MEMORANDUM

DEVELOPMENT SERVICES/BUILDING DEPARTMENT

4-30-09

April 29, 2009

TO: **PHIL BURNS, BUILDING DIRECTOR**

FROM: **PETE JACKSON, ELECTRICAL SPECIALIST**

SUBJECT: **TARGET ROOF PV FIRE OF 4-5-09**
9100 ROSEDALE HWY BAKERSFIELD, CALIFORNIA

PV System Description:

Based on the City of Bakersfield approved plans of 1-29-08, the PV system on the Target store at 9100 Rosedale Hwy consists of 1826 Sunpower SPR-210-WHT photovoltaic modules arranged in 166 strings of 11 modules. The strings are connected to the two Xantrex inverters through four fused combiner boxes (two 30 string, one 50 string and one 56 string). The strings are individually fused with 12 amp fuses. The string short circuit current (Isc) is 5.75 amps and the open circuit voltage (Voc) is 575 Vdc. String operating current is 5.25 amps. String operating voltage is 440 Vdc. **See Exhibits A and B.**

The 56 string combiner box (A1) along with the two 30 string combiner boxes (A2 and A3) are connected to the Xantrex PV 225S-480P inverter through DC fused disconnects designated as System A. The remaining 50 string combiner box (B1) is connected to the Xantrex PV 100S – 480 - HE inverter through the inverter DC disconnect only and is designated as System B. The positive conductors of the DC systems are grounded per the module and inverter listing/design. The total output from both inverters is approximately 383 kw.

The AC output (three phase, 480 volt) of each of the inverters is connected through individual 225 kva isolation transformers to a 480 volt, 600 amp, 3 phase, 65kaic, NEMA 3R. metered combiner panel before supplying the existing 2000 amp, 480 volt service of the Target store.

The PV modules and combiner boxes are all mounted on the roof. The balance of the system components are installed in a locked equipment yard adjacent to the store.

The plan check and original field inspection confirmed that the system conductors, overcurrent protection and disconnects were installed per the approved plan and the 2004 California Electrical Code (2002 NEC) under which this project was permitted.

Both inverters included optional ground fault detection and interruption system before this became a requirement of U.L. Standard 1741 or the NEC.

After several field inspections and correction notices the installation was approved in March of 2008.

The Fire:

On April 5, 2009 at 4:15 PM a roof fire at the Target store, 9100 Rosedale Hwy was reported via the 911 system. The Kern County Fire Department and the Bakersfield Fire Department responded to this two alarm fire. The store manager was on the roof, fighting the fire with the store extinguishers when the first responders arrived at 4:20 PM. A row of nine PV modules in Sub Array 1 as well as the roof under these modules was completely engulfed in fire. A second smaller fire was also burning approximately 200 feet away which involved a three inch EMT conduit from Combiner Box 1 as well as the roof under this conduit. The fires were extinguished and never penetrated the roof metal decking. The Incident Report indicates that the store was "cleared" to be re-opened at 8:05 pm.

The first responders opened the DC disconnects at the inverters. DC disconnects at the output of the combiner boxes on the roof were not required by code nor were they installed as a part of this design. The only way to turn off the supply of electricity from Combiner Box A1 would be to open all 56 string fuses inside the combiner box. This would not be obvious to the first responders or to anybody else without a detailed knowledge of the PV system wiring. The Target store manager had to call an electrical contractor to open all 56 string fuses, insulate all exposed string conductors and disconnect the combiner output conductors from the combiner box. This was done to limit the path of the electrical current from the PV modules which will continue to produce electrical current when exposed to sunlight. Target personnel stayed the rest of night on the roof as a fire watch.

The fire involved modules connected to Combiner Box 1 and the three inch EMT conduit with four #500 KCMIL (two positive and two negative) and a #3/0 AWG equipment grounding conductor which is the output from Combiner Box 1 to the fused DC disconnect for the 225kw (System A) inverter. The smaller inverter (System B) and associated modules were not involved. **See Exhibits C, D, E, F, G and H.**

Post Fire Investigation:

On Monday April 6, 2009 the investigation into a possible cause was initiated. The following list was determined to be a starting point for this investigation:

1) Interviews with the store manager, Fire Department first responders and Building Department first responder.

2) Review of the "Incident Report".

3) The approved plans reviewed.

4) The entire installation inspected for conformance to the approved plan and the 2004 CEC.

5) Measurements of all system voltages.

6) Testing of all system fuses.

7) Review of real time system monitoring if available.

8) A "Field Report" submitted to Underwriters Laboratories (U.L.)

9) Digital photographs of all affected components with review by appropriate personnel with the necessary expertise.

The observations from the inspection include the following:

1) The row of modules which burned was included in Sub Array 1. Massive arcing occurred in the lid of the metal raceway between this row and the next row of modules towards Combiner Box A1. **See Exhibits I and J.**

2) Combiner Box A1 is the 56 string box which included Sub Array 1. All fuses in this box were removed and checked for continuity. The following fuses were observed to have opened:

   Strings 24 through 29, 31, 32, 38 through 40, 47, 51 through 56

   All remaining string voltages were normal (465 – 475 Vdc)

3) The equipment grounding lugs in this combiner box (as well as all of the others) are labeled for use with the conductor sizes #500 KCMIL - #4 AWG. The equipment grounding conductor from the combiner box to the PV module is #6 AWG.

4) A massive arc occurred in the three inch EMT conduit at a coupling 228' from Combiner Box A1. This conduit contained two #500 KCMIL positive and two #500 KCMIL negative conductors as well as a #3/0 AWG equipment grounding conductor. These paralleled conductors carry the current from Combiner Box A1 to the fused DC disconnect and inverter in the equipment yard. **This conduit is inserted approximately ½" into the compression coupling at this point. A complete insertion would require 3". A coupling in the**

conduit next to this one (from another combiner box) was loose (can be turned by hand). All other couplings were checked and were found to be at least "hand tight". **See Exhibits G and H.**

5) The 600 amp fuses in the fused DC disconnect (DC Fused Switch #1) did not open. This is the fused disconnect at the inverter supplied by Combiner Box A1.

6) The four amp ground fault fuse in Inverter A did open.

7) The strings from the burned row of modules were contained in covered metal channel raceways in contact with the roof. There were (25) #12 USE-2 conductors in each of the two raceways leading in and out of the burned row. The length of the channel raceway(s) is 12 inches. There is evidence that massive arcing occurred at these raceways. **See Exhibits I, J and K.**

8) The following temperatures were recorded on the Target roof (4-20-09 @ 3 PM) with a 5-10 mph NW wind. All temperatures in degrees F:

Air temp – 98
Roof Surface – 130
Channel Raceway Interior – 121
PV Module Underside – 114
Combiner Box Interior – 120
Combiner Conduit Interior – 116

9) The corrected ampacity (temperature and wire fill) for the paralleled #500 KCMIL Combiner Box A1 output conductors is 488 amps. These conductors were protected by 600 amp fuses.

Conclusions:

There were two separate fires on the roof. Fire #1 at the three inch EMT conduit separation and Fire #2 at the row of PV modules 200 feet away. In order to understand how these two separate fires could have been related they must first be analyzed separately. First the fire at the three inch EMT (Fire #1):

The three inch EMT conduit either separated or was never fully inserted during installation. There are marks on the end of the conduit which occur when the compression coupling is installed. This would indicate that the conduit was completely seated in the coupling when first installed. Massive arcing between the grounded and ungrounded conductors along with arcing to the equipment grounding conductor and EMT conduit was a cause of the roof fire at this location. The coupling here is destroyed along with the conduit. **It should be noted that during the post fire inspection of 4-6-09 the coupling in the conduit next to the faulted conduit was not "wrench" tight – not even "hand" tight.** It is probable that the coupling in the faulted conduit may not have been "hand" tight as well. Conductor insulation damage is very possible either during installation or over time. There is not any indication of damage or deflection of this conduit from outside

sources such as maintenance work on the roof etc. The District Facilities Manager for Target confirmed that there had not been any operations on the roof since the installation of this system which would have damaged the system in any way or loosened the conduit coupling. The first responders confirmed that the conduit and coupling were not damaged by their activities.

Thermal expansion would occur in this conduit installation given the temperature differentials over time. This fire occurred one year after the initial installation, a full year of the normal summer/winter temperature differentials. This conduit installation is the longest on the roof at 423 feet. Assuming a differential temperature of 113 degrees F and using the coefficient found in NEC 300.7 (B) FPN results in an expansion of 3.7":

423" x (12"/ft) x 113 x .0000065 = 3.7 inches

An O-Z GEDNEY AX series expansion coupling was installed 198 feet from Combiner Box A1 (30 feet from the conduit separation). This expansion coupling was not specified to be installed as a part of the design. **This fitting is not listed for use with EMT conduit.** It is intended to be used with RMC or IMC only (threaded conduit systems). The manufacturer produces another fitting for use with EMT. In addition, a mixture of different straps were used to secure the conduit to the UNITSTRUT topped blocks on the roof surface. A total of 24 POWERSTRUT PS1100 STD straps were used which would not allow movement of the conduit on its support blocks. One POWERSTRUT PS 3126 strap and nineteen UNISTRUT P 255830 straps were installed which may have allowed some movement since washers were installed under the clamps to provide annular space around the conduit. A review of the manufacturer's literature for both products did not indicate that the products were intended to be used for applications where movement in the conduit would be needed. **Both B-LINE and UNISTRUT (manufacturers of conduit straps) specify both a one-piece strap which is one pipe size larger than the conduit used or a two piece strap with an insert between the strap and pipe which allows conduit movement in their product catalogs. A B-LINE representative who visited the site confirmed this as well.** The conduits are all supported and secured on the roof by recycled rubber blocks which have a UNISTRUT type of channel for connection of the pipe straps. These blocks are then attached to the roof membrane by strapping (made with the roof material) to the roof itself in accordance with the roofing product standards. These roof support blocks are not designed to slide or move on this roof. If movement is to occur it should occur with the conduit moving on the UNISTRUT topped blocks, not the rubber blocks moving on the PVC roof. **The conduit had an expansion and contraction linear movement of 3.7 inches. The incorrect expansion fitting and straps could cause the movement to occur at one or more of the compression couplings. A loose coupling would very possibly experience the most movement. Conductor insulation damage is a likely result. Conductor insulation damage did occur here. There would be no faults without insulation damage at this point. See Exhibits G, H, L and M.**

Now for the fire at the row of modules (Fire #2):

The PV modules and associated mounting hardware were completely destroyed by the time the first responders arrived. Any evidence which the modules could have provided is gone. The metal channel raceways for the string conductors leading to and from the affected modules did survive along with the string conductors at these locations. There was major arcing between these string conductors and the metal channel raceway(s). Did the arcing cause the fire or did the fire melt the conductor insulation which then faulted to the metal channel raceway? There is no evidence that the fire was caused by any source other than the PV system at this point. There is no other source of heat on the roof or under the roof at this location. Arcing did occur here and would have started a fire with both the roof and PV modules. **The faulted conduit which caused Fire #1 would have been able to contribute fault current to the string conductors at this location.** The fact that both of these fires occurred at the same time does indicate that the fires were related. It is very possible that a low level fault in the string conductors was in existence at the module location for some time. A fault like this would occur when the string conductor insulation is damaged during installation. This fault would not necessarily rise to a level which would open the ground fault fuse at the inverter. A fault here could provide a path for current from the faulted conduit (Fire #1) once the ground fault fuse did open. There is no doubt that this contribution of fault current did occur during the event. It is probable there was an existing low level fault in these string conductors. This "existing" string fault would explain the current path(s) necessary for the two fires/faults in the two locations 200 feet apart. **See Exhibit N.**

Corrective Items:

1) High voltage insulation testing (megger) all of the existing system wiring and any new or repaired wiring per CEC 110.7.

2) The conduit systems installed on the roof need to be engineered for the thermal expansion which will occur per CEC (NEC) 300.7 (B) FPN. Expansion fittings and straps listed for the purpose and the conduit system installed must be utilized.

Recommendations:

1) The ampacity of all conductors on the roof should be re-evaluated based on Table 310.15 (B) (2) (c) from the 2008 NEC. This table provides ambient temperature adjustment for conduits exposed to sunlight on roofs. This table was not included in the NEC when this project was engineered or permitted. The conditions on the roof top fit the intent for the use of this table and the conditions exist regardless of which Code cycle is legally mandated. This is not meant to suggest that the ampacity of the existing conductors on the roof is a cause of the fire, only that the ampacity should be evaluated based on the best information/engineering data available.

2) Provide DC disconnects at the output of all combiner boxes on the roof. The first responders had no way to turn off the supply of electricity to the faulted three inch conduit conductors except by opening 56 separate fuse holders in Combiner Box A1. This is impractical in an emergency situation. The fire fighters were looking for disconnects which were not there. A disconnect at the output of these combiners is not a current Code requirement but should be considered.

3) Re-configure the strings and combiner boxes with a maximum 100 amp fused output for each. So that, a fault in one combiner output will result in the 100-amp fuse opening from reverse currents supplied by the other sources.

cc: Stanley Grady, Dev. Svcs. Director
Ron Fraze, Fire Chief
Doyle Trankel, Target Corp.
Troy Lauterbach, Sunpower Corp.
John Wiles, New Mexico State University
Frederic J. Cleary, Underwriters' Laboratory

Exhibit A

Exhibit B

Exhibit C

Exhibit D

Exhibit E

Exhibit F

Exhibit G

Exhibit H

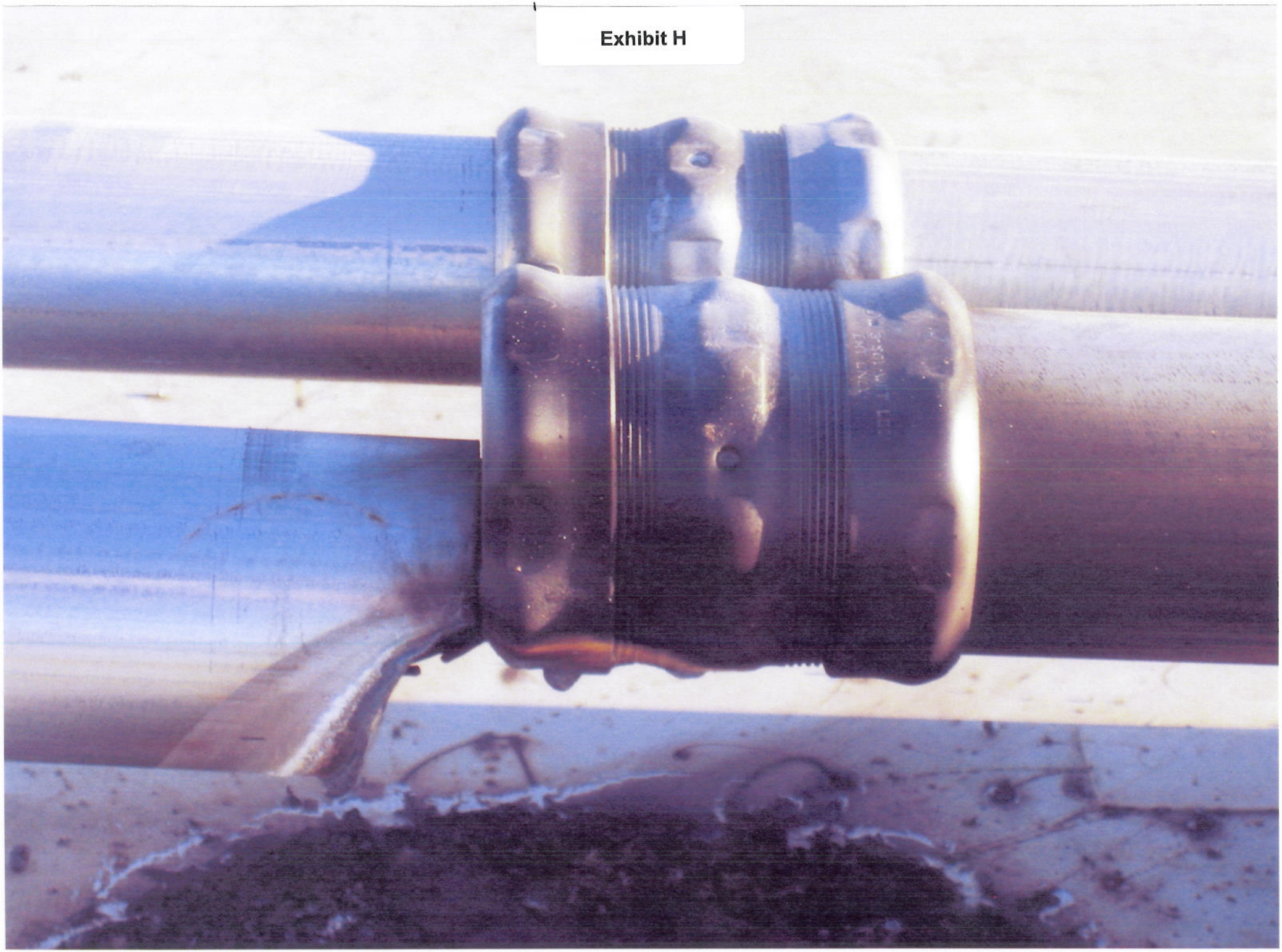


Exhibit I

Exhibit J

Exhibit K

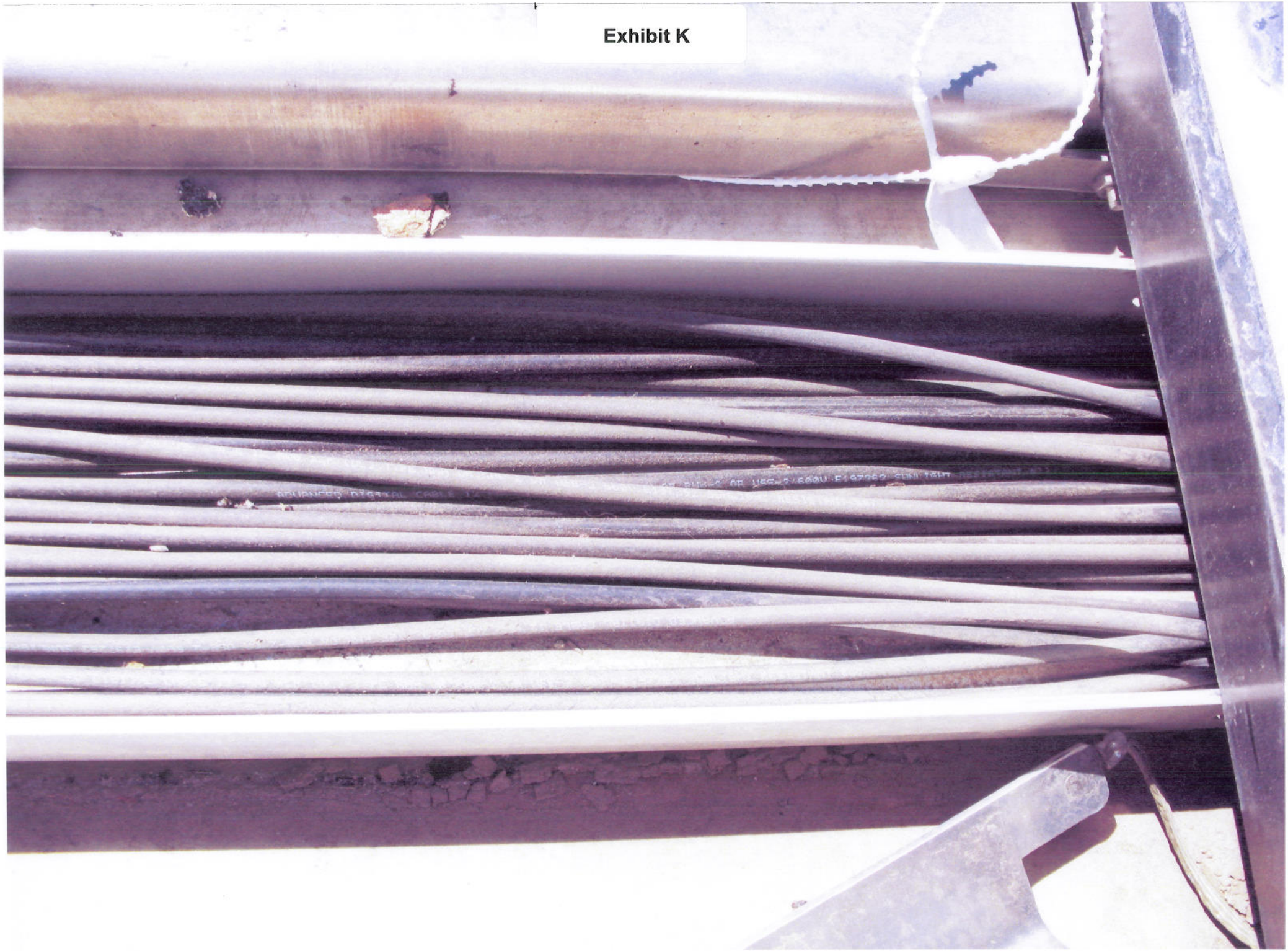

Exhibit L

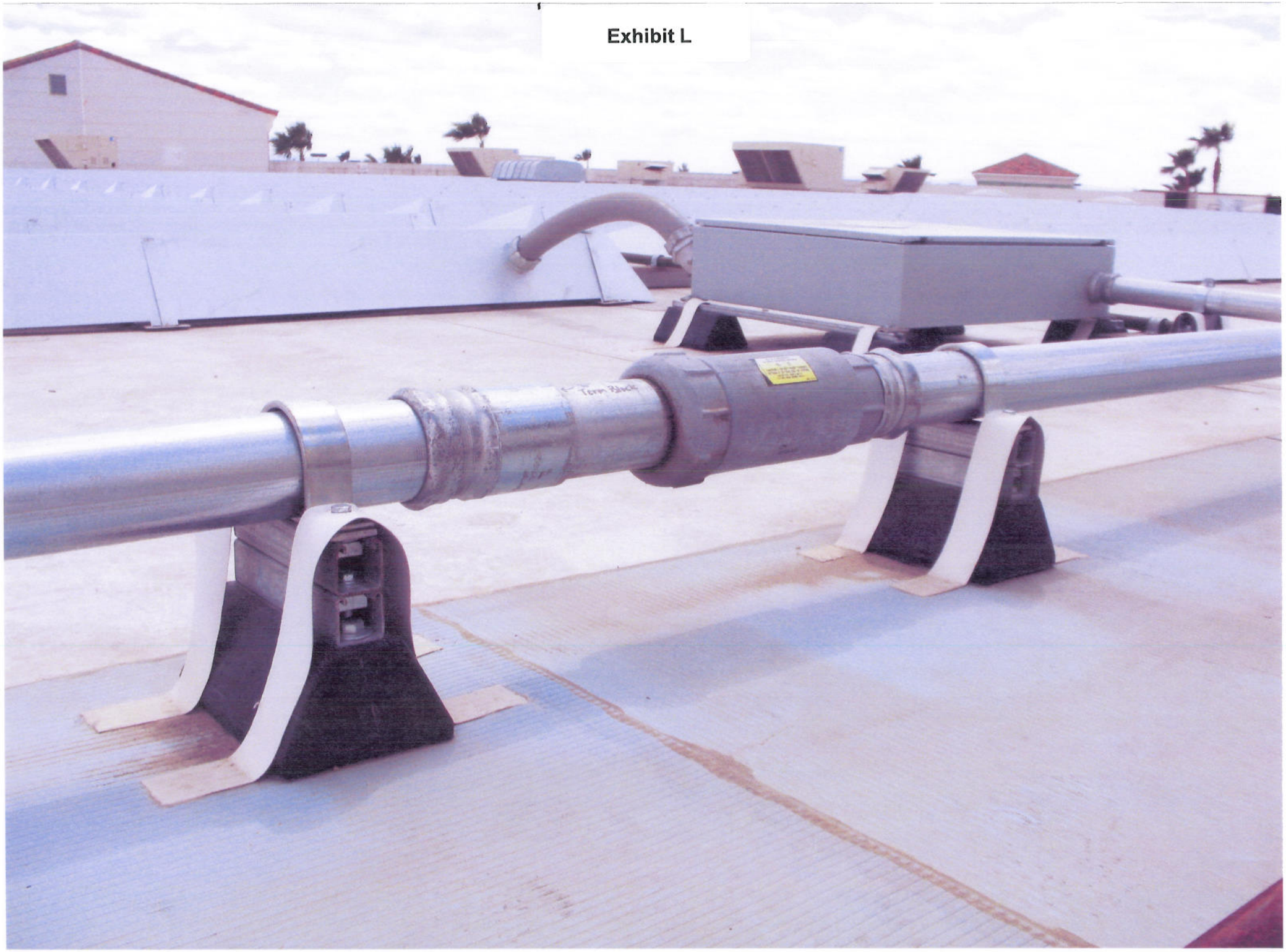

Exhibit M


←185' to
Term Block
O-Z / GEDNEY
AX SERIES EXPANSION COUPLINGS
CAUTION - DO NOT PAINT CONDUIT
WITHIN 8" OF THIS END OF FITTING

Possible Fault Current Paths