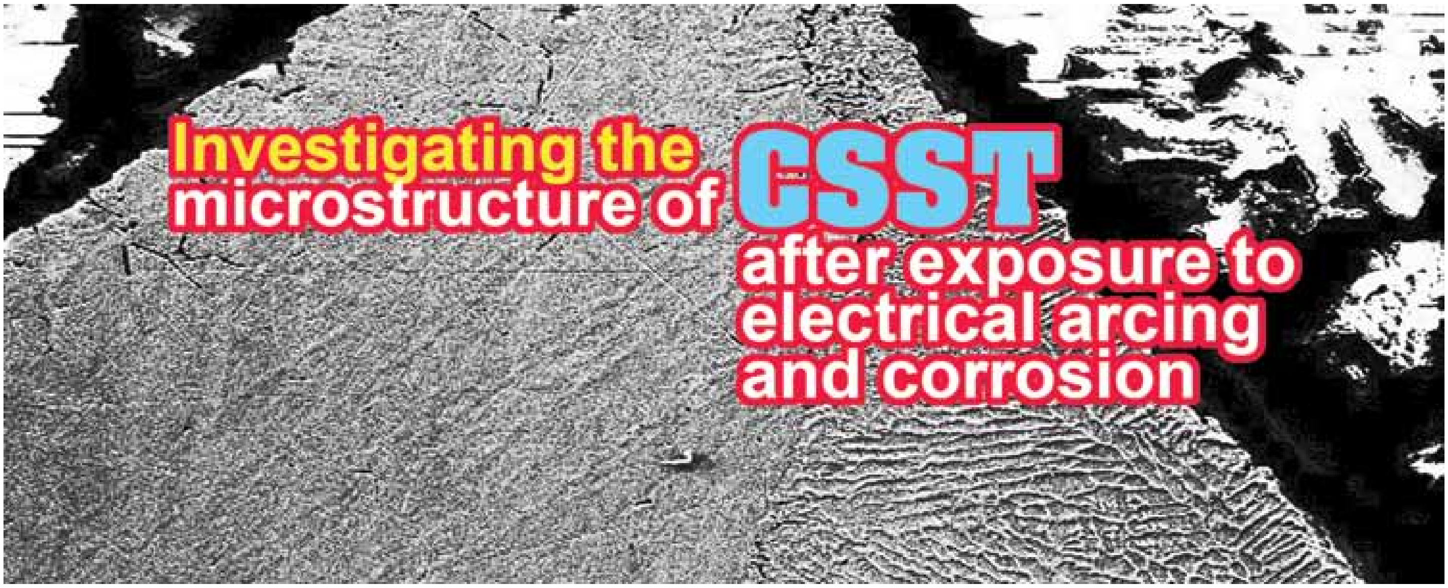

Investigating the microstructure of CSST after exposure to electrical arcing and corrosion

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717,115,310 Feet

Seven hundred seventeen million, one hundred fifteen thousand, three hundred ten feet-- that is the most recent estimate of installed Corrugated Stainless Steel Tubing (CSST) in homes across America since its commercial introduction in 1988[1]. As CSST grew in popularity, correlation appeared between lightning strikes and fires in structures with installed CSST. The phenomenon comes from perforations in the CSST caused by its thin wall construction combined with the overabundance of energy as lightning dissipates through the CSST to ground. Presently, literature is available which explains the correlation between lightning strikes and fires related to CSST[1-4]. In such literature and in researchable events, CSST perforations have been satisfactorily identified as a fire cause.

This article has the goal of empirically examining CSST breaches to determine whether electrically induced discharge damage can be differentiated from other causes of non-mechanical breaches, such as corrosion, and what impact this testing has upon the current state of investigation and litigation related to this product. Most recently, Applications Engineering Group, Inc. (AEGI) has conducted research to find indicators which could objectively differentiate electrically induced discharge damage in CSST from corrosion produced pitting perforations. Electrically induced discharge damage is a potential source of gas release, while corrosion produced holes are often a result from environmental corrosion caused after a fire.

THE PRODUCT

CSST is made of a 300 series stainless steel (SS) which is rolled and welded into a round tube and then formed with convolutions along its length to permit flexibility. CSST was introduced into the U.S. market in 1988 as a lighter, less labor intensive, and simpler gas delivery alternative to black steel pipe. CSST was sold as a complete system with proprietary connections and peripherals, and it gained popularity over conventional black steel pipe due to ease of installation from its thinner, 0.008 to 0.010 inch (0.02 to 0.025 centimeter [cm]), and flexible corrugated construction.

