		103	119	222

5.4.2 Database Management

5.4.2.1 Specific Data Sources

On-site survey data were collected for a census of specific measures from the 1997 retention panel. All data came directly from the retention panel.

5.4.2.2 Data Attrition

All data elements mentioned above were first validated and then merged together to form the final analysis data set.

5.4.2.3 Internal Data Quality Procedures

The data quality procedures are consistent with PG&E's internal guidelines and the guidelines established in the Protocols. The on-site audits were validated by an agricultural engineer prior to data entry.

5.4.2.4 Unused Data Elements

All data collected specifically for the Evaluation were utilized.

5.4.3 Sampling

5.4.3.1 Sampling Procedures and Protocols

The limited participant population necessitated an attempted census of retention panel participants. The number of completed participant surveys, as mentioned above in section 5.4.1.5, reflects that a census was audited.

5.4.3.2 Survey Information

On-site audit instruments are presented in Appendix C.

5.4.3.3 Statistical Descriptions

The only variables in the model were whether the measure had failed and time. No covariates were available. Descriptive statistics for variables in the models are shown in Exhibit 5.6

Exhibit 5.6
Descriptive Statistics

End Use	Average Age (Years)	Standard Deviation	Percent Surviving
Pumping	3.36	0.78	86.5

5.4.4 Data Screening and Analysis

5.4.4.1 Outliers and Missing Data

When the failure date was unavailable, the date of removal was set for 1.5 years before the 3rd year retention evaluation completed its on-site audits. There were no outliers in the analysis.

5.4.4.2 Background Variables

There were no background variables modeled.

5.4.4.3 Data Screening Process

No data were screened from the retention analysis.

5.4.4.4 Model Statistics

Classic Survival Analysis: Pump Repairs

The following tables provide the basic model results for pump repairs using classic survival analysis.

Exhibit 5.7
Estimated Pump Repair EULs and 80% Confidence Interval, by Functional Form

Functional Forms	EUL	80% Confidence	Log-Likelihood
Log-logistic	10.5	6.5 - 14.4	68.61
Weibull	9.3	6.1 - 12.4	68.78
Log-normal	12.7	7.1 - 18.3	67.76
Generalized Gamma	N/A	N/A	N/A
Exponential	17.3	11.9 - 22.6	71.05

The first thing to note is that the generalized gamma model failed (i.e., it did not converge), making it impossible to estimate a reliable log-likelihood and to estimate a median EUL and standard error. Of the models that could be estimated, all, except the exponential, produced 80% confidence intervals that include the ex ante value of 9 years.

Another side effect of the failure of the generalized gamma model is that it also makes it impossible to conduct many of the formal hypotheses tests. This is because all but one of the formal hypothesis tests uses the generalized gamma model as the point of comparison. The only hypothesis test that could be conducted is presented in Exhibit 4.5 and is presented again below.

Exhibit 5.8
Model Comparisons

Comparisons	Likelihood-Ratio Chi-Square
Exponential vs. Weibull	4.54

That the exponential model should be eliminated seems clear cut given that it produces an implausibly high EUL estimate (17.3 years) and a large chi-square that indicates that it is significantly different than the Weibull model ($p < .05$). All three of the remaining models have 80% confidence intervals that include the ex ante value of 9 years.

Except for the exponential model, these results strongly support the conclusion to accept the ex ante value of 9 years. Because of the failure of the generalized gamma to converge, one can only select the model with the highest log-likelihood statistic, which is the log-normal model. Thus, for reporting purposes, the results from the log-normal model (EUL=12.7 years) are recommended.

Ordinary Least Squares (OLS): Pump Repairs

The final model used for the pump repair measure only was an OLS model with time as the independent variable and percentage surviving as the dependent variable. The final model equation was:

$Y = 1.0107 - .0033X$

where:

Y = percentage surviving
X = months

The equation had an R^2 of 0.893.

Assumed Functional Form: Pump Repair

The key inputs come from the site survey that provides the percentage surviving ($\hat{S}$) and the average age of the pumps (t).

