

Report on the Step-Up Transformer Failure and Fire at Palomar Unit 1 - December 2010
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Executive Summary

On December 22, 2010, the main step-up transformer at Palomar Power Energy Center Unit 1 experienced an internal electrical short and caught fire. The unit automatically shut down and plant personnel called the Escondido Fire Department. The Escondido Fire Department coordinated a multi-agency response to the fire, and the notification of the public within a mile of the unit of the fire and resulting smoke. The transformer was a total loss, but the fire did not spread onsite and did not cause any injuries to the workers, responders or to the public. The experience of this particular event also tends to confirm that the risk to public safety from such events is not likely to be significant because they are rare, the fact that no PCB's are present in the oil that might burn, and the required engineering measures are in place to prevent the fire from spreading.

The summary of the fire and the response are based on the information available to date. Staff will continue to work with the project owner and local agencies to determine the efficacy of project design and procedures in minimizing fire risk. It is staff's recommendation that no additional mitigation be required for the Palomar facility or for new facilities to be permitted by the Energy Commission in the future, except in cases with particular site-specific circumstances. Staff will continue to monitor the outcomes of any future transformer fires at both Energy Commission projects and other power plants to ensure that staff's conclusions remain valid. One concern that still remains is the confusion over whether the project owner was required to report the fire to the Energy Commission in a timely manner. As a result of this concern staff will add a new general condition of certification that clearly requires future Energy Commission-permitted facilities, or existing projects that are being amended, to report any fire or emergency events to the Energy Commission within two hours, and to provide a detailed incident report within a month of the event.

Description of the Project

The Palomar Energy Center consists of a two unit natural gas-fired combined cycle power plant with a nominal electrical output of 546 megawatts. It is owned by San Diego Gas and Electric Company (SDG&E). It was permitted by the Energy Commission in August 2003 and has been in commercial operation since the summer of 2004. The project location is a 20-acre site within a 186-acre industrial park in the City of Escondido, San Diego County, California. The project site is about 600 feet southwest of the intersection of Auto Park Way and Enterprise Street, and about three-quarters of a mile west of Interstate 15 and south of State Highway 78.

The project includes two natural gas-fired combustion turbine-generators, two heat recovery steam generators, a common steam turbine-generator and wet cooling tower, and associated auxiliary systems and equipment. Each unit can operate independently. The project includes a

230 kV switchyard connecting with an SDG&E electric transmission line located immediately adjacent to the project site.

The design of fire protection systems at gas-fired power plants are specified by National Fire Protection Association (NFPA) Standard 850: Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations. Fire protection features associated with generator step-up transformers include a fire-resistant secondary containment catchment basin with adequate capacity to capture any insulating oil that may leak and an explosion/fire-wall to protect nearby equipment and prevent escalation of the fire to other parts of the power plant. Power plants also have an assortment of fire hoses, fire pumps, reserve fire water supply, hydrants, extinguishers, etc. It is standard practice for plant personnel to attempt to extinguish only incipient fires, and leave larger fires such as this one to the local fire department.

At Palomar Energy Center, the transformer that failed contained 11,120 gallons of mineral oil as insulating and heat transfer fluid. By law, the mineral oil does not contain any polychlorinated-biphenyl chemicals (PCB's). A 24 foot tall concrete fire wall separated the 17 foot tall transformer and the 30 foot x 30 foot concrete catchment basin from nearby equipment on two sides. The transformer basin was open on the other two sides, allowing access from an on-site service road to the transformer and catchment basin. Across the service road, potential impacts from the fire were limited by a large earthen berm on one side and the large expanse of the switch yard on the adjacent open side.

Description of the Transformer Failure and Subsequent Fire

On December 22, 2010 (day 1) at 12:08 pm, during a rainstorm, a generator core monitor alarm triggered, indicating that an irregular current was detected by the automated protection system in one phase of the three-phase generator step-up transformer (GSU) of the Unit 1 combustion turbine. Within three cycles of grid voltage (about 50 thousandths of a second), automated protective circuit breakers tripped, isolating the transformer from the generator and from the switchyard (and the electrical grid).

