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## **“Generator Field Winding Shorted Turns: Moisture Effects”**

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Generatortech, Inc.’s experience in the field of generator rotor shorted turn detection has helped in developing an understanding of the types and causes of shorted turns, the general frequency of occurrence and the eventual disposition of the problems.

In the past two decades, the use of on-line testing of generator rotor windings has surged. The benefit of on-line testing has been recognized throughout the power generation industry and the installation of air-gap flux probe monitoring equipment has become almost standard procedure for utilities and OEM’s. On-line testing for field winding shorted turns gives operators positive answers that can be used in trouble shooting generator operational problems and helps determine whether rotor rewinding is required. Because of the perceived value of on-line testing, most first time users soon embark on programs to retrofit their entire fleets with air-gap flux probes.

This paper is an extension of a paper presented at the EPRI January 2003, Electric Generator Predictive Maintenance and Refurbishment Conference in Orlando, FL. That paper covered the nature of operational problems arising from shorted turns, the causes of shorted turns in the field winding and introduced the subject of moisture/foreign material contamination as instigators of shorted turn development.

This paper deals more directly with the effect of moisture on the insulation systems and rotor winding turn shorts.

### **Moisture and Foreign Material/Contamination as a Newly Identified Issue**

Generatortech noted the issue of the effects of moisture on rotor winding insulation a few years ago while reviewing particularly troublesome machines that continually developed shorted turns. In the process of comparing these machines’ operating conditions with those of similar machines, it was noted that excessive amounts of moisture were present in the hydrogen cooling gas and seal oil systems of the troubled machines. Since that time, we have extended our investigation of the role of moisture by review of similar cases, review of other investigations into the effects of moisture in generators and some laboratory testing.

## Studies of the Presence of Moisture

In the mid-1980's, a study was conducted by J. Bothwell (Reference 2), regarding the effects of high moisture content on gas cooled stator winding faults in Westinghouse generators. Gas cooled stator windings have high voltage copper exposed at each end of the stator bars. Because of this, they must rely on long creepage paths to ensure that there are no high voltage phase to phase or phase to ground faults.

Mr. Bothwell, was investigating a stator ground fault which had tripped the unit off-line. The particular generator had a top mounted hydrogen cooler that ran the length of the machine. He was able to enter the machine near the cold gas exit of the cooler. Much to his surprise, there was a considerable amount of water in pockets in the frame. Water was actually found from the outlet of the cooler to the inlet area of the cooler. The greater amount of water was found near the cooler outlets. A trail of whitish stains was also found the entire length. The staining was identified as lead carbonate, which was generated in the coolers. Also of note, is that there was no water found at the stator leak detectors at the bottom of the frame.

The presence of lead carbonate and moisture is well known now to degrade the electrical creepage strength of a surface. The ground fault failure in this machine was attributed to moisture contamination. The significance of this problem was not lost on the engineers at Westinghouse. Although we are not aware of all the recommendations, we do know that Westinghouse advised their customers to install hydrogen dryers and maintain dew points below 10°C (50°F). This appears to have been effective in that no failures of this type have been experienced in machines that have hydrogen-drying systems.

It is interesting to note that generators, utilizing water-cooled stator windings, where the ends are completely encapsulated, were not susceptible to the creepage path failure. The manufacturers of water-cooled stator windings generators did not see the need to advise on the use of hydrogen dryers and dew point monitors.

There remain in service today, many generators that are operated without the benefit of hydrogen gas dryers. Our observations and customer reports of conditions of lead carbonate contamination and moisture indicates that many generators may be operating at problematically high dew points.

## Significance on the Rotor End Winding Turn Insulation

The significance of the high moisture condition is that water particles, lead carbonate and other contaminants are carried to the field end turn area. Once in place in the end turns, the moisture attacks the interturn insulation and results in shorted turns.

## Distribution of Water and Contaminants During Start/Stop Cycles

Figure 1 shows a simplified ventilation circuit of an air-gap pickup field design. The cold gas from the cooler goes directly under the retaining ring to the end winding copper. The cooling gas emerges into the air gap just inboard of the retaining ring. The rotor ventilation holes pick up the gas from the air-gap to cool the field body copper and discharges it back to the air-gap. The gas then flows radially through the core and back to the coolers.