Percentage Surviving	86.5%
Average Age of Pumps	3.36 years

These two values are inserted into the equation below to derive the estimated EUL.

$$E\hat{U}L = \frac{t \ln(0.5)}{\ln(\hat{S})}$$

5.4.4.5 Model Specification

Classical Survival Analysis – Specification was not an issue since there were no other variables other than whether the measure had survived up to the time of the field survey and the date of installation. There were no covariates.

OLS Analysis – Specification is not an issue since there was only one independent variable available, time. There were no covariates. The chosen model had the highest R^2 and, therefore, the best predictive power.

Assumed Functional Form Analysis – Specification is not an issue since the functional form is assumed.

5.4.4.6 Measurement Errors

The main source of measurement errors is the on-site survey. Our approach has been to proactively stop the problem before it happens so that statistical corrections are kept to a minimum.

Measurement errors are a combination of random and non-random error components that plague all survey data. The non-random error frequently takes the form of systematic bias, which includes, but is not limited to, ill-formed or misleading questions and miscoded study variables. In this project, controls were implemented to reduce the systematic bias in the data. These steps included auditor training and instrument pre-test.

The random measurement error, such as data entry error, has no impact on estimating mean values because the errors are typically unbiased.

5.4.4.7 Influential Data Points

Since the analysis consisted of a simple regression of the percentage of surviving pumps by time, there were no influential data points in the OLS analysis. There were no outliers in the analysis.

5.4.4.8 Missing Data

When data were unavailable, the date of removal was set for 1.5 years before the 3rd year retention evaluation completed its on-site audits.

5.4.4.9 Precision

The precision was determined as specified in Section 3.4.

APPENDIX A

REFERENCES

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APPENDIX B

CADMAC WAIVER

PACIFIC GAS & ELECTRIC COMPANY
REQUEST FOR RETROACTIVE WAIVER FOR
COMPANY WIDE MODIFICATION TO THIRD AND FOURTH EARNINGS
CLAIM CALCULATION METHODOLOGY
Study ID: All study IDs for all PG&E programs.
Date Approved: February 17, 1999

Summary of PG&E Request

This waiver requests deviations from, or clarifications of, the Protocols[6] by PG&E for the third earnings claim methodology for PG&E's 1994 programs and for all future third and fourth earnings claims. The Protocols, as written, require that all third and fourth earnings claim impacts be calculated as the sum of the measure level AEAP values as adjusted by appropriate ex post Technical Degradation Factors (TDF) and Effective Useful Life (EUL) values. Since all PG&E second earnings claim AEAP amounts are agreed at the end use level, PG&E does not have the measure level AEAP values. PG&E seeks approval to use the first year ex post evaluation measure level findings to allocate the AEAP end use values into estimates of individual measure savings. These measure level estimates will then be combined, as specified in the Protocols, with the measure level ex post EUL and TDF values to calculate the third and fourth earnings claims.

Proposed Waiver (see Table A for Summary)

PG&E seeks CADMAC approval to:

Use the first year ex post evaluation measure level findings to allocate the AEAP end use values into estimates of individual measure savings. These measure level estimates will then be combined, as specified in the Protocols, with the measure level ex post EUL and TDF values to calculate the Resource Benefit, Net for the third and fourth earnings claims.

Parameters and Protocol Requirements

Table 10, item A.3.b.1 and 2, and A.4.a. and b., require the Resource Benefits, Net to be calculated at the measure level, then summed, using the net load impacts as "determined in the second earnings claim AEAP."

Rationale

The Protocols, as written, require that all third and fourth earnings claim impacts are calculated as the sum of the measure level second earnings claims AEAP values as adjusted by appropriate ex post TDFs and EULs. Since all PG&E second earnings claim AEAP amounts are agreed at the end use level, PG&E does not have the measure level second earnings claim AEAP values required by the methodology. PG&E cannot "back calculate" measure specific level AEAP values since there is no clear information on how to "allocate" the end use level AEAP values to the individual measures. PG&E can, however, use the measure level information from the first year evaluations to proportionally allocate or prorate the end use level AEAP values into estimates of the measure level AEAP values. These measure level estimates will then be combined, as specified in the Protocols, with the measure level ex post EUL and TDF values to calculate the Resource Benefit, Net, for the third and fourth earnings claims.