A tear-down inspection of the transformer conducted after the fire revealed that an internal short-circuit arc had occurred resulting in a significant release of energy into the insulating oil. The resultant internal pressure burst caused an electrical bushing where current enters the transformer to rupture and the transformer case to open at a seam, starting a fire inside the transformer. Burning oil leaked from a small opening in the upper portion of the transformer. The burning oil collected within the catchment basin, and continued to burn producing a column of black smoke. The fire was extinguished by the fire department 26 hours later. While the failure and fire was catastrophic to the transformer (i.e., it was a total loss), the fire did not spread to any other parts of the power plant or cause damage beyond the transformer.

Description of Emergency Response

After confirming the transformer fire, plant personnel contacted the City of Escondido Fire Department at 12:10 pm to request assistance. Engine companies from Escondido Fire Department arrived at 12:18 pm. Because the fire was contained and the smoke was

considered to be of low toxicity, the Fire Department's initial decision was to let the fire continue to burn, expecting it to be diminished and extinguishable within two to three hours. Assistance was requested from the San Diego Fire Department Hazardous Incident Response Team (HIRT) to conduct an assessment of the potential toxicity of burning material and a San Diego County Environmental Health (Air Quality) Response Unit to monitor ambient air quality.

After arriving on scene, the fire department's fire team first verified that electrical components within the vicinity of the fire and within potential reach of fire water and the immediate smoke plume were powered off. An on-site incident command structure was set up, and duties were assigned to responding personnel. The staging area for emergency response vehicles was on Citracado Parkway near the plant entrance, causing the temporary closure of Citracado Parkway.

Because the wind was blowing towards the east, the Incident Commander met with the City of Escondido's Police Department Press Information Officer to request a reverse-911 call to address public concern about the smoke. After obtaining approval from the air pollution control district (who were on-site), a shelter-in-place reverse-911 call was placed at approximately 1:00 pm to residents and businesses within a mile radius (in all directions) of the facility to inform them that the fire department was working to extinguish a transformer fire at the SDG&E Palomar Energy Plant, that the fire was contained and under control, but that there might be heavy smoke in the area for the next two hours, that people should shelter-in-place, remaining inside their place of work or residence until the smoke dissipated, and that there would be a second message when it was deemed safe to go outside. Even short term exposure to air-borne particulates (i.e. smoke) can trigger reactions in some people. Local news coverage teams were also informed of the situation, as was the local "2-1-1 San Diego" public information phone service.

The fire team then evaluated possible plans for extinguishing the fire, while the hazmat and environmental health units evaluated chemical and air quality hazards. A concern was that the use of fire water in the rain might spread the fire because burning oils can float on top of the fire water as it accumulates in the catchment basin and subsequently spills over, carrying the fire to other parts of the site.

The initial decision of the fire department had been to let the fire continue to burn, until it diminished in size. The primary recommendation from HIRT was to let the mineral oil burn, but they agreed that an attempt at suppression was an option. It was not known how much oil remained in the transformer, or how long it would take to burn itself out. A meeting was convened between HIRT, County Health, SDG&E, and the Escondido Fire Department and a plan developed to attempt to suppress the fire using "Class-B" (designed for flammable liquid fires) foam. A call was placed at 3:35 pm to request the assistance of the Camp Pendleton Marine Corps Air Station Crash Fire Team's foam tanker. Foam is more effective on oil fires as it smothers the fire with a lower volume of fire water, but it can create slipping hazards.

The Unit 2 combustion turbine-generator had continued to operate normally during the fire. In support of the plan to attempt to extinguish the fire, Unit 2 was removed from service at

3:41 pm (via normal shutdown) in response to safety concerns that would be posed by having a portion of the site still energized while emergency fire crews and equipment were operating on-site.

