Infrared Thermography for Plant thermal Loss Management

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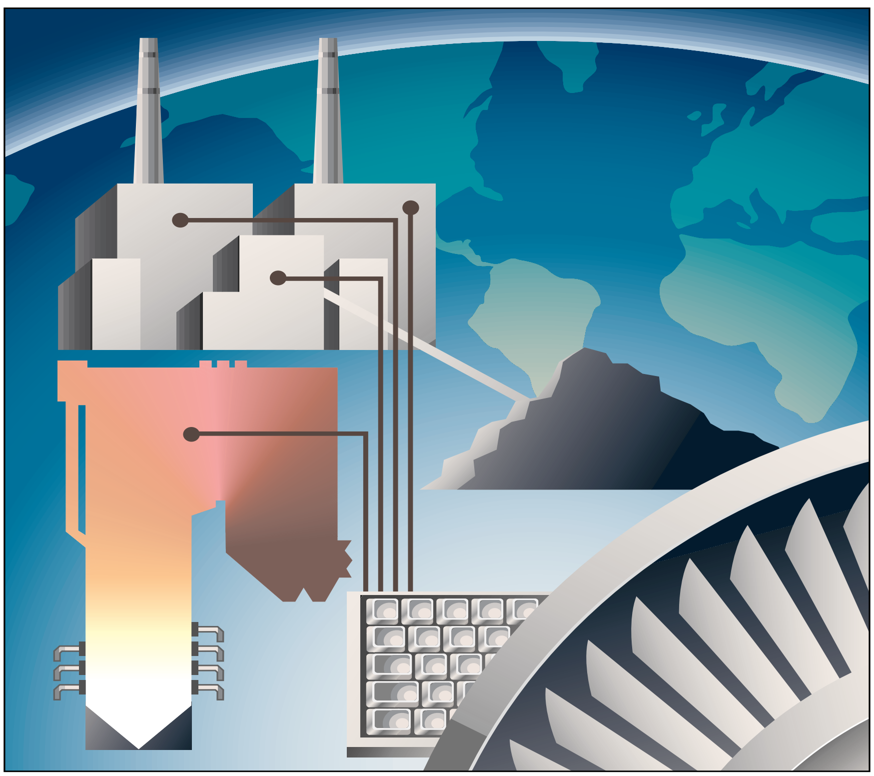

Infrared Thermography for Plant Thermal Loss Management

TE-114093

Technology Review, November 1999

Project Manager

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This document describes research sponsored by EPRIGEN.

The publication is a corporate document that should be cited in the literature in the following manner:

Infrared Thermography for Thermal Loss Management, EPRIGEN, Palo Alto, CA: 1999. TE-114093.

Infrared Thermography Plant Thermal Loss Management

1. Introduction

This project is part of EPRI's development efforts under the Plant Maintenance Optimization (PMO) Target conducted at EPRI's M&D Center. The PMO mission is to lead the industry by developing and demonstrating products and services for improved utilization of power plant maintenance resources and increased profitability for the generation industry.

The Technology Review contains the following sections:

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2. IRT Data Collection Methods and Measurement Techniques
3. Thermal Losses
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The generation of electric power is basically accomplished by converting fuel energy into steam and then into mechanical and electrical energy. Generally, the energy losses in power plants are classified as "stack losses" and "system losses" and they represent the amount of energy in the fuel that is rejected to the stack, lost at the condenser, or lost through piping; therefore, it is energy that is not converted to useful shaft horsepower at the turbine generator to generate Megawatt output. Limitations in modern power plant design make these types of losses inevitable, even when a facility is operating according to the optimum design specifications for maximum efficiency. These unavoidable losses explain why design heat-rates will always be somewhere in excess of the theoretical 3,413 BTUs (3.6MJ) required to generate a kilowatt hour of electricity at 100% conversion efficiency.

However, there are certain energy losses that occur at all generating facilities, classified as 'performance losses', that are avoidable. These performance losses are basically heat, water, and steam leaks; and, the energy losses associated with these types of leaks can also significantly impact heat rate and efficiency. They are not only bothersome maintenance issues, but they impact the plant thermal efficiency, and collectively they can be significant. The reduction of these thermal losses is called Thermal Loss Management; and, since Infrared (IR) thermography is technically a 'thermal' instrument, it is an ideally suited tool to apply to reduce or eliminate these losses and therefore to help realize the benefits of Thermal Loss Management. A secondary benefit is the reduction of treated system make-up water.