Conclusion

[6] Protocols and Procedures for the Verification of Costs, Benefits, and Shareholder Earnings for Demand-Side Management Programs.

PG&E is seeking a retroactive waiver to clearly define, in advance, acceptable methods for calculating third and fourth earnings claims. The AEAP process results in AEAP values which cannot be used to estimate the third and fourth earnings claims as required by the Protocols. PG&E's waiver proposes a straightforward alternative that fulfills the spirit of the Protocols.

TABLE A

TABLE 10, EARNINGS DISTRIBUTION SCHEDULE			
Parameters	**Protocol Requirements**	**Waiver Alternative**	**Rationale**
Calculation Methodology for Third and Fourth Earnings Claim.	Sum the product of measure level second earnings claim AEAP, ex post TDF, and ex post EULs.	Allow the use of the first year ex post evaluation measure level findings to allocate the AEAP end use values into estimates of individual measure savings. These measure level estimates will then be multiplied by the measure level ex post EUL and TDF values to calculate the Resource Benefit, Net for the third and fourth earnings claims.	The AEAP results in end use level AEAP values. The proposed method makes maximum use of evaluation findings to allocate the end use level AEAP values to the measure level. Allocation to the measure level allows both third and fourth earnings claims to be calculated as specified in the Protocols.

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APPENDIX C

ON-SITE AUDIT INSTRUMENTS

1996 AG PROGRAM RETENTION QUESTIONNAIRE

Customer Name		Audit Num:
Business Name		Orig CAQ Surveyor
Customers Address		Division
City		Assigned To:
Phone		Old Audit ID:
New Contact Name		Date Customer Talked To:
New Phone Number	Area Code	Is a Site Visit Necessary?
PG&E Audit Acct.		Date Site Visited
New PGE Acct.		

<u>1996 Measure:</u> <u>Measure Code</u> <u>Measure Description</u>

Pump Repair
Low-Pressure Sprinkler Nozzle
Micro-Drip Conversion
Indoor Lighting

<u>Location Description – Pumping & Related</u> <u>Location Description – Lighting</u>

Is the 1996 measure still present (yes/no)

If not present, explain why not

Was the measure used in 1999?

If no, explain why not

Approximate date removed from service ______________________________

Continue for Lighting Audits ONLY

<u>Num Fixtures</u> **<u>Group Descriptions Watt</u>** **<u>Lamp Fixture</u>**

What % of the equipment from this measure is still in use? _________________

When was the unused portion removed from service? (approx.) _________________

Why was it removed from service?

Auditors Comments:

PY1997 AGRICULTURAL PROGRAM RETENTION QUESTIONNAIRE

Customer Name		Audit Num:
Business Name		Orig CAS Surveyor
Customers Address		Division
City		Assigned To:
Phone		Old Audit ID:
New Contact Name		Date Customer Talked To:
New Phone Number	Area Code	Is a Site Visit Necessary?
PG&E Audit Acct.		Date Site Visited
New PGE Acct.		
1997 Measure:	Measure Code	Measure Description

Pump Audit
Micro Conversion Audit

Location Description – Pump Repair, Micro Conversion

Pump Repair Audits ONLY

Is the 1997 measure still in place and operable? (yes/no) ____________________

If no, approximate date removed from service: ____________________________

If not in place and operable, explain why not.

____

Has this pump been repaired since participating in the PG&E program? (yes/no) If so, when? ______

Micro Conversion Audits ONLY

There were ____ original acreage converted to micro irrigation. How many acres still have it? _______

If not 100% still there, when was it removed from service? (approx.) ________________

If not 100% still there, why was the micro irrigation removed from service?

Auditors Comments: