

REFLECTIVE RADIANT BARRIERS

Good for Energy Savings – Bad for Fire Safety

Ronald Simmons, P.E., C.F.E.I.,
Eric Benstock, P.E., MIFireE, C.F.E.I
Nestor Camara, B. Sc., C.F.I.
MCDOWELL OWENS ENGINEERING, INC.

In recent decades much of the world (and especially the U.S.) has become very conscious of energy consumption. As a result, many energy saving initiatives and products have been introduced. One of the most successful lines of products has been the reflective radiant barrier materials which are installed in the attic spaces of homes. Available evidence strongly suggests that these products can in fact provide significant reductions in home energy consumption (U.S. Department of Energy, the Oak Ridge National Laboratory, et al.). Unfortunately, the use of these products also provides some insidious and unintended side effects. The physical and electrical properties of these materials are such that they introduce new and very serious dangers of ignition and fire.

In an earlier report published in Fire Findings (2009) we discussed results from testing performed on certain reflective radiant barrier laminated sheet material, which is purchased in rolls. This is the material commonly installed on attic floors (above the insulation) to provide an effective thermally reflective barrier above the ceiling of a building. That testing demonstrated conclusively that, if electrically energized by incidental contact with a powered conductor in a standard branch circuit, this material would “arc and spark” rather violently and would frequently catch fire and sustain flame (Simmons, et al.). Clearly, this could ignite other nearby more flammable materials, and thus initiate a major structure fire.



**PHOTO #1 (from a previous study)
Radiant Barrier Material in Flames
After Being Energized by a 20 Amp Circuit**



In the first report we focused specifically on the rolled type of barrier material as that is where we had our first direct house-fire experience. However, there were obvious questions about other applications of similar radiant barrier material in home construction. One of the most prevalent of these applications is when the barrier material is permanently bonded to one side of conventional roof sheathing material. Thus, when the roof sheathing is installed, an instant reflective radiant barrier is created which completely covers the underside surface of the roof deck.



PHOTO #2

**A Typical Attic During Construction Using Roof Decking with Radiant Barrier Material Laminated on the Underside of the Sheathing
(this photo shows the metal plywood clips at sheathing seams)**

Because of the location of this barrier it would seem much more difficult for it to come into contact with sources of electrical energy. Therefore, we had hoped (and assumed) this application would be less likely than the attic floor installation to be a factor in fire ignition. Unfortunately, experiences in the months since our first report have shown this is not necessarily the case.

In several house fires where lightning was a factor there was extremely compelling evidence that the radiant barrier material on the underside of the roof decking was once again the ignition source. A further investigation of the rooftop electrical environment in these houses, as well as the characteristics of the radiant barrier material, helped explain how and why this was the case.