The application of IR Thermography (IRT) to uncover power plant problems began with the detection of hot (loose or corroded) electrical connections, and the detection of mechanical faults (hot bearings, mechanical rubs, etc.). Since those beginnings were so successful, IRT was extended to detect thermal losses, pipe and valve leaks, and then finally to boiler and condenser applications. The purpose of this Technical Review is to present these latter applications and to demonstrate their effectiveness to Thermal Loss Management.

Before getting into the specific applications of IRT thermal loss surveys, however, it would be well to review the IRT collection and measurement techniques.

2. IRT Data Collection Methods and Measurement Techniques

Data Collection

The IRT Data Collection Methods developed by the EPRI M&D Center Thermographers during the course of conducting numerous IRT surveys can be classified into three (3) categories, which are: baseline, exception, and reference data collection. The following are descriptions of each of the three methods.

Baseline data is generally taken on unique components that have no similar service equipment for comparison; on equipment where operating temperature varies due to load, location, ambient, construction, etc.; or, on equipment where the IR Thermographer is not familiar with the component's normal operating condition.

Exception data is collected when an anomaly is found. The anomaly data is then used to identify and direct the action for repairs. When an anomaly is detected, it is the responsibility of the IR Thermographer to evaluate the condition, and to provide information that may lead to determining its severity, probable cause, and recommended action.

Reference data is used to provide a comparative condition. The reference data may depict a properly operating component that can be compared to a similar service defective component; or, before and after repair to ensure that the problem has been corrected and the work has been done properly.

Reference data is very effective when trying to identify an anomaly. Displaying a reference image is also a very effective method of illustrating an anomaly.

Measurement Techniques

The IR measurement technique used by the EPRI M&D Center Thermographers to determine the on-line condition of a component is referred to as Comparative Thermography. This method of analyzing thermal images (Thermograms) utilizes reference or baseline data to determine a change in the observed component. To analyze a Thermogram using Comparative Thermography, a reference point must be identified. This reference point can be a spot on the piece of equipment that should exhibit similar thermal characteristics, to a spot on a component being analyzed. Thermal characteristics of the reference point are then compared to thermal characteristics of the component being analyzed, and an assessment is made. Baseline data would be used in the same fashion except that initial baseline data would be compared to subsequent survey data.

Depending upon the nature of the component(s) being analyzed, comparative analysis of thermal images can be done quantitatively or qualitatively. To analyze a thermogram quantitatively, the numerical temperature value of the reference point must be compared to the numerical temperature value of the component being analyzed. With this data, a temperature rise (increase) or fall (decrease) is calculated and a severity classification is assigned. A good example of quantitative analysis would be comparing the actual temperatures between "A", "B", and "C" phase connections on an electrical breaker to determine if a temperature difference exists between the phases; and, if so, how much of a temperature difference so that the severity of the anomaly can also be determined.

A qualitative analysis of a thermogram does not require temperature measurement. The reference point is compared to the component being analyzed by observing the thermal pattern of the image, such as cold coal pipe versus a warmer coal pipe indicating some type of blockage or improper valve line-up; whereas, the amount of temperature change between the two coal pipes is not as important as the fact that there is a temperature difference. In summary, some applications require numerical data to determine the severity of a deficiency and some applications do not require numerical data to determine the severity of a deficiency, just comparisons.

Comparative IRT using quantitative or qualitative data techniques can be used to identify these various conditions. To analyze a thermogram using Comparative Thermography, a reference point must be identified. A reference point is a spot on a piece of equipment that should exhibit similar thermal characteristics to a spot on the component being analyzed. Thermal characteristics of the reference point are then compared to thermal characteristics of the component being analyzed, and an assessment is made.

It is recommended that a list be prepared of all components included in the periodic IR surveys. It is expected that components and sub-components may be deleted or added to the list, as the IR Thermographers become more experienced and knowledgeable of the benefits of the thermal profiles.

3. Thermal Losses

Energy Conversion

During the energy conversion process, IRT application attention will initially be given to detecting any losses incurred while converting the fuel to thermal energy. Most of the IRT work completed to date in this area has been on the boilers of fossil plants. It must also be kept in mind that the IRT techniques and procedures presented herein are equally applicable to both fossil and nuclear plants with the exception of fuel applications.

Survey Purpose

The purpose of a prime energy conversion IRT survey is to use temperature data to determine the on-line condition of equipment and to identify potential problems prior to failure as applied to the various types of components. In the case of boilers, the equipment surveyed should include: all system sub-components (i.e. all applicable safety-relief, drain, and bypass valves; boiler casing/insulation; coal piping; back pass ductwork and expansion joints; steam supplied soot blowing system popit valves; and, possibly, internal boiler tube walls and burners). It is recommended that an experienced IR Thermographer, and a person with extensive knowledge of the sub-components being surveyed, perform the IRT surveys on a quarterly basis. The quarterly inspections are recommended due to the IRT technology not being routinely utilized on applicable boiler sub-components. Anomaly detection should remain high during the implementation phases of the boiler inspection; however, after 12 to 18 months from the initial implementation, and as the amount of findings per quarterly survey begins to diminish, the frequency of surveys can be reduced to three times, or even twice, a year as determined by the Boiler Inspection team.

4. Internal Boiler Applications

Fossil fuel power plant boilers operate continuously for months at a time, typically shutting down only for routine maintenance or to address serious equipment failures. These shutdowns are very costly, and diagnostic tools and techniques which could be used to minimize shutdown durations and frequencies are highly desirable. Due to the extremely hostile environment in these boilers, few tools exist to inspect and monitor operating boiler interiors.

The application of IR thermography for external and internal leaks and heat losses is established technology. To apply IR thermography to the study of burner flame performance has also been done with IR cameras mounted on inspection ports, and these techniques are equally documented. To perform IR surveys internal to the boiler, however, is a unique application.

Because of the high temperature environment inside a typical power plant fossil-fired boiler, between 1200°F and 2400°F (649°C and 1316°C), it is recognized that the IR tools would be exposed to those temperatures and will have to withstand them for a specified time, in order to obtain meaningful data. The data is stored in the form of continuous tapes and thermograms.

In addition to the high temperatures, the interior boiler action also includes contaminating particles, especially in coal-fired boilers, that can affect the ability to obtain clear thermal images. IR does not penetrate many materials, and the by-products of combustion causes attenuation of the viewing and temperature measurement capabilities. Research in this area is ongoing.

5. High Temperature Lens (HTL)

The EPRI M&D Center developed a High Temperature Lens (HTL) that can be inserted in a high temperature boiler and produce images. Since boiler access ports are available, HTL actually penetrates the boiler casing, with the thermographic camera placed outside the boiler, and therefore out of the high temperature environment. Two different HTLs are available for boiler flame performance evaluations, passive cooling and active cooling.

Passive Cooling

The passive concept utilizes highly polished and highly conductive materials that reflect and transfer the heat to the outside lower temperatures and thus keep the lens cool. The length of time that the lens can operate inside the boiler is dependent on the location; closer to the flame, shorter is the time (10 minutes to hours).

In the passive cooling design, the HTL shown in Figure 1 is attached to the radiometer which is covered with a protective metal enclosure. Figure 2 is the Alpha version HTL. Note that Figure 1 has a lens cover at the tip of the lens, a radiant shield, and a newly designed coolant fin system. Access ports are located along the walls of the boiler making it convenient to enter the boiler and view the interior from the outside. The access ports are as small as 2 inches in diameter, which controlled the design of the borescope snout. The snout is 2-3/8” in diameter, which allows it to fit in all but the smallest access ports.

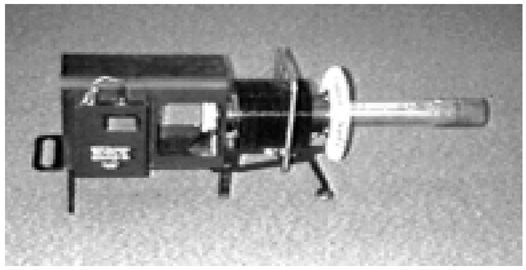

Figure 1: HTL (Beta Version)

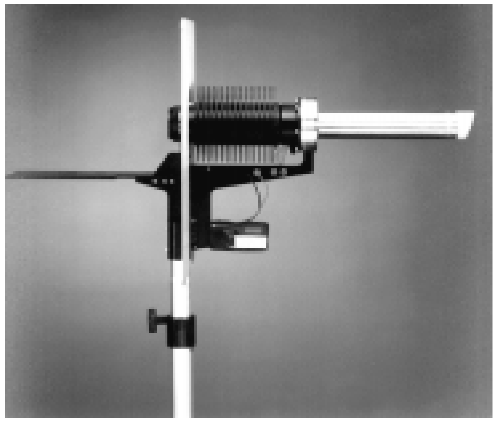

Figure 2: HTL (Alpha Version)

Active Cooling

The active cooling HTL is shown in Figure 3. In this design the cooling scheme utilizes vortex tube coolers and the plant air supply to maintain the lens at an acceptable temperature while inside the boiler.

Figure 3: Active System

6. Thermograms of Internal Boiler Components

Examples of surveys using the High Temperature Lenses in the boiler are illustrated in Figures 4 and 5.

A thermal profile of the inside of a boiler looking down from above (Figure 4) identifies flame impingement toward the lower right hand corner wall section. The image was taken with a High Temperature Infrared Lens from an inspection port in the boiler roof, while the unit was on line at full load.

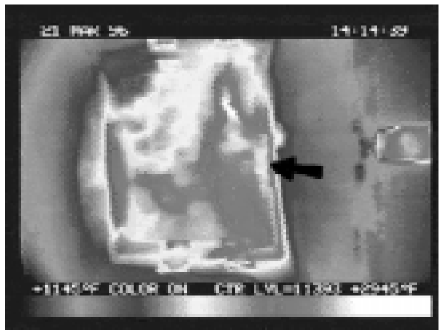

Figure 4: Thermal Image of Boiler Wall Flame Impingement – Top view

Another example of boiler wall flame impingement is shown in Figure 5. The High Temperature Lens looks through an observation port in a side wall across the boiler to the opposite wall. The thermal image serves as a good visual representation of the section of waterwall and it highlights the affected area.

Figure 5: Thermal Image

The thermal image, Figure 6, was taken during an inspection of the superheater section of a gas/oil-fired boiler. This data has contributed significantly to the effort of balancing temperatures by adjusting operating conditions (e.g. air flow, burner position, etc.). Figure 7 is the graph of the points intersected by the horizontal traverse that is superimposed on the thermal image.

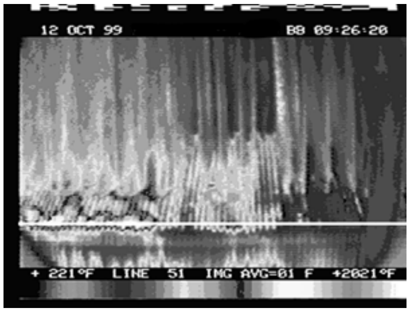

Figure 6: Thermal Image of Superheater Tubes

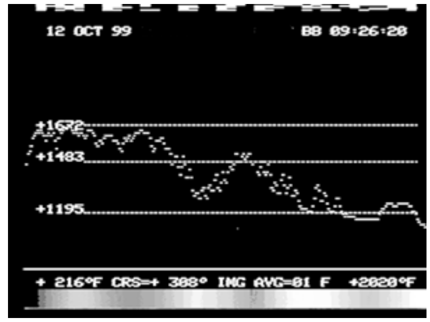

Figure 7: Graph of Thermal Image

7. External Boiler Applications

External boiler component and sub-component problems detectable using IRT include: Leaking safety, drain, or bypass valves; boiler insulation deterioration; restricted flow through coal piping; boiler casing air-infiltration or ex-filtration leaks; back pass ductwork and expansion joint leaks; steam supplied soot blowing system popit valve leaks; and, possibly, internal boiler tube wall and burner anomalies. Several examples included in a typical boiler IR survey, including thermograms follow.

Boiler Drum Safety Relief Valve

The Boiler Drum Safety Relief Valve (SRV) of Figure 8 indicates higher temperatures on the downstream exhaust piping as compared to the SRV in Figure 9. This measurement of higher temperature on the downstream exhaust piping is an indication of steam passage through the right SRV, probably due to a deteriorated valve seat. The valve should be inspected at the next opportunity and repaired as necessary. All applicable boiler SRVs should be surveyed using IRT.

