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# How long does that 10-year Smoke Alarm Really Last? A Survival Analysis of Smoke Alarms Installed through the SAIFE Program in Rural Georgia

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**Abstract** **Background:** When functioning properly, a smoke alarm alerts individuals in the residence that smoke is near the alarm. Smoke alarms serve as a primary prevention mechanism to abate morbidity and mortality related to residential fires. **Methods:** Using survival analysis, we examined the length of operability of 10-year lithium battery powered smoke alarms installed through the Georgia Public Health/CDC SAIFE program in Moultrie, Georgia. Attempts were made to reach all homes in the city limits. The premise of the study is that geographic clusters (in the case of Moultrie city quadrants) are associated with decreases in the length of time that lithium-battery powered smoke alarms function in homes. **Results:** The total installed smoke alarms across the city quadrants were 1,970. The mean survival time for installed alarms was 6.34 years. On average, alarms remained in functioning status for 7.6 years for Northeast quadrant, 5.25 years for Southeast quadrant, 5.67 for Northwest Quadrant and 6.85 years for Southwest quadrant. Alarms in two of the quadrants lasted less than 6.34 years and were statistically significantly different with a $P < .0001$. **Conclusion:** The knowledge of the length of the functionality of a 10-year lithium battery powered smoke alarms is instrumental for developing guidelines and providing recommendations to fire safety programs and fire departments regarding appropriate follow-up time frames to conduct operability check-up visits and the types of alarms to purchase. The association between geographic clusters with smoke alarm survival time potentially reinforces the public health notion that place matters.

**Keywords** Fires/prevention & control, Smoke_Inhalation Injury/prevention & control, Rural population, Burns / prevention & control

## 1. Introduction

Residential fires declined by roughly half (53%) over the past three decades in United States [1]. In spite of the decline, they remain a significant preventable public health problem [1, 2]. In 2014, 386,500 residential fires resulted in 2,745 civilian fatalities and 12,175 injuries. Apartment related deaths increased by 23.1 percent from 2013 [3]. Many of these injuries and fatalities were the result of smoke or toxic gas inhalation [4]. These types of injuries are preventable by installing fire sprinkler systems, developing fire escape plans, avoiding smoking in bed, and correctly installing an early detection system (i.e. smoke alarm) in multiple rooms throughout the residence [3]. When functioning properly, smoke alarms alert individuals in the residence that smoke is near the smoke alarm [5, 6]. Smoke alarms serve as a primary prevention mechanism to abate morbidity and mortality related to residential fires. Living in a residence with a functioning smoke alarm reduces the risk of death by approximately 50% [7]. Despite the protection available from smoke alarm technology, 37% of the homes that have fires are without alarms. When there is a death in a home due to fire, 60% of those homes have either no smoke alarm present or no smoke alarms sounded [7]. Apart from that recently published article has shown that the educational home fire safety intervention can be effective increasing the knowledge about fire safety over time [8].

Rural, low socio-economic and educational attainment communities have low rates of actual smoke alarm usage [5, 6, 9]. States in the southeastern part of the country and rural communities have higher residential fire death rates when compared to other regions [10]. From 1999-2005, Georgia's residential fire death rate was approximately 40% higher than the national average [10-12]. From 1998 to 2013, the Georgia Department of Public Health (GDPH) operated a smoke alarm installation and education program [13]. The program, funded by a grant through the Centers for Disease Control (CDC), worked with fire departments to install alarms. The program also called for post installation

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follow-up to check on alarm functionality.

If the length of time an installed smoke alarm remains functioning were the same across all homes in a community, then fire safety programs would have a similar fixed time to check-up on operability of the smoke alarm. Based on known risk factors, fire prevention specialists know which residences are at greatest risks of having a fire [14]. This research also delineates the likelihood of preventing fire related injuries as a result of not having a functioning smoke alarm in the residence [6, 13, 14]. To further evaluate the program that used long-lasting lithium batteries for fire safety interventions, the authors examined follow-up data to understand if long-lasting lithium battery powered smoke alarms remained functional for 5-10 years after initial program installation.