A follow-up reverse-911 call was placed to the earlier recipients (again, within a mile radius of the site) at 4:36 pm advising them that although the transformer fire was still contained, it was the recommendation of the Escondido Police and Fire Departments that residents and workers in the immediate area should remain indoors until further notice, that however, people could choose to leave, that emergency crews were working diligently to neutralize the incident, and that another message would be forthcoming once the situation had been stabilized.

At 5:05 pm, the Camp Pendleton foam tanker and crew arrived. The foam team was briefed, a planning meeting held to develop the fire attack plan, and a safety briefing held for responders.

At 7:30 pm, foam application to the fire was started. Foam application was called off after 15 minutes of sustained attack that was unsuccessful in knocking down the fire. The fire chief's explanation for the ineffectiveness of the foam was that there was too much heat emanating from the fire for the foam to remain intact long enough to smother the fire. A particular complication in extinguishing large oil-insulated utility transformer fires is that there can be burning oil both inside the transformer after the arc has caused a case rupture, and burning oil in the catchment basin surrounding the transformer. Both fires must be extinguished, first the one in the catchment basin, then the one inside the transformer must be extinguished through the limited access provided by the hole opened in the case. In this case, it was reported that the leaking surface was facing an adjacent transformer component, further limiting accessibility. As the burning oil contained no PCBs, and air quality measurements detected no volatile organic compounds in the local air, the decision was made again to let the fire continue burning until it diminished in size. The responding air quality unit did not have mobile particulate sensors, so particulate levels in the surrounding air were not measured during the incident.

Emergency crews remained on-site throughout the night to monitor the fire and to continue air quality monitoring. During the night the wind died, causing the smoke plume to rise straight up. Also during the night, the fire reduced in intensity as the amount of burning oil diminished. Next morning, December 23 (day 2), the wind reversed and picked up, so another reverse-911 call was placed at 7:42 am, providing an update to residents within a mile radius of the power plant that they should remain clear of the area or stay indoors until the smoke had dissipated; that wind shifts were expected throughout the day that could cause the smoke to spread throughout the area; and that there was no estimate yet for when the fire would be extinguished.

The air district staff visited a hospital construction site about 1,000 feet to the northwest on the morning of the 23rd to alert the workers to the (obvious) drifting smoke and measure ambient air quality. Air quality tests did not detect any volatile organic gases and the hospital construction workers did not stop work.

Because the fire was now reduced in intensity, plans were made to attempt to extinguish the fire with foam once again. Fire suppression operations started at 2:05 pm. The fire in the catchment basin was out by 2:12 pm, and the fire inside the transformer was out by 2:18 pm on December 23. The fire department explained that they were successful on the second attempt because the fire was now smaller with less heat being produced so that the foam was able to hold together and finally smother the fire. At 3:16 pm a reverse-911 call was placed to all recipients of the earlier reverse-911 calls informing them that the fire was now extinguished, that it was no longer necessary to remain indoors, and that they could now resume normal activities.

A chronology of major events in the response to the fire is shown in Appendix A. Appendix B contains photographs of the burning transformer taken on day 1 and day 2, showing the fire, catchment basin, and the fire wall separating the transformer from adjacent equipment. Appendix C is an aerial photograph showing the location within the power plant of the transformer that burned. Appendix D is a map showing the locations of recipients of the four reverse-911 calls. The same 1-mile radius was used for all four calls.

Impacts to Workers, the Public and Appurtenant Facilities

There were no injuries due to the fire to any power plant employees or emergency responders during the incident. One responder was taken to the hospital, but the cause was not related to the fire. There were no reports of injuries to members of the public. None of the reverse 911 calls occurred after hours (after 8 pm and before 6 am). Air quality measurements taken by the County Environmental Health responders indicated that no measureable volatile-organic compounds were detectable in the ambient air at and around the facility and that there was no immediate health concern. There was, however, a particulate-containing smoke plume. Of the 11,120 gallons of mineral oil in the transformer, 6,932 gallons were recovered after the fire. As no oil leaked into the environment, it is estimated that 4,188 gallons burned.

Sourcing and replacing the damaged transformer and appurtenant equipment required SDG&E to keep the Unit 1 combustion turbine out of service until March 24, 2011 when it was returned to full service. Unit 2 was returned to service three days after extinguishment, on December 26, 2010. Until Unit 1 was able to start up again, the power plant was able to operate at approximately half of its normal power capacity.

Recommendations of Responders

After the fire, staff investigated the incident site and viewed damaged equipment. Staff also interviewed the first responding fire chief and incident commander, Battalion Chief Tenger of the Escondido Fire Department; Section Lead Barthel of the Camp Pendleton Crash Fire Team who responded with the fire fighting foam tanker; Nick Vent, Supervising Environmental Health specialist for San Diego County; and Martha Ellis, Communications Manager for the City of Escondido Police Department. All responded that the incident response had gone smoothly, and that the power plant was prepared with the expected emergency plans. None of the interviewees had recommendations for changes that need to be made to planning or preparedness for similar potential emergencies in the future.

The review of events in this particular transformer failure indicates that the installed fire mitigation measures (firewalls and catchment basin) performed as expected and that the fire neither spread to other parts of the facility nor resulted in significant public safety impacts. It further appears that the emergency response of local agencies was fast and well coordinated. The smoke, the duration of the event, and number of emergency vehicles staging on the adjacent Citracado Parkway, causing its temporary closure, may have fostered a perception that the event produced more significant impacts on the surroundings than it actually did.

Feasibility and Justification for Requiring Additional Mitigation Measures

Staff's investigation of this incident focused on both the electrical failure of the transformer, the resulting fire, and the response to the fire. Transformers such as the one which failed are most often designed and built to a customer's specific requirements. As such, costs can approach \$5 million dollars and lead times can range up to a year or more. A transformer failure is a significant impact to a power plant owner, involving the cost of the replacement transformer, and the loss of sales of electrical power through that transformer and its turbine generation train until new parts have been sourced, installed, and commissioned. Spurred by the critical dependence of power plants on transformer reliability, there are considerable ongoing industry-supported academic research and industrial-association efforts (e.g. specifications, standards, guidelines, best practices, etc.) to cost effectively improve transformer safety and reliability while maintaining efficient operation.

Published studies indicate that large transformer failures with subsequent fires such as occurred at Palomar Power Plant are low probability events. This incident is the first known of a transformer fire at a power plant permitted by the Energy Commission. It was also the first experience of a large utility transformer fire for the responders interviewed. That said, a further reduction in the probability of either the initial electrical failure, or second, the consequences of the event, i.e., subsequent loss of containment and burning of insulating oil would reduce the risks presented by potential transformer failures at power plants. Lastly, any system that could ensure reliable rapid suppression of an incipient fire would also reduce the risk of potential fire-related consequences resulting from transformer failure.

Staff evaluated several potential methods of accomplishing these ends. For instance, the probability of initial electrical failure might be reduced by requiring the use of oversized transformers so that they always operate below their designed voltage and current handling capacity. Users, including Palomar, test the insulating oil for certain gases that can predict onset of insulation breakdown and imminent failure. Palomar was in the process of installing a continuous monitoring system to replace the annual or semi-annual oil grab sample method. This does not prevent failure, but can help users potentially predict failures and order and replace parts prior to a catastrophic failure.

Reducing the probability of transformer case rupture with subsequent loss of oil might be accomplished by installing a rapid-acting pressure venting or rupture-disk system that would handle the pressure burst that results from the initial electrical failure. Such a system would also need to instantaneously inject a fire retardant gas to extinguish any fire that may have

started inside the transformer case. Strengthening of the transformer casing would also reduce the probability of loss of oil.

Measures to control any burning oil released subsequent to transformer case failure could include the use of a covered concrete underground vault often supplemented with fire retardant gas injection, or a deep gravel bed, both effectively separating the fuel from oxygen; the use of a less flammable alternative insulating oil; the use of alternative non-oil based (e.g., sulfur hexafluoride gas) cooling methods; and additional measures to suppress large utility transformer fires once they occur. Water deluge sprinkler systems are sometimes used, but add the risk of overflowing the containment basin and potentially spreading the fire and creating unsafe conditions for workers. They are intended to cool over-heated equipment associated with a fire and prevent the fire from spreading, but don't necessarily extinguish an oil-fueled fire. Additionally, prevention or suppression of the fire does not prevent the significant costs associated with the initial failure and lost revenue during repairs. And automated deluge systems run the risk of accidental triggering, potentially damaging the transformer and creating unsafe (e.g., slippery) conditions. Onsite, specialized firefighting equipment requires extensive training of onsite personnel; otherwise, they endanger themselves and the emergency personnel that ultimately respond.

Staff reviewed the available failure analysis report and concluded that in this instance, the operation and maintenance of the transformer had been within specification and that the monitoring of the transformer condition by SDG&E would have been sufficient to detect gradual degradation or aging-type failures. Routine monitoring did not indicate any problems. The tear-down failure analysis indicated that the failure was internal to the transformer, but the specific cause has not yet been determined by the involved parties. Staff's evaluation suggests that this transformer's sudden failure was most likely the result of a design, material, or manufacturing defect in some component of the transformer, particularly since the transformer was only six years into what would typically be a 30 to 40 year lifetime, and there were no detected line-voltage spikes or lightning strikes that might have precipitated the failure. Analysis by SDG&E and Hyundai of the still operating Unit 2 transformer did not discover operations outside of normal parameters, or indicators that might suggest degradation or imminent failure, or commonalities with the failed Unit 1 transformer.

Staff also determined that all measures to reduce fire risk involve significant costs. Many have unproven performance in terms of risk reduction because of limited field performance experience. The sudden failure of large transformers is a relatively rare occurrence. Those that do fail don't always leak oil. When oil does leak, it catches fire and burns in only about half of those instances. The interviewed emergency responders in this instance all reported that this was their first experience with a large utility transformer fire. Because of the unpredictable magnitude and mode with which sudden failure can occur, any of the measures described above to reduce the likelihood of a transformer failing with subsequent leaking and burning of oil cannot be guaranteed to prevent it.

Staff Conclusions and Recommendations

The summary and recommendations herein are based on the information available to date. Staff will continue to work with the project owner and local agencies to determine the efficacy of project design and procedures in minimizing fire risk. In the permitting of Palomar and other power plants, staff evaluates the risk of significant potential for adverse impacts to public safety. In evaluating potential adverse impacts associated with transformer failures at power plants, staff has concluded that the potential for impact is reduced to a level that is below the threshold of significance used by staff in siting cases. This risk reduction is accomplished through the use of fire walls to prevent the spread of any fire that starts, and the use of catchment basins to contain insulating oil that escapes from the transformer case, preventing the spread of the fire or the release of the oils into the environment.

This incident notwithstanding, staff still believes that the potential for an off-site injury or fatality of a member of the public from such an event is insignificant. The experience of this particular event also tends to confirm that the risk to public safety from such events is not likely to be significant because they are rare, the fact that no PCB's are in the oil that might burn, and the required engineering measures that are in place to prevent the fire from spreading. Staff therefore concludes that while further mitigations may be technically feasible, they are not needed and would offer uncertain benefit for the costs involved. For the purpose of risk reduction of potential impacts to the public, added safety measures as described above do not appear to be justified at this time for this project.

It is staff's recommendation that no additional mitigation be required for the Palomar facility or for new facilities to be permitted by the Energy Commission in the future, except in cases with particular site-specific circumstances. Staff will continue to monitor the outcome of any future transformer fires at both Energy Commission projects and other power plants to ensure that staff's conclusions remain valid.

One concern that still remains is the confusion over whether the project owner was required to report the fire to the Energy Commission in a timely manner. As a result of this concern staff will add a new general condition of certification that clearly requires future Energy Commission-permitted facilities, or existing projects that are being amended, to report any fire or emergency events to the Energy Commission within two hours, and provide a detailed incident report within a month of the event.

References

- Reverse-911 Call Logs of December 22 and 23, 2010, City of Escondido Police Department, Received 8/2/2011
- Record of Conversation with Martha Ellis, Communications Manager, City of Escondido Police Department, July 25, 2011
- Record of Conversation with Nick Vent, Supervising Environmental Health Specialist, County of San Diego Department of Environmental Health, June 30, 2011
- Record of Conversation with Battalion Chief John Tenger, City of Escondido Fire Department, June 21, 2011
- Record of Conversation with Section Lead Barthel , Camp Pendleton Air Crash Fire Team, June 14, 2011
- Consultant's Report Re: Site visit – SDG&E Palomar Combined Cycle Power Plant: Transformer Fire, EDM Services, January 7, 2011
- Report to the California Energy Commission Regarding San Diego Gas & Electric Company's December 22, 2010 Transformer Incident at Palomar Energy Center, SDG&E Company, April 13, 2011
- Report of Site Visit to Palomar Energy Center by Dale Rundquist, File 01-AFC-24C, 12/28/2010
- Incident Report Event Number: EF100011271 Case Number: 1011083, Escondido Fire Department, printed 12/28/2010
- Letter from Chief Michael Lowry, Escondido Fire Department to James D. Boyd, Commissioner, California Energy Commission re: Carlsbad Siting Case, May 16, 2011, Docket 07-AFC-6, Exhibit 437
- Transformers: Basics, Maintenance, and Diagnostics, U.S. Department of the Interior, Bureau of Reclamation, April 2005
- Transformer Fire Protection, U.S. Department of the Interior, Bureau of Reclamation, January 2005
- Analysis of Transformer Failures, William H. Bartley P.E., International Association of Engineering Insurers, 36th Annual Conference – Stockholm, 2003
- An Analysis of Transformer Failures, Parts 1 and 2 – 1988 through 1997, William H. Bartley P.E., The Locomotive, <http://www.hsb.com/TheLocomotive>, The Hartford Steam Boiler Inspection and Insurance Company, obtained June 29, 2011
- Progress Report on Failures of High voltage Bushings with Draw Leads, Panel Discussion Led by Phil Hopkinson, IEEE Fellow, Power and Energy Society General Meeting, 2010 IEEE, Minneapolis, MN, July 25-29, 2010

Appendix A. Chronology of Fire Response Events

December 22, 2010

- 1208 Failure of transformer
- 1210 Call to 911 to report fire
- 1218 Escondido Fire Department arrives on scene
- 1235 Decision to let fire burn itself down
- 1247 County Health, SDFD Hazmat, and Escondido Police Department advised
- 1300 First reverse-911 call
- 1330 SDFD Hazmat Unit arrives
- 1410 Camp Pendleton Hazmat, SD County Health, and HIRT arrive on scene
- 1524 Decision to call Camp Pendleton Air Rescue and Fire Fighting (ARFF) Unit Foam Tanker
- 1524 Decision made by SDG&E to shut down remaining generators: Unit 2 Combustion Turbine Generator and the Steam Turbine Generator
- 1535 Call placed to request Camp Pendleton ARFF Unit foam tanker
- 1541 Steam Turbine Generator is taken off-line
- 1542 Unit 2 Combustion Turbine Generator is taken off-line
- 1636 Second reverse-911 call (updating the first call)
- 1705 Orient and brief AARF using camera view from control room
 - Planning meeting for fire attack plan
 - Safety briefing for responders
- 1930 Attack fire with foam
- 1945 Call off attack on fire
 - Return to the decision to let burn itself down
- 2113 Release unneeded resources for the night (Air quality unit, a fire engine, and the foam truck remained on site throughout the night to monitor fire)

December 23, 2010

- 0742 Third reverse-911 call (regarding shifting winds)
 - 1100 Briefing and decision to try foam again
 - Planning meeting to try new attack on fire
 - Temporary berm expansion around catchment basin to handle over-flow potentially caused by foam/fire water
 - 1310 Call in support resources for attack on fire
 - Meeting to brief newly- arrived resources
 - 1405 Attack fire again with foam
 - 1418 Fire fully knocked down, continue with water spray
 - 1501 Fourth reverse-911 call (to cancel earlier calls)
 - 1600 All emergency response units released
- Sources: Incident Report Event Number: EF100011271, Case Number: 1011083, and ROC's as listed in References

Appendix B. Photographs of Palomar Transformer Fire

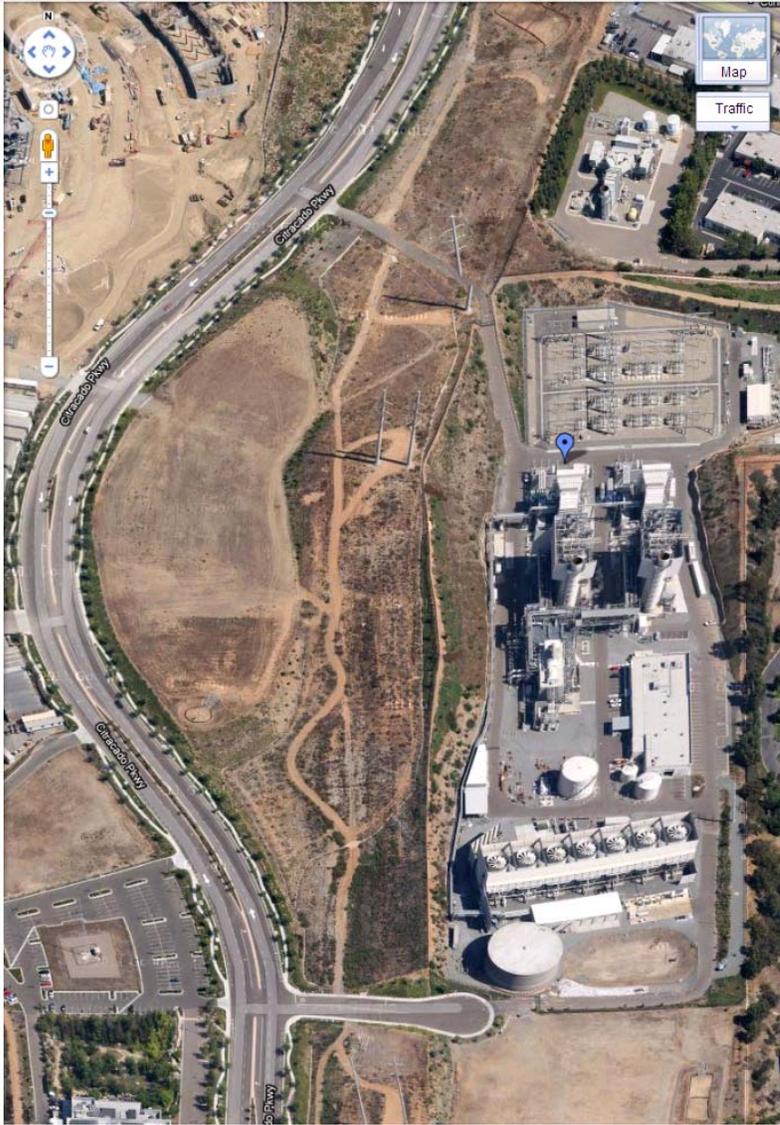


Dec 22, 2010 (Day 1)



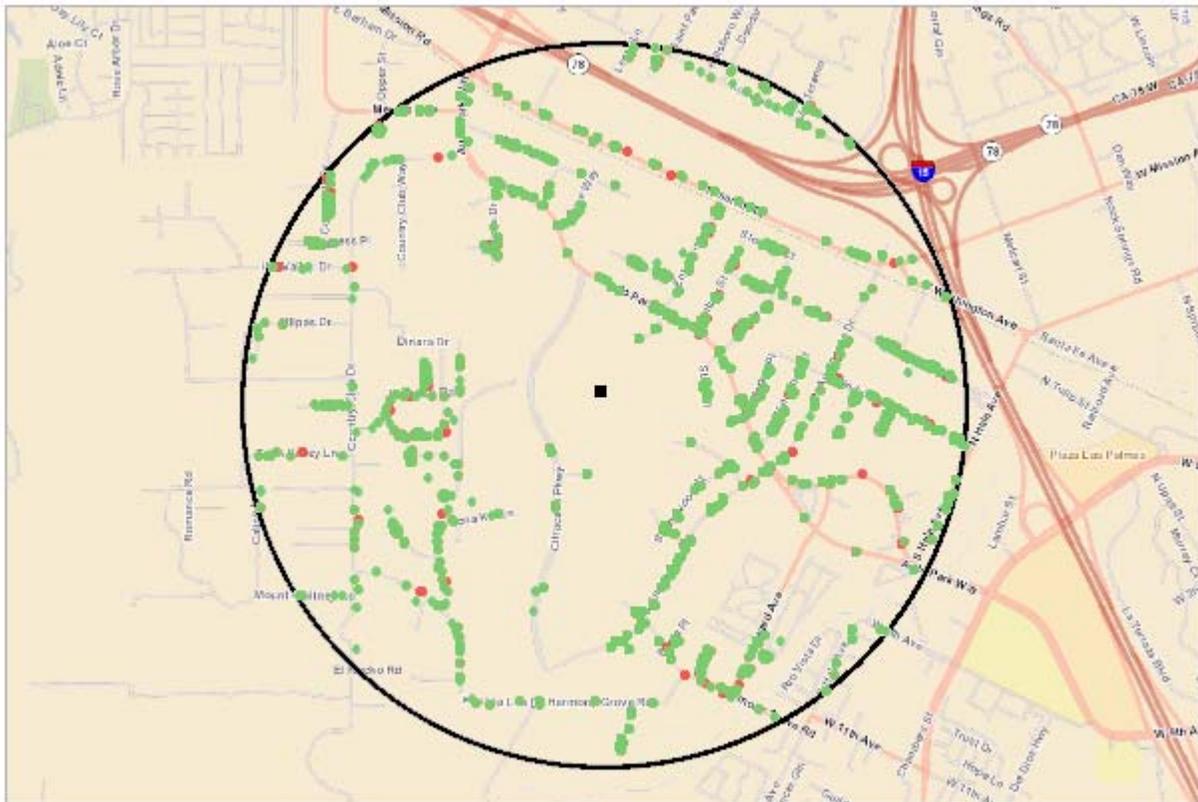
Dec 23, 2010 (Day 2)

Appendix C. Aerial Photograph of Palomar Energy Center



Photograph of Palomar Energy Center with Citracado Parkway running north-south on west side. Marker indicates location of transformer that burned. An earthen berm lies between the power plant and Citracado Parkway.

Appendix D. Map of reverse-911 Call Recipients re: Palomar Transformer Fire



Map showing locations of reverse-911 call recipients within 1-mile radius of Palomar Energy Center on Dec 23 and 23, 2010. Source: City of Escondido Police Department