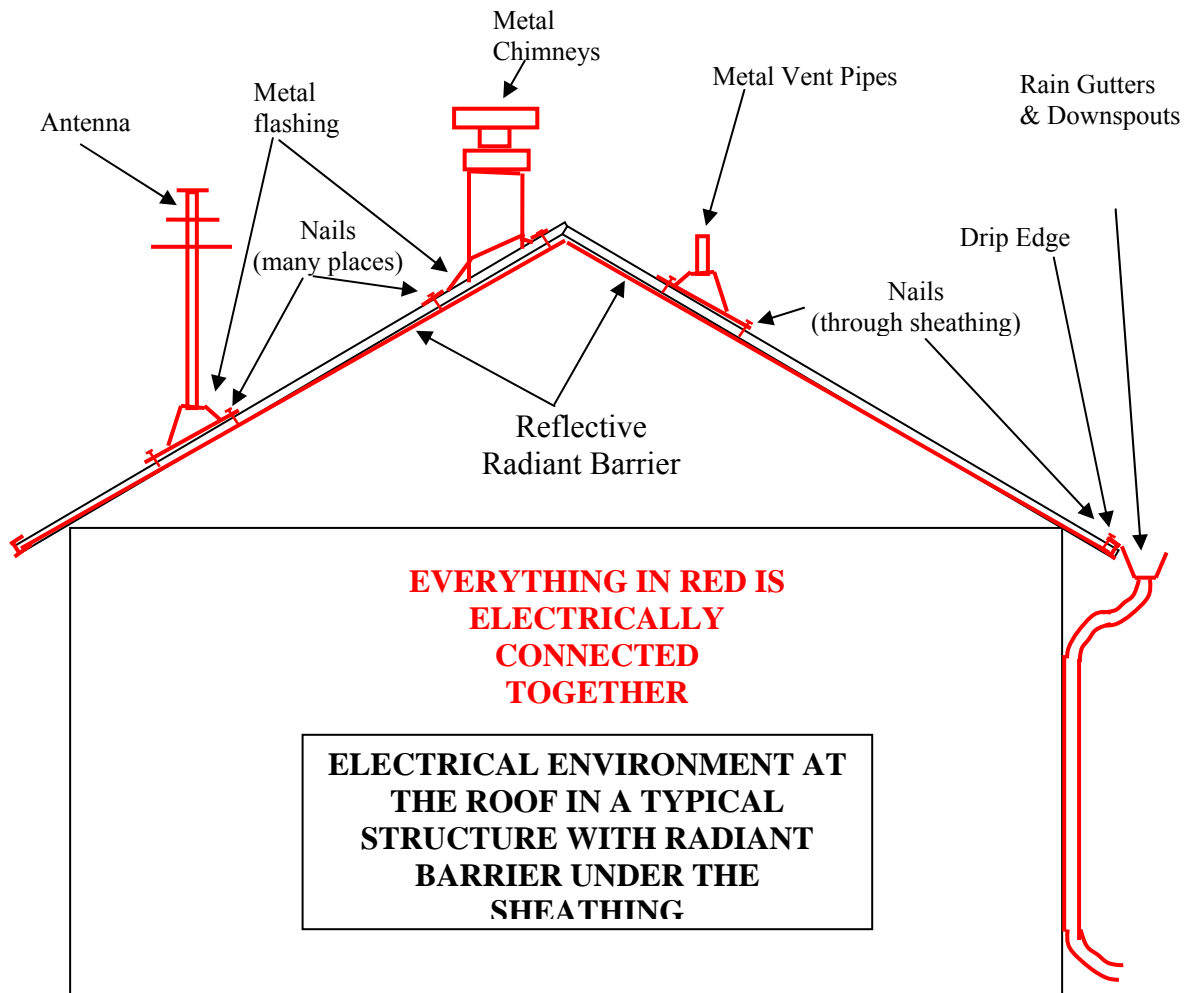


DIAGRAM 1

Diagram 1 illustrates the roof electrical environment we typically find in a structure which has installed the roof sheathing with radiant barrier glued to the underside. Virtually everything metal on and around the roof of the structure becomes electrically connected through the radiant barrier, and there is almost always a path to ground. The “electrical interconnection” of everything on and around the roof occurs because of several factors incidental to the installation. The first factor is that when roof decking is installed, proper construction methods require that all sheets of roof sheathing are “supported” in spaces between the roof trusses using “plywood sheathing clips” which slip over the edges of adjacent roofing sheets (see photo #2). These clips are metal, and the result is that the radiant barrier foil on every sheet of roofing is electrically connected to every other sheet.

The second factor results from the fact that roof nails are metal. When installed, the nails penetrate the roof sheathing and contact the aluminum foil on the bottom. On a typical roof installation there are literally thousands of nails. All of these nails and everything



they touch is now connected to the radiant barrier metal. Items on the roof which the nails touch (and penetrate) include essentially everything on the roof such as rain gutters, drip rails, chimneys, vent flashing, antenna mounts, satellite dish mounts, and so forth.

Now we have situation where every sheet of the radiant barrier and everything metal on or around the roof is electrically connected together. What this means is that if lightning strikes virtually anywhere on the roof, it is highly likely that the current will find its way to and through the radiant barrier material at some point.

This brings us to the third incidental factor. With all of the many features and facilities on the roof, it is highly likely at least one of them will be bonded to an earth ground connection somewhere. It might be a water heater vent pipe, a gas fireplace chimney, an antenna, an electrical service entrance masthead, or any of dozens of possibilities.

Putting all the factors together we get a situation where the significant ramifications are as follows: if lightning strikes virtually anywhere on or very near the roof, it is highly likely the current will pass through at least a portion of the radiant barrier on the way to earth ground.

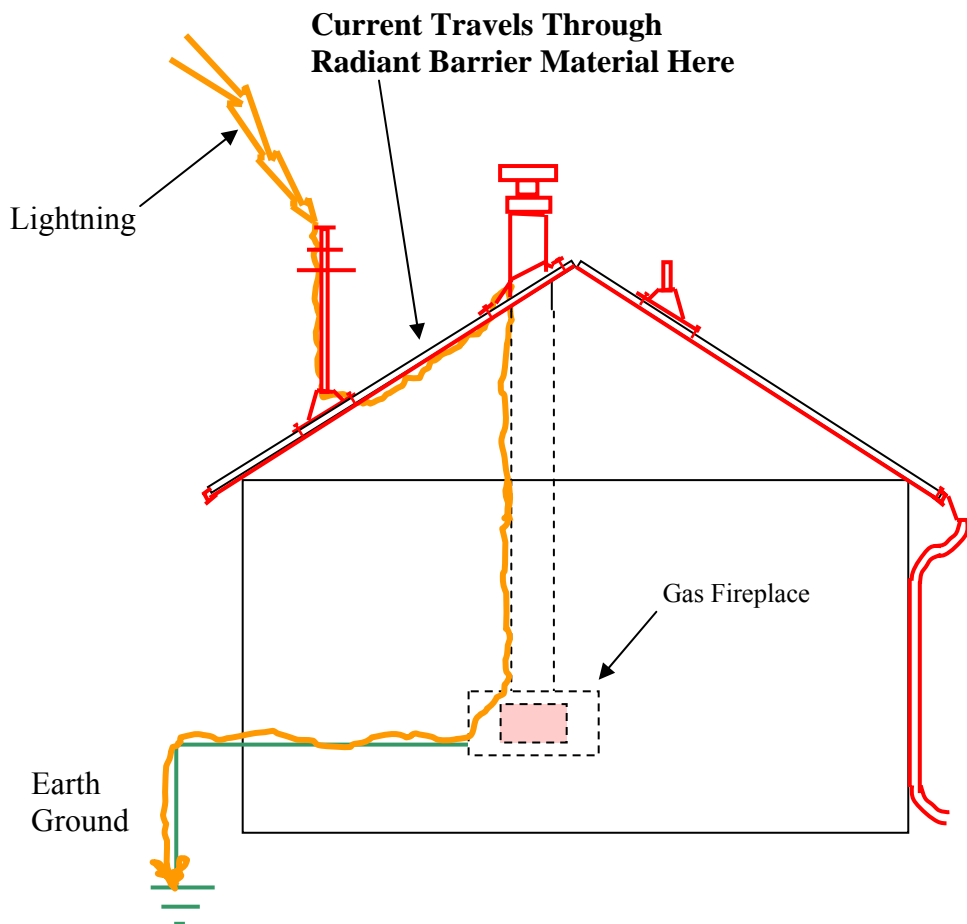


DIAGRAM 2
A Typical Path for Lightning Current



PHYSICAL AND ELECTRICAL PROPERTIES OF RADIANT BARRIER MATERIAL

This is where the real problem shows up. The physical and electrical properties of the radiant barrier foil are such that the material is not only an excellent electrical conductor (Fink) (Wikipedia), it is also a very viable ignition source. When electrical current flows through it the material not only readily generates heat necessary for ignition, it also becomes the first ignited material!

EXAMINATION OF PHYSICAL PROPERTIES

The essential physical characteristics of the radiant barrier material which is glued to the underside of the roof sheathing were examined. We found that the material is comprised of two layers. The first layer (which is the one we see on the underside of the roof) is a sheet of aluminum which is approximately 0.01 mm thick. The second layer (between the aluminum and the wood sheathing) is a sheet of paper approximately 0.02 mm thick. These can be seen in photo number 3.



PHOTO #3

**Louisiana Pacific "Techshield" Roof Sheathing
A section has been cut and "peeled."**

This shows the layer of thin aluminum over a layer of paper.

The primary physical property of the aluminum foil itself which we are concerned with is the melting temperature. It was not necessary to measure this as it has been well documented in many places (Avallone). The common melting point of aluminum is generally considered to be approximately 1,100 degrees F, but this is different for different alloy compositions. The lowest documented aluminum melting point we could



find was 900 degrees F. This means, if heated by electrical current flow, the foil should remain intact and continue conducting until it has reached at least 900 degrees F.

The primary physical property of the paper we are interested in is the ignition temperature. This value can vary significantly for different types of paper (Babrauskus); however it is virtually always less than 500 degrees F. Measurements in our study showed that the paper ignited when the foil temperature was between 420 and 450 degrees F.

Clearly then, if the radiant barrier foil material is overheated as a result of electrical current flow, the temperature of the material will easily exceed the ignition temperature of the paper backing.

We did not do further analysis of the physical properties at this point as we shifted focus to the electrical and “heating” properties.

ELECTRICAL PROPERTIES of RADIANT BARRIER MATERIAL

It is common knowledge that aluminum is an excellent conductor. Of the “affordable” conductor materials (other than silver and gold), aluminum is second only to copper in conductivity (Fink) (Wikipedia). Our objective in this study was to examine the resistivity and ampacity characteristics of this particular radiant barrier material. More specifically, we wanted to determine the sheet resistance of the aluminum, the current carrying capacity (ampacity), how resistance varies with current level, and how the material reacts in an overcurrent condition. Resistivity is the inverse of conductivity, so knowing sheet resistance tells us two things. It first tells us how readily this specific material conducts electricity. The second thing it tells us is how much resistance the current sees when it is flowing. Heat is generated when current flows through resistance (Ohms Law says $P=I^2R$), so knowing the resistance tells us how readily it generates heat.

For measuring and analyzing these parameters we needed some carefully prepared test strips of the radiant barrier material. Photo 4 shows the two different sets of test strips we used.



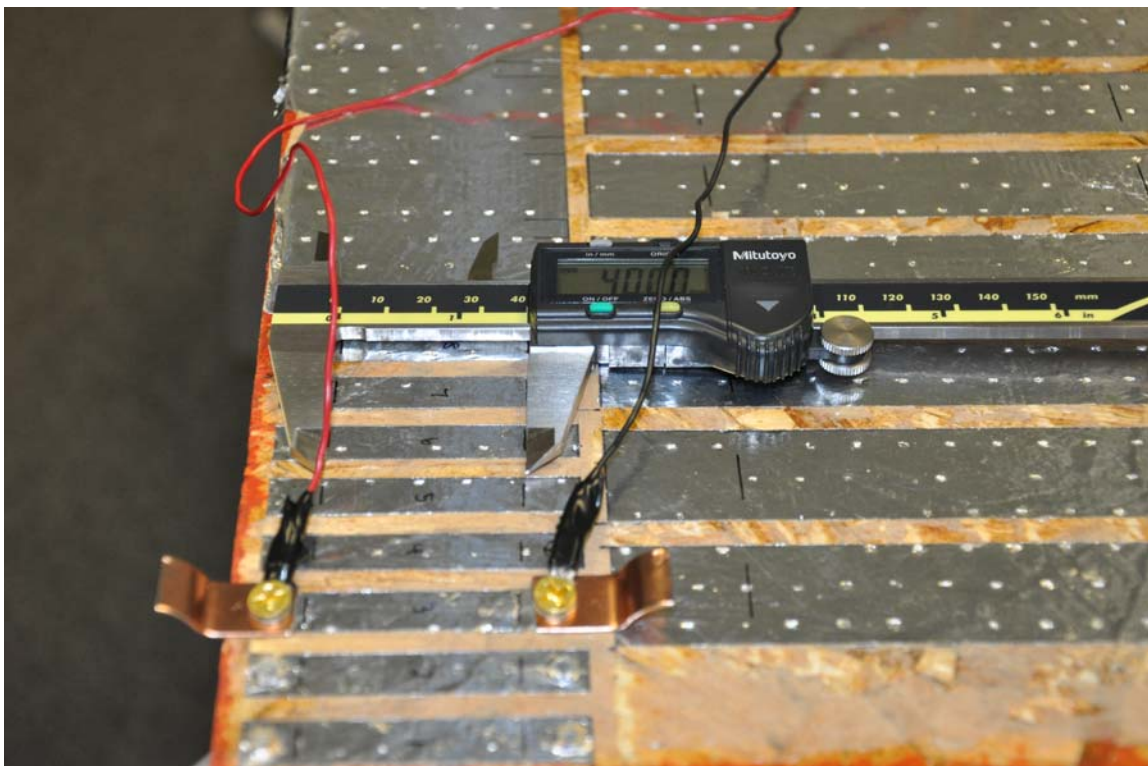


PHOTO # 4

Shows the two sets of sample test strips

One set 1cm wide x 4cm long

One set 1 inch wide x 4 inches long

The electrical “resistivity” of pure aluminum has been studied many times, and the values are available in many different reference tables (Engineering Toolbox) (Fink) (Wikipedia). The values published vary between 26.5 and 28.2×10^{-9} ohm-meters. For our calculations we used a value near the middle of the published range (we used 27.5). For actual measurement we decided to use test strips which were one centimeter wide and four centimeters long. When we plug the value for aluminum resistivity into the resistance formula for a 0.01 mm thick and one centimeter wide strip, we get a theoretical test strip resistance value of 11.0 milliohms.

CALCULATIONS OF TEST STRIP RESISTANCE USING THE RESISTIVITY VALUE FOR PURE ALUMINUM

Test strip thickness = (.01mm) = 1×10^{-5} m

Test strip width = 1cm = 10mm = 1×10^{-2} m

Test strip length = 4cm = 40mm = 4×10^{-2} m

Cross sectional area = Thickness x Width => $(1 \times 10^{-5} \text{ m}) \times (1 \times 10^{-2} \text{ m}) \Rightarrow 1 \times 10^{-7} \text{ m}^2$

From tables, Resistivity = $\rho = 27.5 \times 10^{-9}$ ohm-meter

Resistance formula: $R = \rho \times (\text{length} / \text{cross sectional area})$

$$R = (27.5 \times 10^{-9} \Omega \text{ m})(4 \times 10^{-2} \text{ m} / 1 \times 10^{-7} \text{ m}^2) = (27.5 \times 10^{-9} \Omega \text{ m})(4.0 \times 10^5 / \text{m}) = 11.0 \times 10^{-3}$$

Therefore assuming pure aluminum and resistivity of $27.5 \times 10^{-9} \Omega \text{ m}$, the calculated test strip resistance = $11.0 \times 10^{-3} \Omega$, or 11.0 milliohms.

EMPIRICAL MEASUREMENTS OF TEST STRIP RESISTANCE

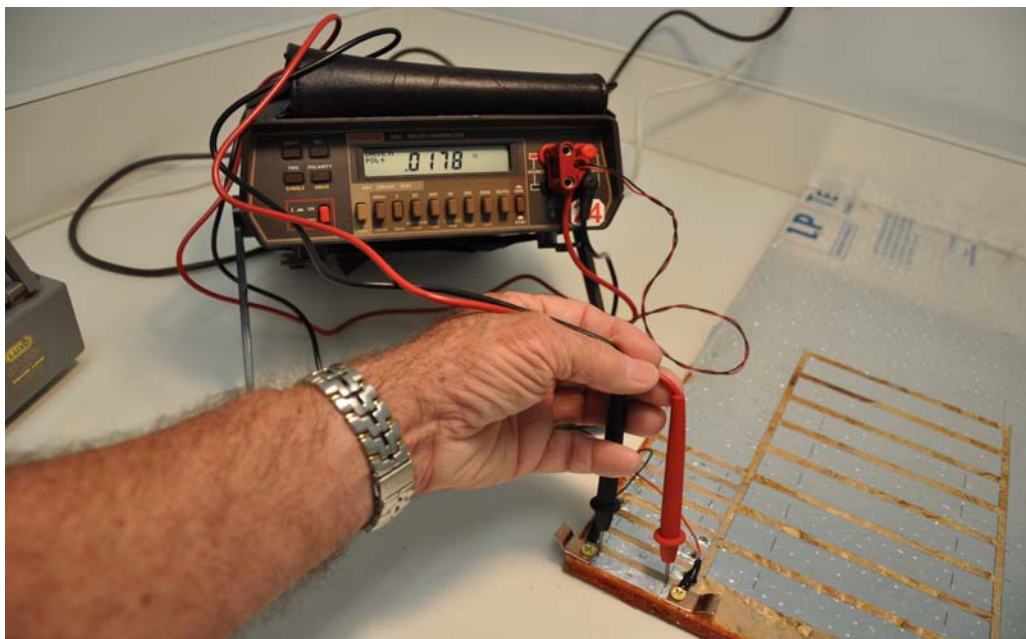


PHOTO # 5

Four Point Measurement of Test Strip Resistance

We performed four point resistance measurements on the test strips using a very accurate milliohm meter (as seen in photo # 5). We measured between 17.7 and 18.2 milliohms of resistance. Thus the theoretical value for pure aluminum test strips was about 35% lower than our measured value. This was actually about what we expected. Although we did not have the exact metal alloy composition analyzed, we can be virtually certain that the aluminum in these foils is not high quality “pure” aluminum. We can be highly confident that there are impurities in the aluminum and that the impurities will have the effect of increasing resistivity (Engineering Toolbox) (Fink) (Wikipedia). The fact that the theoretical values (for pure aluminum) differ from measured values in the direction we expected and by about the amount we expected provides us with a good “sanity” check



on our measurement methods. The measurements we made were highly repeatable across samples, from reading to reading and over time, so we are very confident in these values. Since our test strips have an aspect ratio of 4:1, that gave us a sheet resistance value of 4.50 milliohms per square. To further confirm this value, we created test strips which were one inch wide by four inches long and repeated the four point measurements. Once again our measurements read between 17.9 and 18.4 milliohms. We are highly confident that the actual sheet resistance for the particular piece of roof sheathing we tested is very near the value of 4.50 milliohms per square.

AMPACITY CHARACTERISTICS

After determining the sheet resistance, the next important parameter to examine was the current carrying capacity and characteristics. The specified “ampacity” of sheet material is highly dependent on the particular application it is used in, so there really is no sound theoretical basis for calculating it. Therefore, it is necessary to measure it in the actual application. We really wanted to determine (1) how the resistance varies as current density increases (2) what is the actual (not theoretical) maximum current density the material will sustain and (3) how the material would behave in an “overcurrent” situation.

For these measurements we needed to force a known (and variable) current through a test strip of known dimensions and then measure the voltage drop. We accomplished this by using a bench power supply with an adjustable current output, and then measured the voltage drop at the ends of our test strips with a separate digital volt meter. This allowed us to determine the resistance over a range of current density points.

From experience in the semiconductor industry we knew that the current density at which aluminum conductors actually fail can be much greater than 10 Amps per square millimeter. Our bench power supply had accurately adjustable current output up to slightly more than 3 amps. In order to achieve the needed current densities at these low current levels we needed a test strip with a small cross sectional area. We created strips which were one millimeter wide by “splitting” our original one centimeter strips.



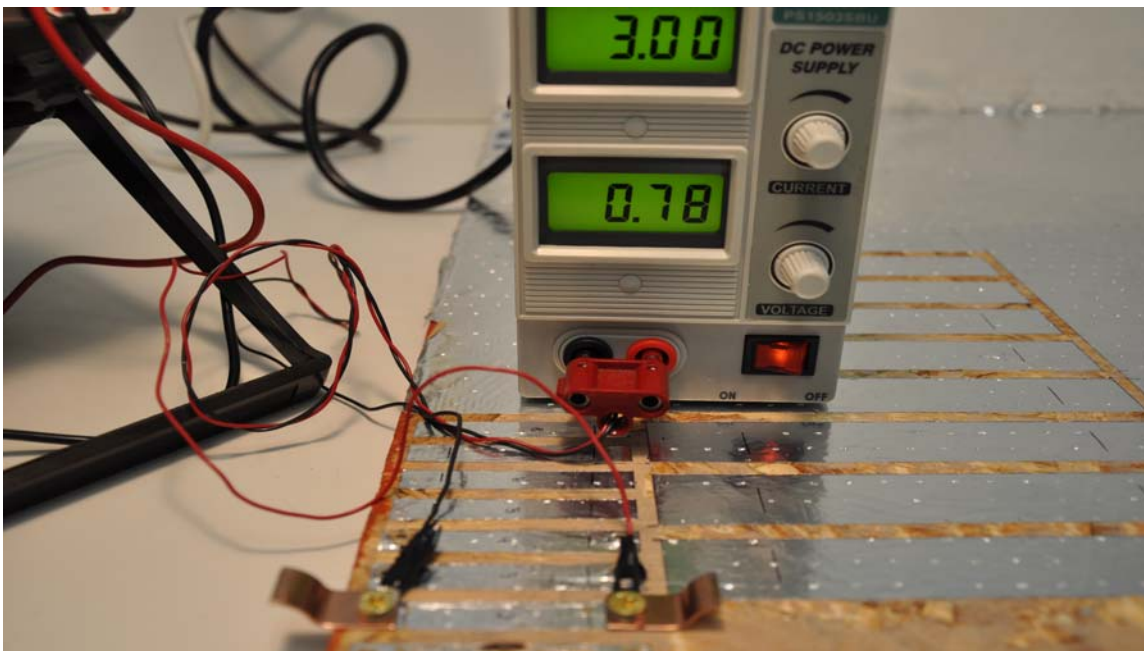


PHOTO # 6
Forcing 3.00 Amps Through a One Millimeter Test Strip

At 0.1 amp intervals from 0 amps to 3.2 amps we carefully measured the voltage drop, then used this to calculate the effective resistance at each value. The variations in test strip resistance versus current density are shown in chart #1.

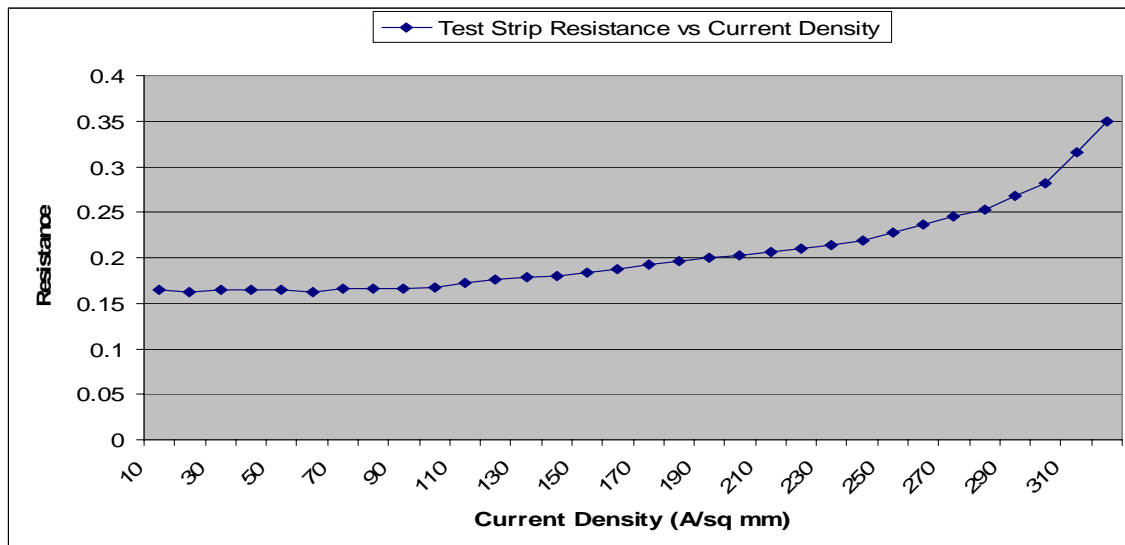


CHART # 1
Test Strip Resistance vs. Current Density



At a current density level of slightly under 300 amps per square millimeter, the material ignited and sustained flame. This is clearly seen in photo #7.

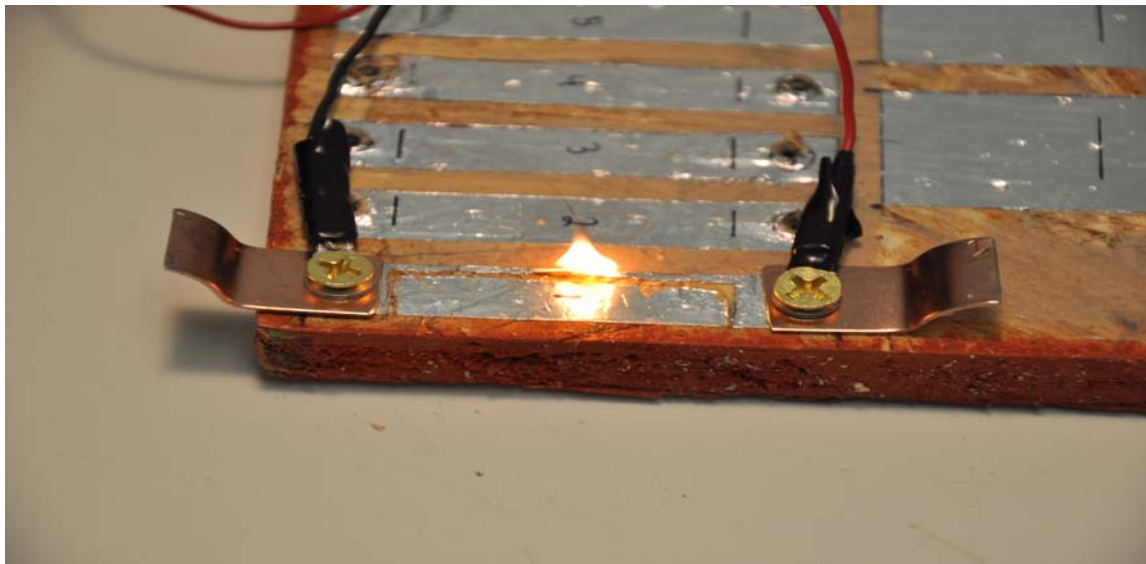


PHOTO #7

Test Strip Ignites at a Current Density of 300 Amps per Square Millimeter

The current density versus resistance measurements revealed two very valuable pieces of information. First, at levels above approximately 200 Amps per square millimeter, resistance of the material begins to increase rapidly (see chart 1 above). Second, at levels around 300 Amps per square millimeter our material quickly ignites and sustains flame. It should be noted that the material will ignite at current densities much less than this value (maybe 50% less) if enough time is allowed.

SUMMARY of IMPORTANT PHYSICAL and ELECTRICAL CHARACTERISTICS:

1. CONSTRUCTION: Aluminum Foil bonded to Paper.
2. MELTING TEMPERATURE of the ALUMINUM: >900 degrees F.
3. IGNITION TEMPERATURE of the PAPER: <500 degrees F.
1. SHEET RESISTANCE of the ALUMINUM: 4.50 ohms per square.
2. CURRENT DENSITY for FAST IGNITION: Approx 300 Amps per sq. mm.

ACTUAL BURN TESTING

Detailed analysis of the properties and laboratory testing of the radiant barrier material reveals that theoretically, in most installations it could easily generate ignition temperatures and sustain flame if energized with sufficient electrical current. The obvious next question is *“How do large sections and full installations of the material*



behave actually (not theoretically) when energized with large amounts of current?" In order to study this condition we conducted a series of tests. First we energized our larger test strips with a current of approximately 50 amps. Next we used a typical plywood clip to connect two large pieces of roof sheathing, which we energized with approximately 50 amps. Finally we constructed a small actual roof section. We energized portions of the roof decking which would conduct through a single plywood clip. Then we energized a section which would conduct through a clip covered with a typical rafter vent channel. The results of these tests can be seen in photos 8 thru 11.



PHOTO #8

One Inch Wide Test Strip Energized With Current of Approximately 50 Amps



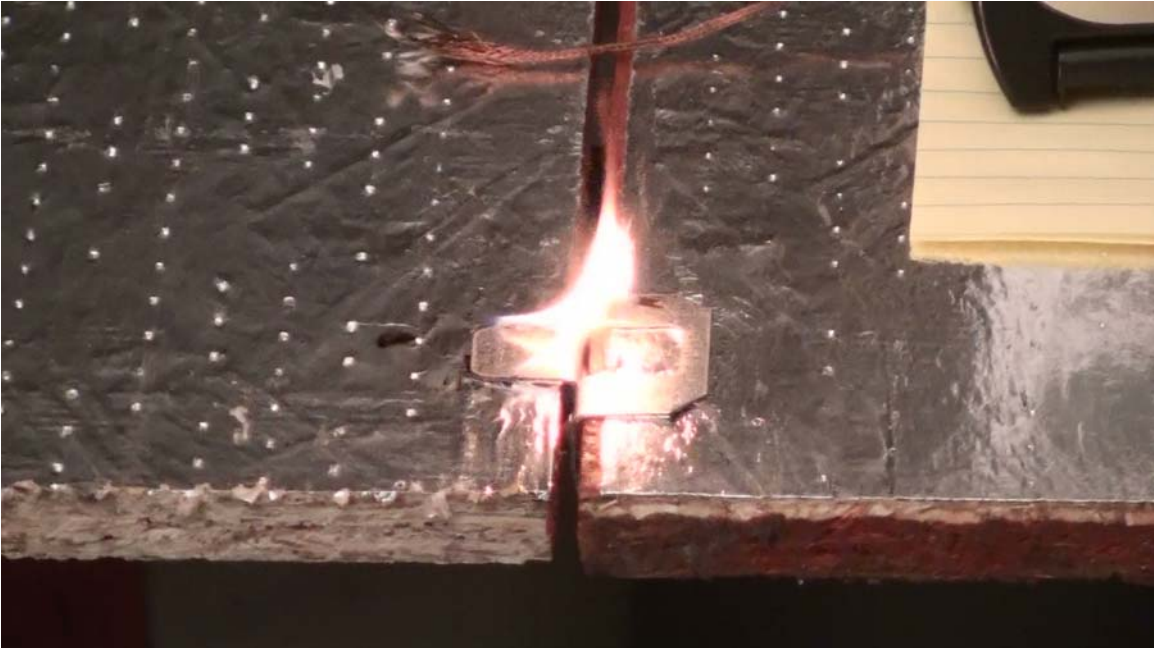


PHOTO #9
Roof Sheathing and Clip Energized With Current of Approximately 50 Amps



PHOTO #10
Plywood Clip on an Actual Roof Section – Approximately 50 Amps.
(Note that it is the barrier material which is igniting. This is because the current in the foil is “funneled” near the clip, thus the current density is highest near the clip)



PHOTO #11
Underside of Roof Deck – With Soffit Vent Channels Installed
Radiant Barrier was Energized with 12 volts @ 50 Amps

The results demonstrated in these photographs conclusively answer the questions about how the radiant barrier material reacts in larger scale tests and in actual installations. When energized and heated by electric current flow, the material readily generates heat beyond ignition temperatures of many materials. The barrier material itself becomes the first ignited material as it quickly burst into flame. If there are other flammable materials nearby (such as soffit vents channels) that material is easily ignited and the fire spreads quickly.

SPECIAL NOTES ABOUT THE ELECTRICITY

It is very important to keep in mind that the behavior of the radiant barrier material which is documented in this report is COMPLETEY a function of the properties of that material itself. The ability of the material to generate heat, to ignite and then to actual burn with flame is a result of the combined material properties of conductivity, resistivity, melting temperature, and ignition temperature. This behavior is NOT a function of the electricity. The only requirement of the electricity is that it is able to deliver enough current to provide a current density (in at least one location on the material) of approximately 200 amps per square millimeter. The actual voltage and total amount of current depends entirely on the physical configuration of the installation. Remember that in some of our testing we achieved ignition and flame with 0.78 volts at 3.0 amps. It is possible to have ignition and burning at even lower voltage and current levels than that. Even in our “large scale tests” on actual roof sections the most “electricity” we utilized was 12 volts at 50 amps.

So clearly, it is not necessary to have the energy levels from lightning in order to have a fire which originates in the radiant barrier. This study has shown it is possible to have a



fire originate in the radiant barrier if it becomes energized by virtually ANY commonly available electrical source. However, it should also be clear that if there is danger of a fire from “single digit” voltage levels and “tens” of amps, the danger from lightning at 15,000,000 volts and 100,000 amps will be MANY times greater. This is why we feel strongly that the presence of radiant barrier material in a structure greatly increases the risk of a fire in the event that the structure experiences a lightning strike.

SPECIAL NOTES ABOUT LIGHTNING STRIKES

The probability of a structure experiencing a lightning strike is much higher in some geographical areas than in others. An excellent map showing the geographical distribution of lightning strike density can be viewed by selecting the link “unclassified choropleth maps” at the following web site (Vaisala):

(http://www.weather.gov/os/lightning/images/Vaisala_96-05_Flash_Map.gif)

Unfortunately, the areas with the highest probability of a lightning strike correspond almost exactly with the same areas where the use of reflective radiant barriers is considered to be needed the most (Fairey).

(<http://www.fsec.ucf.edu/en/publications/pdf/FSEC-DN-6-86.pdf>)

Obviously, any time a radiant barrier equipped structure experiences a fire when there is evidence of a lightning strike, an examination of the barrier material should be included in the investigation.



Photo # 12

Photo from an Actual Attic Fire After a Confirmed Lightning Strike

In photograph 12 note the clear evidence of localized heating and barrier material burning around the metal sheathing clips.



SUMMARY of FINDINGS

1. Standard installation methods for roof sheathing with integrated radiant barrier are such that the end result is an overall environment where all of the radiant barrier material and virtually everything metal on and around the roof are electrically connected.
2. In most cases, something in that environment is connected to earth ground. If anything in the roof environment becomes electrically energized (by lightning or any other common source) there is a high probability the current will pass through the barrier material at some point on the way to earth ground.
3. The physical and electrical properties of reflective radiant barrier materials which we tested are such that the material in a structure provides two new and unique hazards relative to fire causation.
 - (a) When energized by an electrical current the material readily generates temperatures sufficient to ignite MANY materials.
 - (b) The barrier material itself readily serves as the first ignited material.

CONCLUSION

The presence of integrated roof deck radiant barrier in a structure provides a significant new risk of fire should the barrier material become electrically energized.

POST SCRIPT

To date we have completed investigations of two forms of the most commonly used radiant barrier material. There is still more work to be done in studying these materials as well as other forms of radiant barriers. We hope to be able to provide more information as we complete further studies in the future. For any questions or more details about the work completed so far please contact:

Ronald Simmons
McDowell Owens Engineering
281-358-2876
r.simmons@mcdowellowens.com



Works Cited

Avallone, Eugene A. Marks' Standard Handbook for Mechanical Engineers. Boston: McGraw-Hill, 1987.

Babrauskus, Vytenis. Ignition Handbook. Issaquah, WA: Fire Science Publishers, 2003.

Engineering Toolbox. Resistivity, Conductivity and Temperature Coefficients for Some Common Materials. 22 October 2010 <http://www.engineeringtoolbox.com/resistivity-conductivity-d_418.html>.

Fairey, Philip. Radiant Energy Transfer in Radiant Barrier Systems in Buildings. 1986. 22 October 2010 <<http://www.fsec.ucf.edu/en/publications/pdf/FSEC-DN-6-86.pdf>>.

Fink, Donald G. Electronic Engineers Handbook. New York: McGraw-Hill, 1975.

Simmons, Ronald D., et al. "Special Report: Reflective Radiant Barriers." Fire Findings (2009): 7.

U.S. Department of Energy, the Oak Ridge National Laboratory, et al. Radiant Barrier Attic Fact Sheet. 27 June 2001. 22 October 2010 <http://www.ornl.gov/sci/roofs+walls/radiant/rb_02.html>.

Vaisala. 1996-2005 Flash Density Map. 2006. 22 October 2010 <http://www.weather.gov/os/lightning/images/Vaisala_96-05_Flash_Map.gif>.

Wikipedia. Wikipedia. 22 October 2010 <<http://en.wikipedia.org/wiki/aluminum>>.
—. Wikipedia. 22 October 2010 <<http://en.wikipedia.org/wiki/resistivity>>.



APPENDIX 1

Possible Evidence that Radiant Barrier Material Has Been Electrically Energized

All investigators know that fire destroys a lot of evidence. After a fire, physical evidence which may have provided clues about the origin of the fire may be significantly changed or completely destroyed. If there are indications that radiant barrier material may have been causally involved, and if some of the material is available which has not been subjected to a high amount of radiant heat from the fire, there are some possible indicators which may be examined. We found that electrical heating of the material seemed to generate some distinctive patterns. Photos demonstrate some of these patterns.

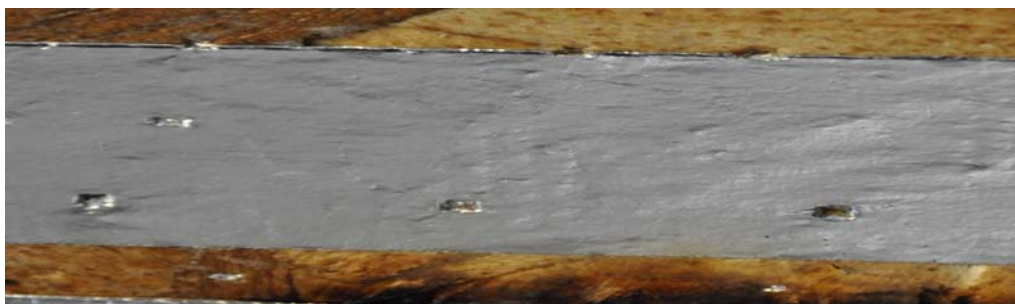


PHOTO #13

A Test Strip Which Has Not Been Subjected to Electrical Current

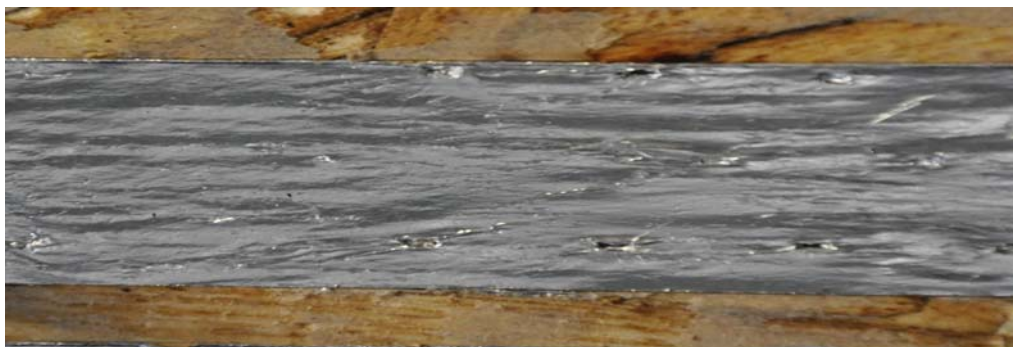


PHOTO #14

A Test Strip Which Has Been Heated Slowly By Approximately 30 Amps

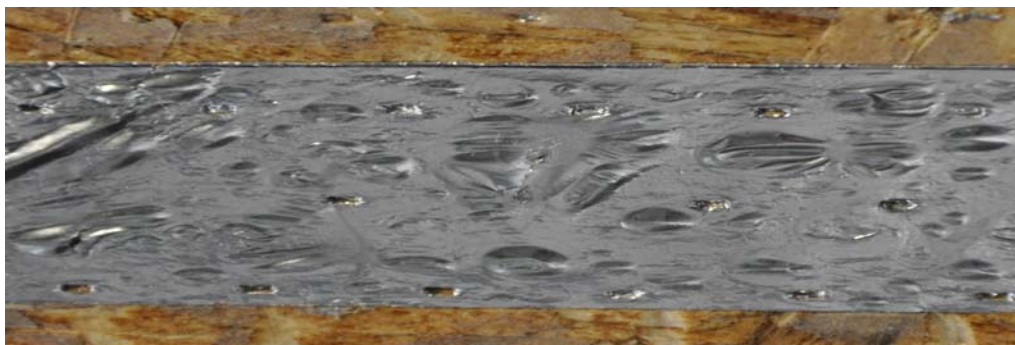


PHOTO #15

A Test Strip Which Has Been Heated Quickly By Approximately 100 Amps



ABOUT THE AUTHORS

Ronald Simmons, P.E., C.F.E.I., studied engineering at California State Polytechnic University. He has been a forensic engineer with McDowell Owens Engineering for most of the last three years. In the preceding 20+ years Mr. Simmons worked as a senior design, test, and reliability engineer in the electronics industry where he was recognized as an electrical testing expert. For several years Mr. Simmons served as Test Engineering Manager for Intel Corporation.



"I just can't seem to get a handle on it!!"



"These Heavy Equipment investigations Are SO tiring!!"

Eric Benstock, P.E., MIFireE, C.F.E.I.; received a BS in Mechanical Engineering from the University of Houston. He is licensed P.E. in six states (Texas, New Mexico, Arkansas, Louisiana, Mississippi, and Pennsylvania). In addition, he is a Member of the Institute of Fire Engineers, UK, and he is a Certified Fire and Explosion Investigator. He has been with McDowell Owens Engineering since 1995 and has been the Director of Operations since 2001.

Nestor Camara, B. Sc., C.F.I.; received a BS in Fire Science from the University of Maryland. He is a Certified Fire Investigator (CFI) through the I.A.A.I. He is a Senior Fire Analyst with McDowell Owens where he has been a member of the staff since 1989. Mr. Camara is also responsible for the operation of the firm's Fire Research and Testing Center, where he has been extensively involved in the design and instrumentation of fire related testing.



Cool, it looks like little bitty sparklers in here!