THE CAUSE FOR CONCERN

One of the first places where CSST was suspected in causing fires was Frisco, Texas, where a series of houses containing CSST had fires immediately following nearby lightning strikes. Each fire revealed that the area of origin contained CSST with a perforation that had allowed gas to escape. It was proposed by Goodson that because CSST was extremely thin, 0.01 inch (0.03 cm) or less, the energy required to cause failure was significantly less than what was required for 1/2 inch (1.3 cm) outer diameter black iron pipe which has a thickness of 0.12 inch (0.30 cm)[2].

Research continued to emerge as Durham found further justification of the weakness of CSST with a study showing the product's particular susceptibility to induced and direct lightning energies due to lightning's super high frequency[3, 4].

While most manufacturers were originally silent about whether bonding and grounding were needed for their product, most ultimately updated their installation manuals to specifically require bonding and grounding for their products. However, most manufacturers were not specific about how they wanted it performed and they recommended it be in accordance with National Fire Prevention Association (NFPA) 54 and NFPA 70. All manufacturers now require that their products be directly bonded.

Bonding and grounding is the joining of CSST to the ground system in a structure in an attempt to dissipate unexpected electrical energy in the CSST. It can be accomplished by use of a third prong of a gas utilizing appliance with an electrical connection, or it can be done by the use of a bonding clamp and a grounding wire (Figure 1). However, CSST manufacturers no longer consider the use of a third prong a sufficient means of bonding their product.

FIGURE 1
Bonding clamp attached to a gas regulator.

MORE CAUSE FOR CONCERN

It is well documented that lightning and other electrical arcing activity can cause failures in un-bonded CSST systems. Manufacturers of CSST maintain that CSST is safe and cannot fail if direct bonding is used, but the manufacturers have provided no testing data to substantiate this claim, despite requests by the NFPA for such data. However, the most recent April 2011 NFPA report prepared by SEFTIM noted that there are documented cases in which lightning had created perforations in CSST which was properly bonded per NFPA 54 and the manufacturers recommendations[1].

One common failure mode for CSST during a lightning strike is the transference of energy between CSST and another conductor at a different electrical potential, via an arc. Electrical arcing causes the melting and removal of material through the quick application of heat energy, known as ablation. Ablation, as it pertains to CSST, looks as if the hole was caused by melting, as manifested by a small bead raised above the metal surface surrounding the hole (Figure 2).

FIGURE 2
Ablation caused by electrical arcing.

The stainless steel alloy used in CSST is not immune to corrosion following a fire in certain environments. Chromium provides the corrosion resistance in stainless steels, and when CSST is subjected to high temperatures, such as during a fire, it may become *sensitized*. *Sensitization* is the depletion of chromium adjacent to the grain boundaries, which then allows for corrosion at those boundaries. The indicators of lightning induced failures become less obvious to the naked eye when CSST evidence is left to sit in wet aggregate at a loss site for extended periods of time. Perforations, of which there may be dozens, caused by pitting corrosion of CSST may have to be differentiated from lightning failures to assist with origin and cause investigations.

TYPICAL INSTALLATIONS

The gas supply originates either from a natural gas pipeline (Figure 3), or a container held propane gas source (Figure 4), which can hold up to 180 pounds per square inch gauge (psig) (1241 kilopascals [kPa]). Both natural and propane gas sources are normally at pressures which must be regulated down prior to entering the structure. In the case of propane systems, lines from the container to the service entrance are usually plastic or copper and are not CSST unless a specific subterranean grade is used. In propane systems, a ball valve is installed just upstream of the low pressure regulator at the entrance to the structure, and the low pressure regulator lowers the pressure to 0.5 to 2 psig (7 to 14 kPa) leading into the structure. Natural gas systems are regulated by a utility regulator and meter equipment and will lead directly to the system.

After the propane or natural gas service entrance, the CSST, which is jacketed in a yellow or occasionally black plastic sheathing, is routed into the structure and connected to a manifold. The manifold distributes gas via multiple branch lines, and each line is connected to a single appliance. The CSST diameters depend on the flow required. CSST fittings are yellow brass and are customized to fit the CSST to standard National Pipe Thread Taper fittings.

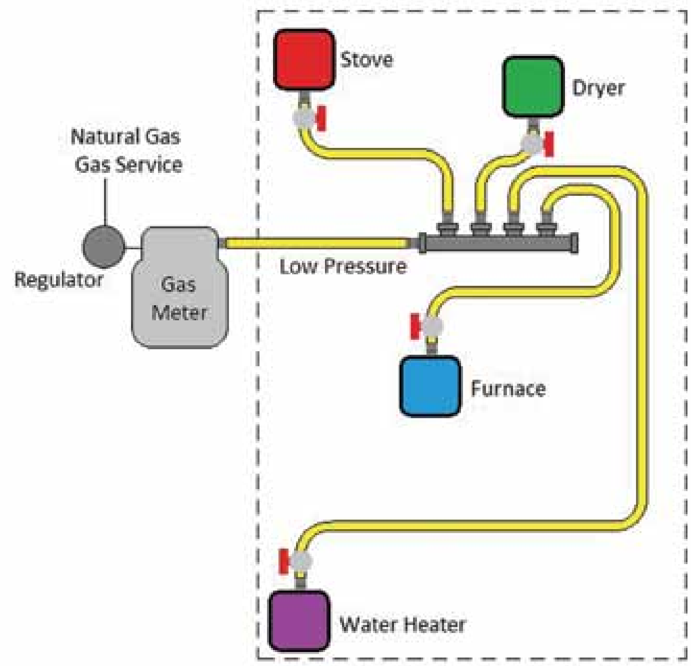

FIGURE 3
Typical natural gas installation layout.

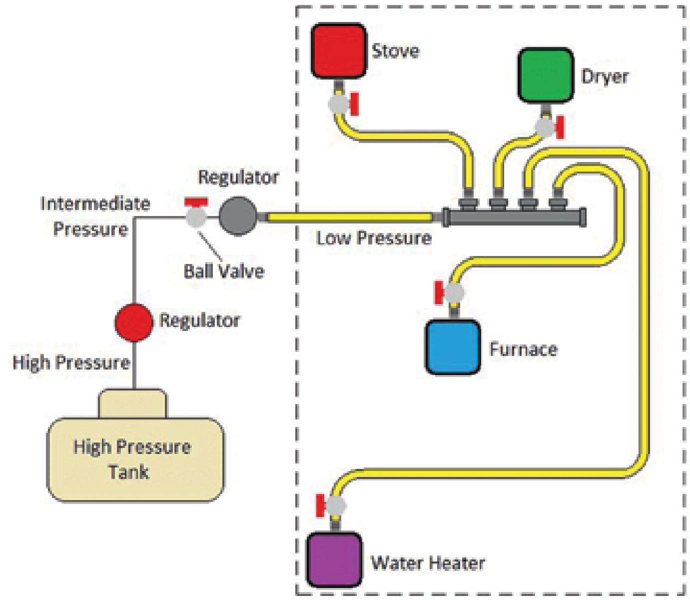

FIGURE 4
Typical propane installation Layout.

INVESTIGATION GUIDELINES

In a loss where CSST is suspected in playing a role, it is imperative to determine the configuration of the system before a cause and origin decision can be made. Working the scene from the "outside-in" or "downstream" along all parts of a CSST system helps to avoid missing important information. Efforts must be made to identify and understand the entire gas system and appliances that make it up, as well as to identify potential paths that lightning energy may have taken to ultimately energize the gas lines.

After a fire, CSST is often presented as sheathless and sometimes corroded (rusted). After an intense fire, CSST lines may continue to corrode over time under certain conditions, and thus it is important for the first individual on the scene to properly inspect and document the CSST condition. Visual inspection for electrically induced discharge damage is crucial and should be assisted by pressure testing the gas system to find any leaks. Because corrosion is time sensitive, it is obviously preferable to examine any CSST perforations before corrosion sets in. However, even in those instances where the product has been forced to sit for an extended period of time, laboratory testing presented here can determine whether observed perforations are electrically induced or corrosion related.

CURRENT TESTING at AEGI

Arc Microstructure

In 2010, AEGI conducted testing to determine the differentiating characteristics between electrical arc and corrosion perforations in CSST. All of the tested samples were made of 304 SS, which is an alloy composed of approximately 18-20 percent chromium, 8-10.5 percent nickel, and iron, with small amounts of manganese, silicon, carbon, sulfur, and phosphorus. In this part of the testing, CSST samples were subjected to electrically induced discharge damage using a 120 V alternating current line voltage in a laboratory environment, in which the effect was found to be analogous to lightning induced discharge damage described by Goodson[2]. Upon sectioning through CSST samples and applying a chemical etchant, a Scanning Electron Microscope (SEM) was used to reveal microstructural features nearest the perforation. Normal 304 CSST grains exhibit an equiaxed austenitic microstructure, meaning the grains are all roughly the same size in all directions and have a close packed atom arrangement. It was determined from analysis that rapid re-solidification of CSST yields a ferritic/austenitic microstructure, whereby some of the grains have a less densely packed atom arrangement called ferrite. The molten metal caused by the arc had solidified so rapidly that it was frozen in

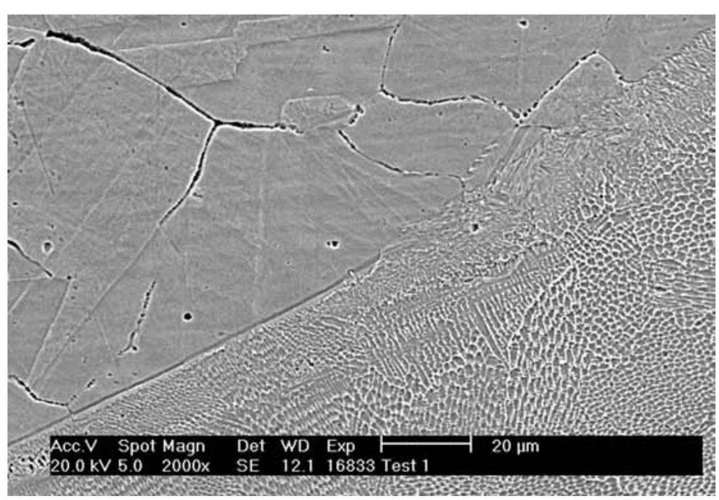

FIGURE 5
Normal equiaxed grains in CSST (upper left), re-solidified CSST microstructure (lower right)

a non-equilibrium state containing extremely small finger like grains called dendrites. Areas which were not subjected to arc melting exhibited large equiaxed grains characteristic of the bulk material, and the re-solidified metal had a much smaller and elongated granular appearance. In Figure 5, the normal equiaxed grains appear on the upper left of the micrograph, and the re-solidified grains are on the lower right.

Sensitized Arc Microstructure

Several samples with electrical arc damage were exposed to *sensitization* temperatures of 1350 to 2000 degrees Fahrenheit (°F) (732 to 1093 degrees Celsius [°C]) for 2 hours. The ferritic/austenitic microstructure was easily visible in each of the sensitized samples after all six tested temperature exposures (Figures 6 and 7).

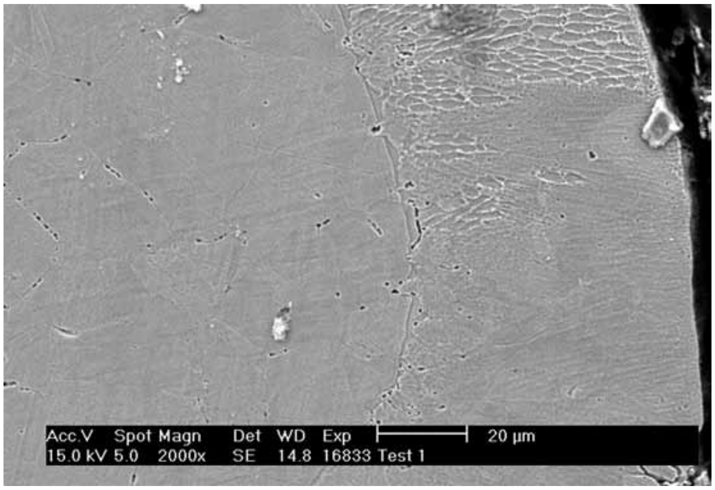

FIGURE 6
Sensitized CSST (1350 °F/732 °C)
Normal equiaxed grains in CSST (left),
re-solidified CSST microstructure (right)