This paper uses survival analysis to examine the length of operability of 10-year lithium battery powered smoke alarms installed through the SAIFE program in Moultrie, Georgia. Better knowledge about the length of time a 10-year lithium battery powered smoke alarm will function is instrumental for developing guidelines and providing recommendations regarding appropriate periods for follow-up visits and determining the type of alarm purchased. Our primary hypothesis for the study is that there would be variance in the length of survival of the 10-year sealed lithium alarm that were installed in homes in Moultrie, Georgia (Rural Setting). As a secondary hypothesis for the study, we believed that the variability would be associated with the quadrant geographic cluster of the city.

## 2. Methods

### 2.1. Setting: Moultrie, Georgia

Moultrie, Georgia, located in Colquitt County, is a rural town of approximately 14,500 people in southwestern Georgia. The town has a high unemployment rate, a crime rate nearly twice the national average at 544.3 per 100,000 people (compared to the national average of 300.2 per 100,000 people), and low educational attainment [15]. Eleven percent of the population hold a Bachelor's Degree or higher, 66% have a high school diploma, and 27.5% did not complete high school. Fire safety is particularly important to Moultrie due to the number of fire incidents that occurred in the city. The National Fire Incident Reporting System (NFIRS) reported 187 fire incidents and 59 fire-related hazardous conditions [12]. Moultrie spends roughly $122,000 a month to pay its 43 firefighters, which comprises the most government employees in the city. Fire safety is the second highest governmental expenditure for the town. Moultrie is divided into four geographic quadrants: The *Northwest Quadrant (NWQ),* the *Southwest Quadrant (SWQ),* the *Northeast Quadrant (NEQ)* and the *Southeast Quadrant (SEQ)*. For instance Southwest Quadrant is the southwest area of the city. The fire station jurisdictions relate to this geographic distinction and as the fire department carried out the program, they visited homes by quadrant.

### 2.2. Intervention and Data Collection

From 2002 - 2012, the Centers for Disease Control and Prevention (CDC) funded the community-based Smoke Alarm Installation and Fire Safety Education (SAIFE) program implemented by the Georgia Department of Public Health (GDPH). The program worked with local fire fighters to educate residents about fire safety, install an appropriate number of long lasting 10 – year lithium battery powered smoke alarms based on size of residence per local and state regulation, and conduct follow-up visits. Per the Georgia SAIFE protocol, the local fire department conducted the home visits on weekday evenings and Saturday mornings and afternoons. One geographic quadrant was completed each calendar year. Firefighters worked in groups of three to collect data. One firefighter safe guarded the truck (standard procedure) while one installed the smoke alarms and the other completed program related paper work and provided the resident education. Residents in homes that were visited for smoke alarm inspections and fire safety education signed a release of liability related to the function of the alarm and documenting their decision to be part of the program.

*Education:* Resident education covered smoke alarms, fire escape planning, and fire hazard mitigation. After face-to-face education occurred, residents received a locally developed educational pamphlet describing smoke alarms and fire safety. Using this method, firefighters covered every home in Moultrie as indicated in Table 1. Firefighters recorded information about households at the time of initial installation of the smoke alarm. Information collected on the data sheet included pre-intervention smoke alarm status. Once initial data collection occurred, the shift Lieutenant and Captain reviewed the forms submitted by firefighters to avoid duplication, ensure consistency, completeness, and accuracy of data. The forms were then sent to the Injury Prevention Program at GA Department of Public Health (GDPH).

**Table 1.** Fire fighter visit attempt stratified by quadrant

| | NEQ | NWQ | SEQ | SWQ | Total |
|---|---|---|---|---|---|
| Completed Visits[1] | 372 | 2015 | 2604 | 2160 | 7151 |
| Refused[2] | 73 | 269 | 595 | 604 | 1541 |
| Unsafe Condition[3] | 6 | 33 | 36 | 21 | 96 |
| Return[4] | 0 | 1 | 1 | 2 | 4 |

[1]Completed visit: a visit where the home was inspected for alarms, alarms were installed as needed and residents were educated
[2]Refused: the resident refused to be visited
[3]Unsafe Conditions: situations where the firefighters noticed something that would be hazardous to them if they conducted the visit
[4]Return: when on the first visit no one was home the fire fighters would return at a later date to try to complete the visit

*Follow-up:* Each fire department was responsible for annual follow-up visits in their respective quadrants. Each home was revisited every fourth year. Homes were revisited within the month if the occupant was not home at the initial attempt. If after two attempts, the occupant was not home, the home was not visited until the annual follow-up. If the occupant called the fire department between initial visit and annual follow-up, then firefighters inspected the home.

### 2.3. Statistical Methods

Survival analysis is a statistical method used extensively for analysis of time-to-event data in social sciences [16-18] and epidemiological studies [19, 20]. The events of interest can include time-to-death, time-to-injury, length of stay in a hospital, or for this analysis, time-to-alarm death (i.e. alarm no longer functions). Smoke alarm survival time was measured in years. Survival analysis codes observations as censored when information about their survival time is incomplete; therefore, if an alarm is not dead during the follow-up period, we coded it as a censored observation. If the installed alarms were not working, absent, or broken at the time of visit, those observations were coded as uncensored observations. Kaplan-Meier (KM) estimation was used to generate the fraction of working alarms survival curves [21]. The nonparametric log-rank test was used to test whether two (or more) survival functions were equal or not [22].

## 3. Results

Descriptive statistics in Table 2 summarize the total number of completed installed alarms in all four quadrants (Northeast Quadrant (*NEQ*), Southeast Quadrant (*SEQ*), Northwest Quadrant (*NWQ*), and Southwest Quadrant (*SWQ*)) from 2002 to 2012. The descriptive statistics for survival time (i.e. length of time alarm was in working status) such as 25$^{th}$ quartile, median and mean survival time in years were used to describe the working status of installed alarms.

The total installed smoke alarms across all quadrants were 1,970. The mean survival time for all quadrants was 6.34 years. Over the 10-year follow up period, 35 smoke alarms in the NEQ, 280 in SEQ, 223 in NWQ, and 336 in the SWQ stopped functioning at some point after installation and prior to follow-up. Fifty percent of installed alarms were working at 9.4 years for NEQ, 5.7 years for SEQ, 5.9 years for NWQ and 7.9 years for SWQ. On average, alarms remained in functioning status for 7.6 years for NEQ, 5.25 years for SEQ, 5.67 for NWQ and 6.85 years for SWQ over the period of follow up. Among quadrants lasting less than 6.34 years, the greatest proportion was quadrants that were in the SEQ and NWQ. These quadrants were statistically significant with a $P < .0001$ (Table 3).

Figure 1 compares KM estimates for all four quadrants simultaneously. Overall, alarms lasted longer for the NEQ compared to the other quadrants. Figure 1 also illustrates that the estimated survival function for NEQ is completely above that for NWQ, which indicates that alarms installed in NEQ stayed in working condition longer compared to those NWQ quadrant. A similar interpretation can be drawn from the rest of the graph in Figure 1. Table 3 represents the log-rank statistics and associated p-value for all pair-wise quadrant comparisons. Log-rank tests (Table 3) are statistically significant at level or each pairwise comparison over each quadrant.

**Table 2.** Estimated Percentile and Means Survival times for quadrants

| | 25$^{th}$ Percentile | Median (Years) | Mean (Years) | Total Installed | Total Stopped Working |
|---|---|---|---|---|---|
| North East | 6.7707 | 9.4 | 7.6 | 121 | 35 |
| South East | 3.2389 | 5.7 | 5.25 | 488 | 280 |
| North West | 3.5072 | 5.9 | 5.67 | 466 | 223 |
| South West | 3.9973 | 7.9 | 6.85 | 895 | 336 |
| All Quadrants | 4.38 | 7.22 | 6.34 | 1970 | 874 |

**Table 3.** Test of equality by quadrants

| | Log-Rank Statistic | P-value |
|---|---|---|
| NEQ vs NWQ | 16.4798 | <0.0001 |
| NEQ vs SEQ | 42.3402 | <0.0001 |
| NEQ vs SWQ | 4.1562 | 0.0415 |
| NWQ vs SEQ | 6.9986 | 0.0082 |
| NWQ vs SWQ | 12.3227 | 0.0004 |
| SEQ vs SWQ | 49.0744 | <0.0001 |

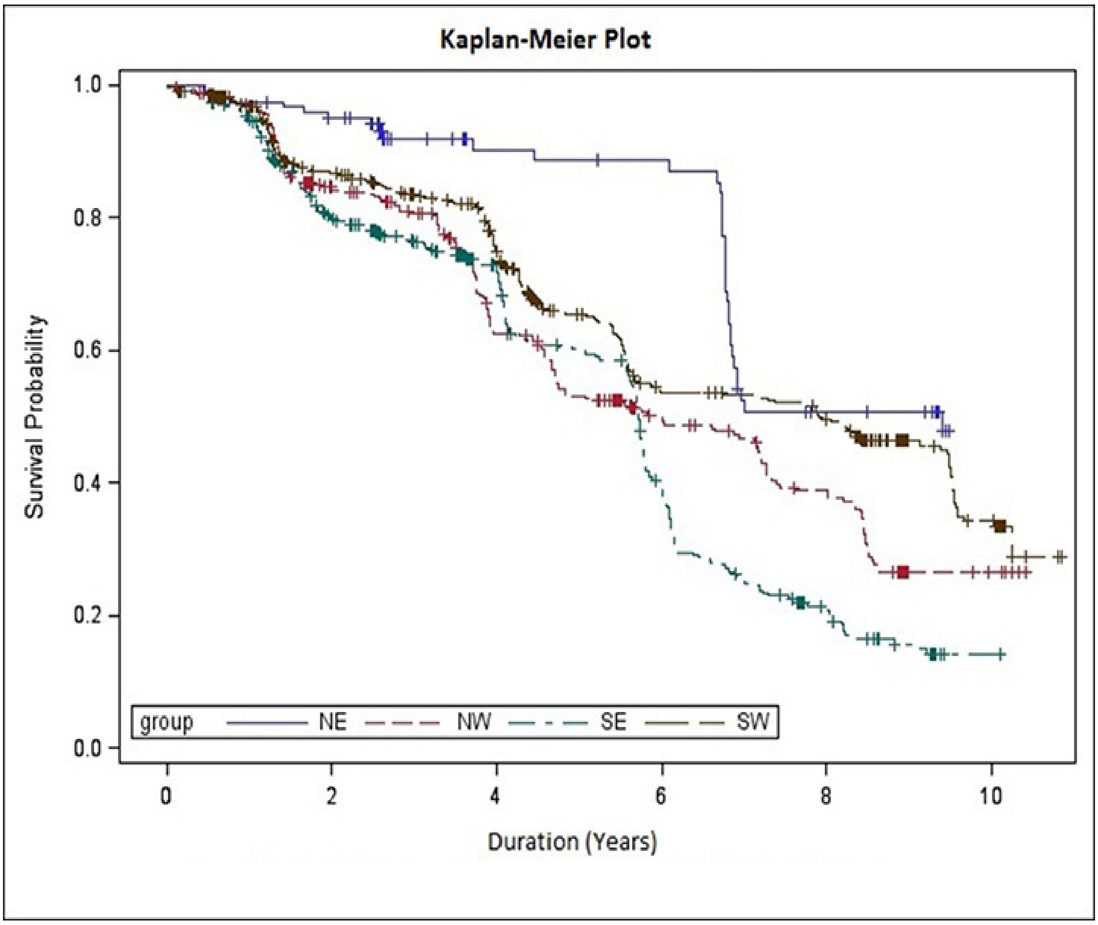


**Figure 1.** Kaplan-Meier Estimate of the survival functions of NE, NW, SE and SW quadrants

## 4. Discussion

When the initial installations occurred in Moultrie, only forty percent of homes had at least one operable smoke alarm, which is significantly lower than the reported 95% of households nationally (95% confidence interval [CI] 94.4%, 95.4%) [6]. In the United States, sixty percent of reported home fire deaths between 2007 to 2011 resulted from fires in home with no alarms or no working smoke alarms [7]. Rural areas with populations of 5,000 to 24,999, particularly in Southern states like Georgia, had the highest fire loss rates in 2014 [3] are at higher risk for fire injury because of poorer housing quality and longer emergency response times due to longer travel distances [23].

The CDC recommends installation of a 10-year sealed lithium alarm as a best practice. At least fifty percent or more of this rural town in Georgia is at risk of living in dwellings that have inoperable smoke alarms within 6 years of installation. The survival analysis data indicates that fifty percent of the 10-year alarms installed lasted less than six years in Southeast (5.72 years) and Northwest (5.92) quadrants. These drops in functionality of the smoke alarms especially after 4-6 years is consistent with current literature that evaluated smoke alarm functional status after similar installation programs utilizing similar alarm types as this study [5, 24, 25]. It is important to note that the CDC SAIFE program installed alarms with long-life lithium batteries; therefore, a battery discharge (i.e. death) should not have occurred between installation and follow-up.

During the duration of the SAIFE program, a decline in the percentage of working smoke alarms occurred. The survival data indicates that there is a significant difference of smoke alarm survival by neighborhood quadrant in Moultrie. Similar to other study findings, these findings report that smoke alarms are lasting less than the anticipated 10 years depending on the neighborhood [5, 13]. It is clear that residential location is a factor in how long a smoke alarm functions. The survival analysis data indicates that smoke alarm disparities exist based on neighborhood location. Other factors influencing alarm survival could include removal of battery due to noise nuisance, lack of understanding that the battery does not need to be replaced annually, or the resident may have replaced the non-functioning lithium battery with a non-lithium one as discussed in Ballesteros, Jackson [13] study.

When equaled against the NEQ, the NWQ and SEQ quadrants significantly differ in survival indicating that differences develop over time between quadrants. Since each quadrant has the same 10-year lithium powered ionization smoke alarm installed, other confounding factors such as knowledge of smoke alarm maintenance not explored in this analysis are conceivably influencing the functioning of the alarm. Education was an integral component of this intervention but comprehension of alarm maintenance by residents' pre and post installation is not examined in this analysis.

Since battery functioning was not compared to alarm life, it cannot be ruled out as a possible confounder along with others such as disabled or removed smoke alarms due to noise annoyance as a result of malfunctions or cooking smoke. The Consumer Product Safety found in a nationally representative survey that over half of respondents reported that their smoke alarms have gone off when there was no fire, and cooking was the reason in eighty percent of these instances [26]. The findings in the report indicate an opportunity for additional education in utilizing the "hush" function in recurring years post initial installation to mitigate nuisance noise smoke alarm disabling especially in rental dwellings where residents change frequently [13, 26].

If the length of operable time for installed smoke alarms were relatively similar across communities and dwellings, then the follow-up safety checks could be uniform across neighborhoods. The survival analysis indicates that certain neighborhoods require follow-up sooner for 10-year lithium smoke alarms after installation to ensure operability and potentially reduce fire related morbidity and mortality. The results indicate that the SEQ and NWQ should be on different smoke alarm follow-up schedules than the NEQ and SWQ. These quadrants warrant follow-up visits on every 4 or 5 years instead of 10 years by the fire department. The continued functioning found in the NEQ indicates that there are communities where a longer follow-up and the used of ten year alarms could be quite effective.

## 5. Limitations

This study has several limitations. First, over the period of this program, data collection forms and field definitions changed. This did not allow for mapping of similar data in relation to assessing whether homes had adequate smoke alarm coverage throughout the house at baseline and at follow-up. The Georgia SAIFE program installs alarms outside of every sleeping area and on every level of the home, including the basement. Depending on the size of the home, this requires multiple alarms and leads to variability of alarm functionality within the same house. Second, limited and inconsistent data existed on some homes with follow-up times longer than four years. While documentation of a decrease in operable smoke alarms compared to time to event within homes was possible, understanding how this decline progresses over longer periods is better for recommending when specific follow-up visits to re-install alarms should occur. Third, this evaluation was not designed to assess the impact of this program on fire injuries and deaths. While reduction in fire related morbidity and mortality is the ultimate goal, documenting this is difficult because these numbers tend to be small when examining community-level settings. Demonstrating impact is critical for maintaining current and attaining new resources and interest, and it continues to be a challenge for all fire safety initiatives. Last, there is unquantifiable data for those coded as existing working smoke alarms at the time of visit. The working smoke alarms that were in the house could be either 1-year or 10-year alarms. Therefore, the censored observation could be a mix of one and 10-year failing alarms.

## 6. Strengths

There are a number of strengths to this study. First, this analysis is based on a population and not a sample. Second, this study accounts for the censored observations as well as the time to event by neighborhood quadrant, captured 100% of the total dwellings within the town of Moultrie, and provided education at the time of installation as recommended by previous studies [27, 28]. Third, there was continuity throughout the program with minimal turn over in firefighters. The SAIFE worked with local fire department personnel who were responsible for smoke alarm installation, testing, follow-up. According to the NFPA, programs that utilize firefighters increase the chances that the fire alarm is installed properly [29]. This ensures that smoke alarms are installed, tested, and determined inoperable by the same fire department personnel that serve the community. Fourth, this report is an example of programmatic staff working with academia using program evaluation data to address gaps in knowledge.

Lastly, to address the primary interest, the survival rate for 10-year lithium powered smoke detector alarms; we used survival analysis (Kaplan Meier Estimates) as a statistical method. This differs from previous studies that utilized logistic regression methods to ascertain the length of time an alarm functions [28]. Survival analysis is more robust in determining the true survival of smoke detector alarms. By using survival analysis instead of logistic regression, we incorporate partial information for time calculation instead of the assumption that all alarms were installed at the same time. Survival analysis accommodates staggered dates of entry for alarm installations, which gives a truer alarm survival time than logistic regression. In general, survival analysis methods are more powerful than logistic regression methods for determining length of time a smoke detector alarm functions.

## 7. Conclusions

This study used longitudinal data to examine length of time a 10-year lithium battery powered smoke alarm functioned in a rural area. Knowing the length of time a 10-year lithium battery powered smoke alarm will function is instrumental to developing guidelines and providing recommendations to fire safety programs and fire departments regarding appropriate follow-up time frames to conduct operability check-up visits. By using a new not previously published method to analyze the data, we were able to identify the areas in rural Georgia where lithium powered alarms last the shortest and longest time. This knowledge is particularly important for rural and low socioeconomic income areas with limited fire department resources and high-risk populations. These results demonstrate that when resources are available, it may be necessary to install new smoke alarms between years five and seven depending on the neighborhood. Since smoke alarms are the first line of defense for residential fires it is imperative that municipalities, property owners, and rental residents are cognizant that inoperable smoke alarms are a serious public health and safety issue that requires frequent attention. Having a functioning smoke alarm in a residence has the potential decrease injuries and loss of lives for firefighters and civilians because they are able to handle the fire before it becomes heavily engaged.

# 8. Recommendations

Though research exists on risk factors for fires, actually knowing which house will burn next is not possible. Estimations based on risk factors are the best we can do. Risk factors such as not having a smoke alarm, having a non-functioning alarm, space heaters, smoking in bed, and socio-economic status increase the chances of having a fatal fire [27, 30]. Research exists on the likelihood of an operational smoke alarm in a home based on demographic and other variables [14]. The more that is known about the locations of homes containing inadequate amount or inoperable smoke alarms, the more effective a tailored program intervention involving fire fighters could be in saving lives. It is imperative for fire departments and public health agencies to work together to increase the availability of smoke alarms to rural towns and establish operability checkup visits scheduled based on data associated with the survival period of the alarm installed in the geographic area. At each of these follow-up visits an educational component should occur. If the resident received the initial education component, then a modified education session suffices. If a new resident resides in the dwelling, the initial educational component should be administered. If completed as recommended, these follow-ups are beneficial to educating residents on the hazards of disabling an alarm due to nuisance and encouraging residents and property owners to maintain and check operability of alarms based on the recommended fire safety best practices.

Furthermore based on the survival analysis data, fire departments, community-based organizations, and insurance companies should have special educational and installation initial and follow-up programs that targets neighborhoods with high turnover dwellings such as apartment buildings and transient living spaces (i.e. motels and weekly rentals) that occur more frequently. This lets new residents who may be least likely to maintain their alarms properly to receive education on alarm and fire safety as well as provide an opportunity to check alarm functionality. Similarly, based on previous studies, neighborhoods with low-income, racial and ethnic minorities, high transient populations, and documented heavy smokers should also be targeted for shorter periods between follow-up visits [9, 24, 31]. Current alarm intervention programs purchase and use ten-year lithium battery powered smoke alarms, which on average can cost five to thirty dollars or more depending on the brand, and typically cost more than five-year smoke alarms. This data suggests that five-year alarms may be more cost-effective and efficient than 10-year alarms if their survival rate is actually 5 years. The research presented in this paper suggests that after five years, in certain neighborhoods in Moultrie, these alarms are inoperable. Additional research is needed to determine if these findings can be substantiated. If other studies find that after five years the majority of 10-years are inoperable, then programs might consider using five-year alarms as a cost-effective measure. This switch allows for reduced costs and increases coverage in neighborhoods. Since we did not compare 5-year alarms against the 10-year alarms, we are unable to determine conclusively that it is more cost-effective. The data also indicated that there were some communities where the ten year alarms were effective.

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