Significantly in this cooling scheme, the area under the retaining ring can become collector of sorts for moisture and contamination present in the cold gas.

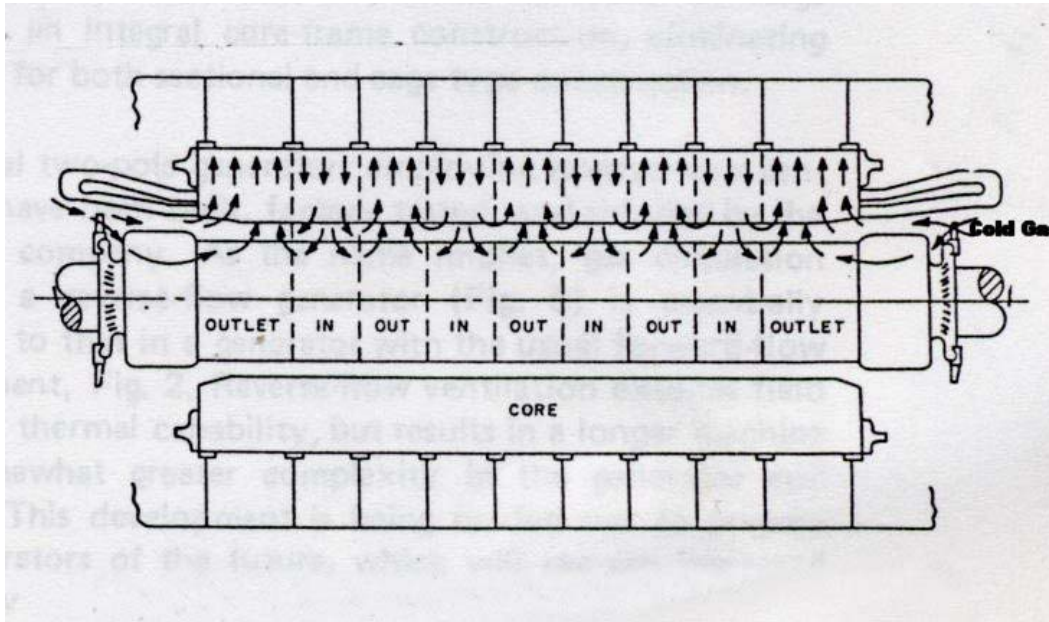


Figure 1 - Ventilation Circuit

Contaminants are impinged on the inner retaining ring insulation surface due to centrifugal forces. Moisture, introduced to the cooling gas, by any number of ways, will be absorbed by the contaminants creating a conductive bridge between coils. Creepage paths in this location have caused coil-to-coil failures. (Fig. 2 and 3) On air-cooled generators, hand wrapping of the top one or two turns may aid in precluding this type of failure.

Figures 2 and 3 show the after effects of a Coil 4 to Coil 5 short to the retaining ring. Both coils were shorted out. Figure 2 is the inner layer of the ring insulation from an air-cooled generator. Similar conditions have been observed in hydrogen-cooled generators. The light colored areas are the outlines of the end windings and blocks. The dark areas are contaminants deposited by centrifuge action on the retaining ring insulation surface. Note the rotational direction arrow and note that the heaviest buildup of contamination is at the leading edge of the blocking. It has been our experience that coil-to-coil shorts due to contamination normally occur at the leading edges of the blocks.

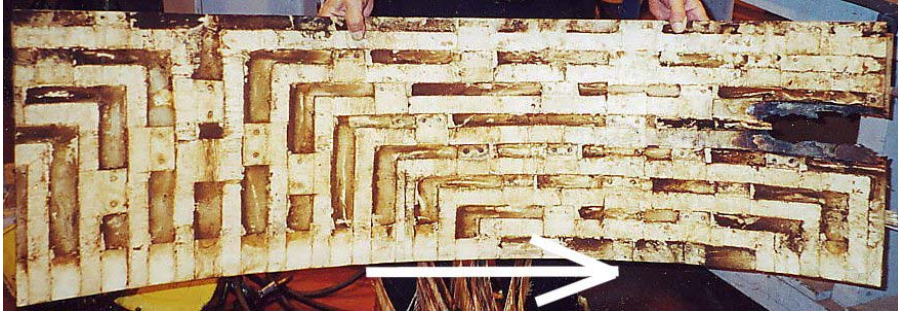


Fig. 2 – Burned R.R. Insulation Contaminant Induced Coil-to-Coil Short



Fig. 3 – Blocking from Fig. 2 failure

Figure 4 depicts another coil-to-coil short as viewed with the retaining ring and insulation removed. This condition had shorted both #8 coils out of the field circuit. This generator had operated for 14 years. Figure 5 is the same field as viewed from 180° from Figure 4. It is clear there is no distortion of the windings. Winding distortion is the most common cause of coil-to-coil shorts. It is therefore reasonable to assume that moisture and contamination that had centrifuged to the retaining ring insulation and created a low resistance creepage path causing the failure.

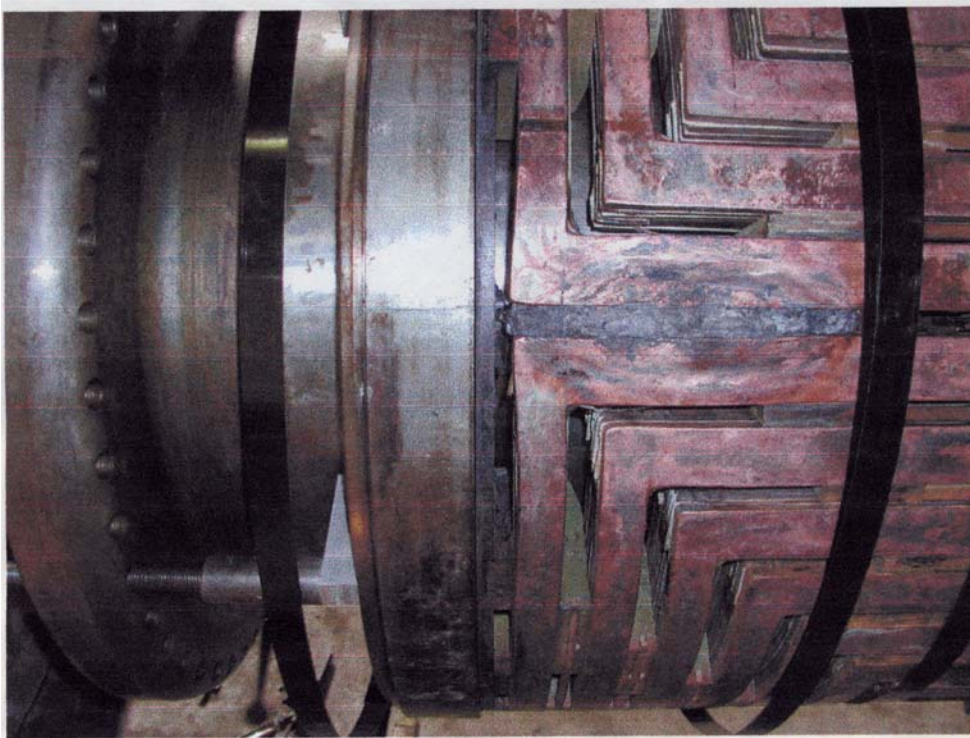


Figure 4



Figure 5

During the rewind of this field, we were able to compare samples of the body insulation to the end-winding insulation. The body copper insulation showed no deterioration whereas the end turn insulation showed significant amounts of deterioration. Deterioration was in the form of color changes (green, red and blue), cracks and carbonization of the glass fibers. Figure 6 shows a comparison of the body and end turn insulation samples from the same generator.