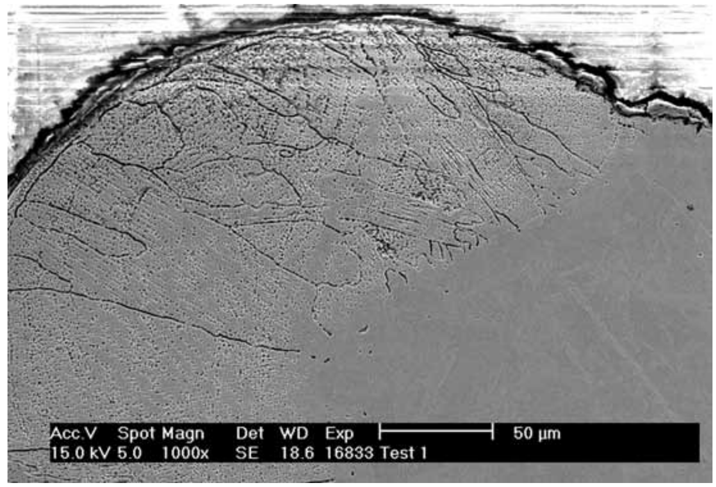

FIGURE 7
Sensitized CSST (2000 °F/1093°C)
Normal equiaxed grains in CSST (lower right),
re-solidified CSST microstructure (upper left)

CORRODED SENSITIZED ARC MICROSTRUCTURE

A second batch of samples were subjected to *sensitization* at 1200 °F (649 °C) for 8 hours, in order to initiate corrosion and simulate the observed rusting conditions in CSST after it has experienced a fire. In this corrosion study, the *sensitized* CSST samples were placed in an air-flow-confined corrosion chamber in a mixture of post-fire ground debris. Samples were corroded for 2 months while maintained in 100 percent humidity at 140 °F (60 °C). The observed corrosion mechanism in the CSST was pitting, and some of the pits developed into perforations that are consistent with the holes in CSST after being exposed to fire events. The corrosion induced holes had sharper and more jagged features than the electrically induced holes (Figures 8 and 9).

Microscopy showed little change in the appearance of the ferritic/austenitic microstructure at the known electrically induced failure sites, even after through-thickness pitting had occurred in the samples from corrosion (Figure 10).