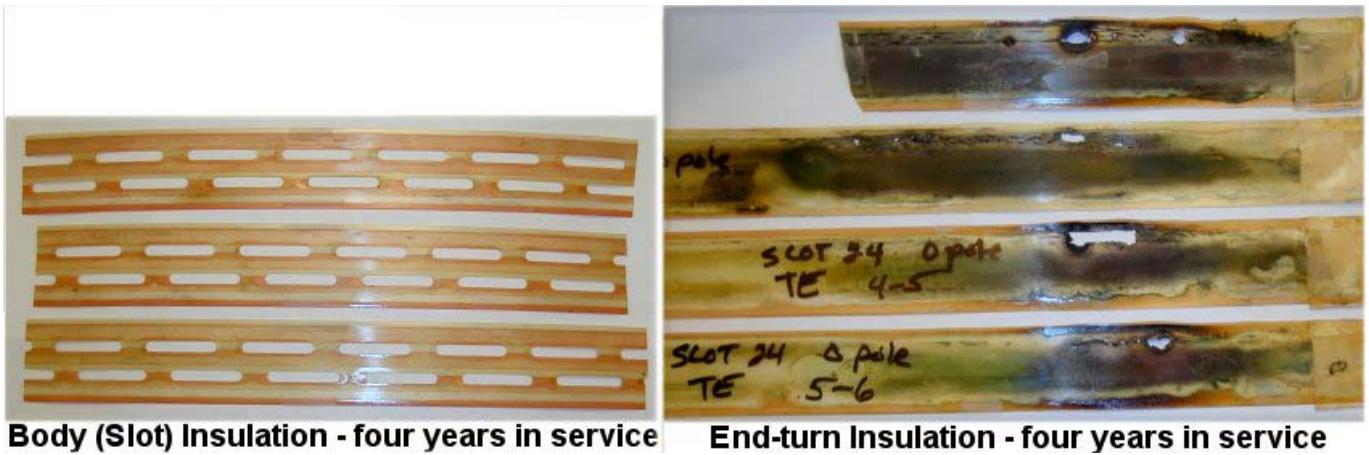


Figure 6

## Temperature Changes on Shutdown

Figure 7 depicts a typical shutdown of a generator. Megawatt load, turbine end and exciter end cold gas temperatures and rotor speed are plotted. It can be seen that the cold gas temperature drops rapidly after the generator is tripped. Figure 7 is a summer shutdown curve. Winter shutdowns generally will result in lower temperatures due to lower cooling water temperatures. The end turn area, being the first to see cold gas and lacking any significant mass to help maintain heat, rapidly approaches cold gas temperature.

What one should recognize from a review of this curve, is that cooling gas dew points must be maintained safely below cold gas temperatures achieved on shutdown. Dew points above the shutdown cooling gas temperature will result in moisture collecting under the retaining rings and significantly increase the risk of shorted turn development in the end turn region.

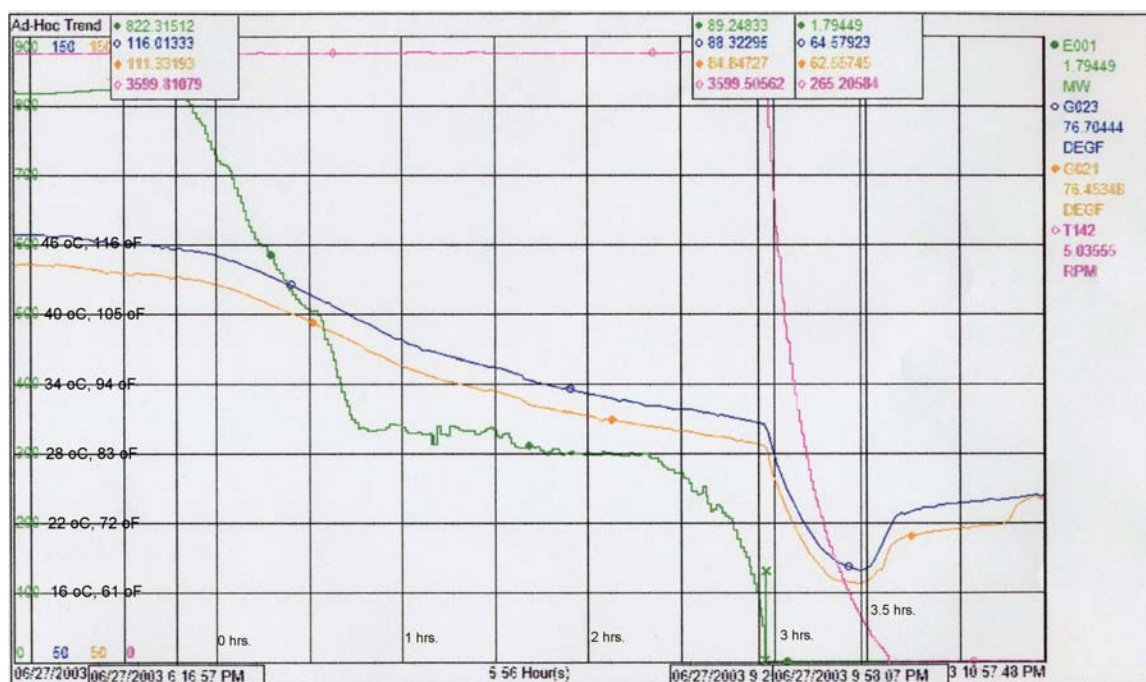
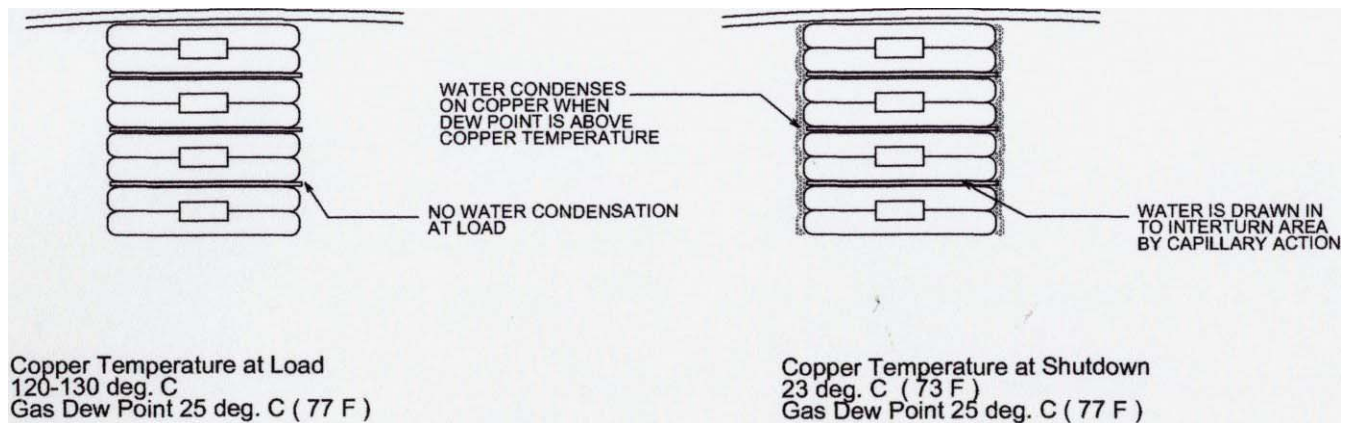


Figure 7

## Moisture Attack on the Rotor End Winding Turn Insulation

When a generator trips and rotor speed decreases, the centrifugal forces that hold the end turns in a compact package decrease dramatically. At low speed, gaps between the copper winding and interturn insulation will occur. The gaps or crevices are a result of the bending and deforming of the copper during the winding process.

If the hydrogen gas dew point is higher than the end winding copper temperature, moisture will condense on the end windings and be drawn into the crevices by capillary action and start to attack the polyester resin. (Fig. 8)



**Figure 8 – Condensation of Water on End Windings due to High Dew Point of Cooling Gas**

When the generator is put back in service, the combination of moisture, high temperature and pressure continues to attack the interturn insulation. The insulation thins under pressure and begins to bond to the copper surfaces. Each start/stop cycle will repeat the same degrading series of events. Eventually, a high resistance hole will occur in the insulation. At this point a partial shorted turn condition will develop and the temperature will rise high enough to carbonize the glass cloth in the insulation. The turn to turn current will rise very rapidly causing a tack weld between turns to occur. The tack weld being of very low resistance, results in a full shorted turn.

## Laboratory Testing

In an effort to provide additional verification of the processes involved in degradation of rotor winding insulation, Generatortech conducted testing to simulate conditions that exist in operation. Samples of interturn insulation were subject to pressure, temperature and voltage similar to that experienced by rotor field windings.

Some samples were periodically subjected to moisture to simulate conditions where high cooling gas dew points results in condensation on the rotor winding. Other samples were not subject to the moisture. In this testing samples were cycled daily from room temperature to operating temperature (130° C). The test jigs were disassembled every 3 to 4 days, relieving pressure from the insulation samples and allowing for the addition of moisture. Each time the jigs were disassembled, some bonding was noted between the polyester resin and the copper in both the moistened samples and the dry. The bond strength however was significantly higher in the samples that were moistened, indicating that moisture contributes to a deterioration of the polyester resin. Some resin eventually transferred, in part, to the copper surfaces in the moistened test fixture, exposing the glass cloth fibers. Resin transfer was not noted in the dry test fixture. The testing continued for 3 months.

Figure 9 shows the test samples. The sample in the center of the figure is the moistened sample. Above it, is the sample from the dry test. The lower sample is a piece of turn insulation from a generator that had experienced many shorts in the end turn region.

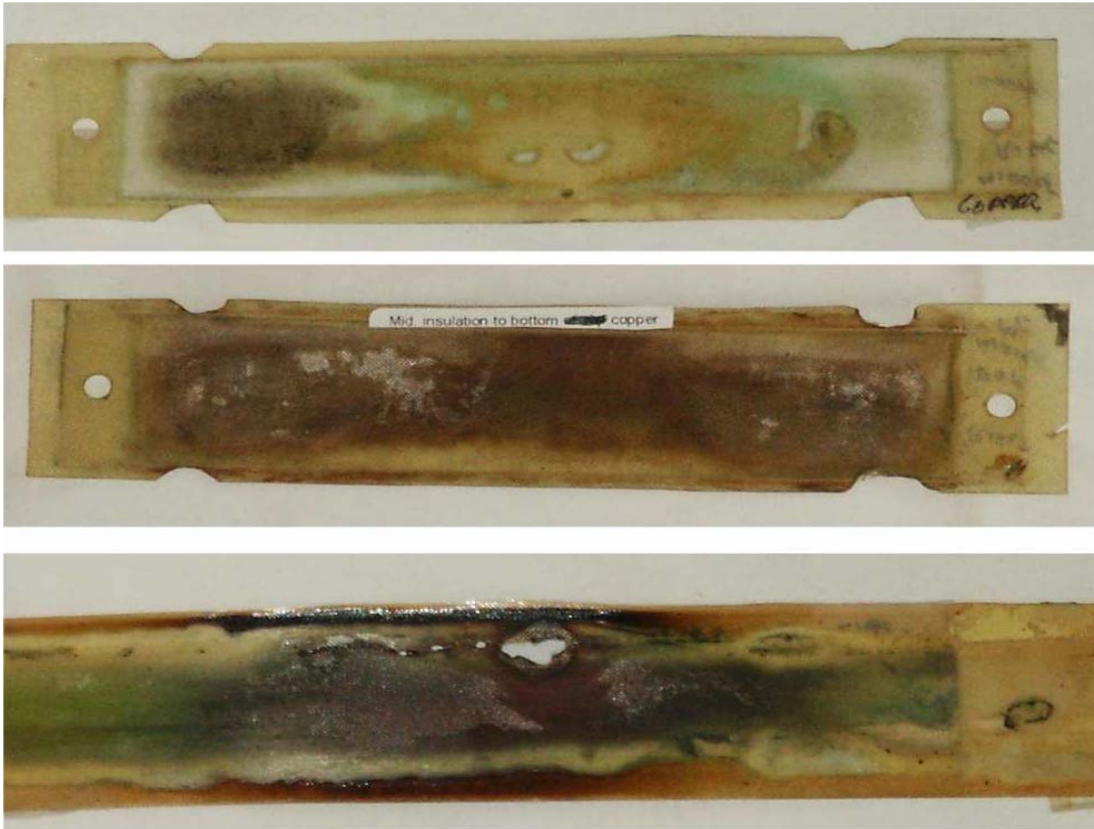


Figure 9

The results of the testing confirm to a high degree that moisture contributes significantly to the breakdown of the interturn insulation.

## Conclusions

It is becoming increasingly clear, as more cases are reviewed, that moisture in cooling gas can cause significant problems with field winding shorted turn development. Operators should be aware of the potential problems and perform the necessary monitoring of cooling gas dew points. We also strongly recommend the use of hydrogen drying systems for those machines that do not currently have them.



## References:

- 1) J.D. Albright, D. R. Albright, "Generator Field Winding Shorted Turns: Observed Conditions and Causes", EPRI International Conference, January 20, 2003, Orlando, FL
- 2) J. Bothwell, "Monitoring Moisture in Hydrogen Cooled Generators", EPRI On-Line Monitoring and Condition Assessment Workshop, August 26, 2003, Nashville, TN