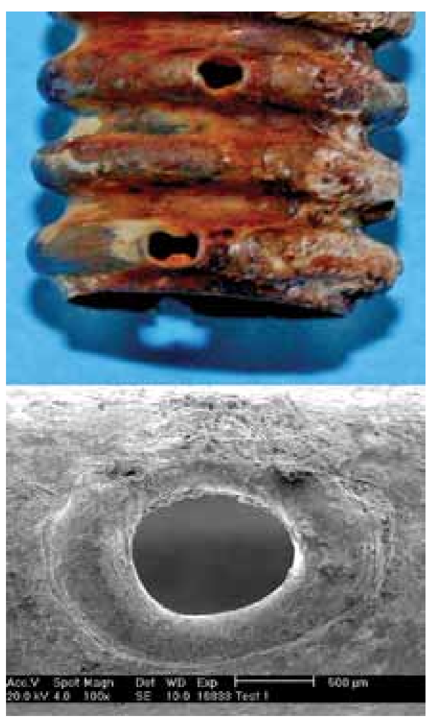

FIGURE 8
Electrically induced hole

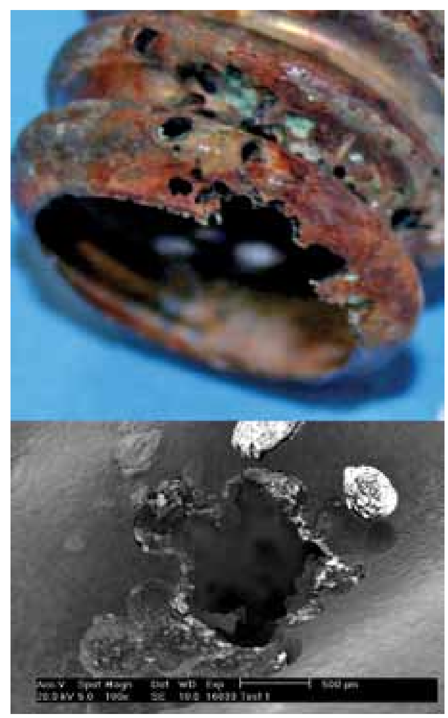

FIGURE 9
Corrosion induced hole

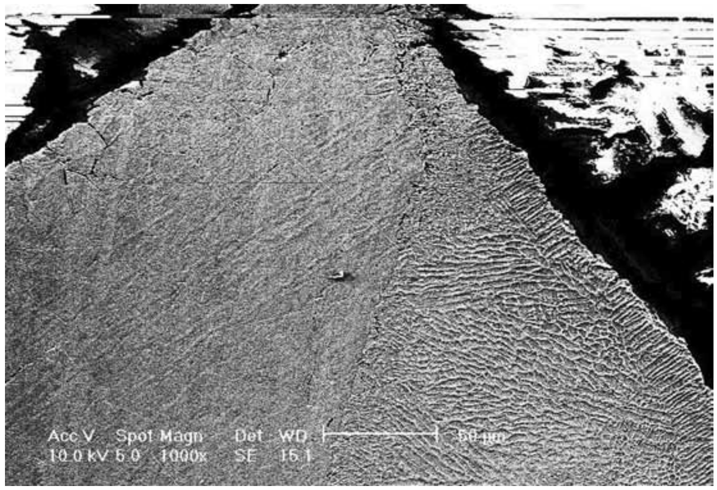

FIGURE 10
SEM micrograph of electrically induced hole after corrosion exposure
Normal equiaxed grains in CSST (left),
re-solidified CSST microstructure (right)

LITIGATION

CSST fires have generated significant litigation. While hundreds of lawsuits have been filed, only one has gone to trial. In October of 2010, a Pennsylvania jury found that the product was defective and unreasonably dangerous because of its inability to withstand energy from lightning[5]. Even still, many fire investigators handle suspected lightning fires without taking the time to examine whether CSST played a role in causing the fire. Even more investigators mistakenly assume that the only issue being litigated is whether the product was properly bonded and grounded.

CSST losses all share core similarities: they occur in newer or retrofitted homes with CSST installations, the area of origin was determined to be in the vicinity of the CSST, and at the time of the fire there were reports of storms or lightning in the area. When presented with these facts, efforts should be taken to identify and place on notice the manufacturer of the CSST and the parties involved in its installation.

CONCLUSIONS

As a fire investigator, your knowledge of CSST and its role in fires is crucial when examining the evidence. The following steps are a recommended guideline for CSST investigations:

1. Trace the gas system to determine if CSST was installed, especially in newer (post 1988) construction and structures with retrofitted gas systems.
2. Determine if there had been lightning activity in the area around the time of the fire.
3. Visually inspect the CSST for any perforations.
4. If possible, perform a pressure/leak test on the gas system to determine if it has been breached.
5. Document and mark all perforations found.
6. If possible, take the CSST into evidence to prevent further deterioration.

These steps are invaluable if, at some later time, there is a need to identify which perforations existed at the time of the initial inspection because the CSST has suffered additional corrosion. A detailed visual examination of the perforations, especially with optical microscopy, will be helpful in identifying breaches which were likely caused by electrical activity. Most importantly, recognize that regardless of the damage to the CSST, perforations can be examined using the metallurgical techniques presented in this paper to positively determine if they are a result of electrical activity.

REFERENCES:
[1] *Validation Of Installation Methods For CSST Gas Piping To Mitigate Lightning Related Damage, Phase 1, Final Report, SEFTIM*, Fire Protection Research Foundation, April, 2011.
[2] *Investigating The Causal Link Between Lightning Strikes, CSST, And Fire*, M. Goodson, M. Hergenrether, FIRE AND ARSON INVESTIGATOR, October, 2005.
[3] *Lightning, Transient & High Frequency Impact On Material Such As Corrugated Tubing*, M. Durham and R. Durham, Frontiers of Power, Oklahoma State University, Stillwater, Oklahoma, 2008.
[4] *CSST Response To Lighting And Transients, A Technical Analysis*, Durham and Durham, FIRE AND ARSON INVESTIGATOR, July 2009.
[5] *Tincher v. Omegaflex, Inc., et al*, Chester County Court of Common Pleas, Pennsylvania, October 20, 2010.

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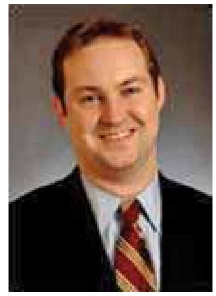

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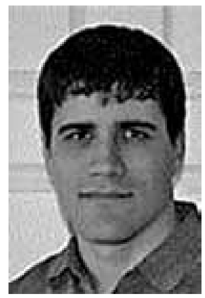

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