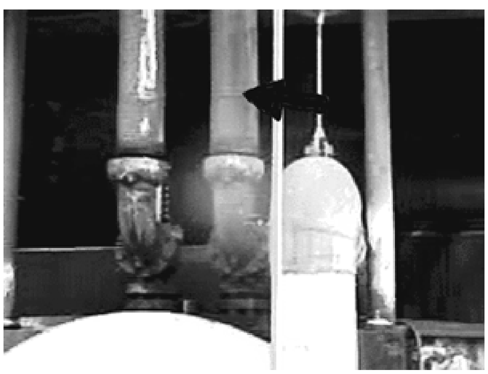

Figure 8: Visual of SRV

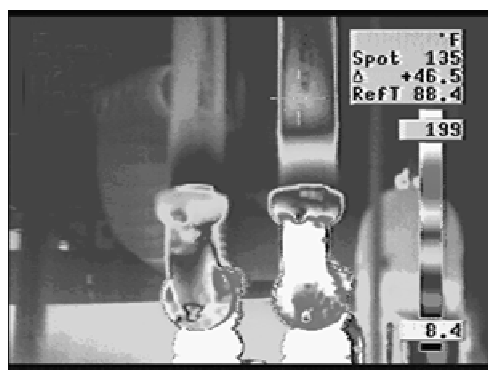

Figure 9: Thermal Image of SRV

Boiler Drain Line Isolation Valves

Boiler drain lines (Figure 10) usually run parallel to the boiler itself, with double isolation drain valves somewhere in-line. These drain valves are usually closed; therefore, any trapped steam in the drain line will condense and become a column of water. That column of water will then cool to ambient temperature and remain at ambient temperature until the valve is opened. Therefore, during normal operation of the boiler, any uninsulated drain line piping or drain valve bonnets should indicate ambient temperature. If valve bonnets indicate temperatures higher than ambient, like the valve shown in Figure 11, it is a strong indication of leaking drain valves.

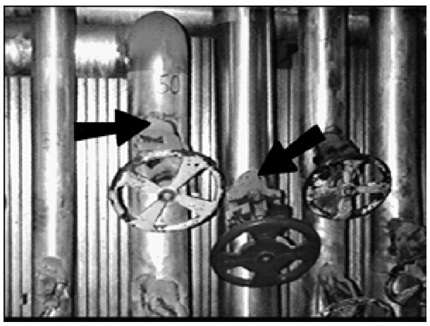

Figure 10:Visual of Drain Valve

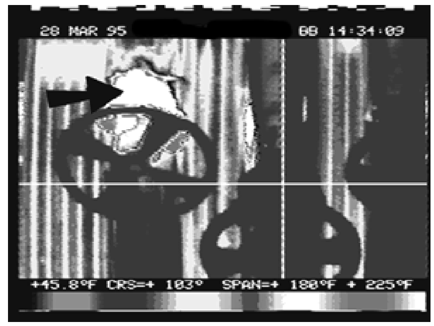

Figure 11: Thermal of Drain Valve

Boiler Mud Drum (Belly) Drain Valves

A visual image of a belly drain line and valve is shown in Figure 12. When viewing the thermal images, Figure 13 is a boiler mud drum (a.k.a. belly) drain line and valve that is indicating a normal thermal pattern, i.e. downstream piping from the double isolation valves is measuring ambient temperature. Figure 14 is a boiler mud drum drain line and valve that is indicating an abnormal thermal pattern, i.e. downstream piping measuring temperatures significantly higher than ambient. (NOTE: Caution must be taken to make sure that downstream piping is not indicating elevated temperatures due to possible back flow from another leak throughout the boiler drain system piping.)

Figure 12: Visual Belly Drain Line and Valve

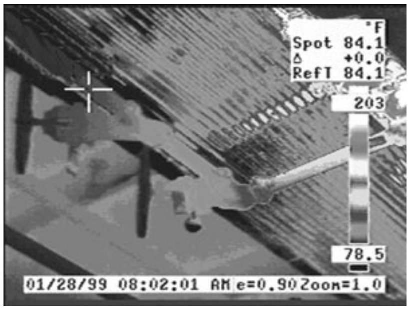

Figure 13: Thermal Normal Pattern

Figure 14: Thermal Abnormal Pattern

Boiler Air-in Leakage

IRT can detect air-in-leakage through voids into a balanced draft (negative pressure) boiler. The visual image of Figure 15 shows a boiler manway cover. The thermal image (Figure 16) displays a pattern that would indicate air infiltration through the upper left-hand side of the manway. The manway cools toward the upper left indicating a draft of air across the cover. If there were no air infiltration, the entire manway cover would be uniform in temperature. Undesired infiltration of air into a boiler will impact the thermal efficiency of the unit, and impact its ability to maintain vacuum.

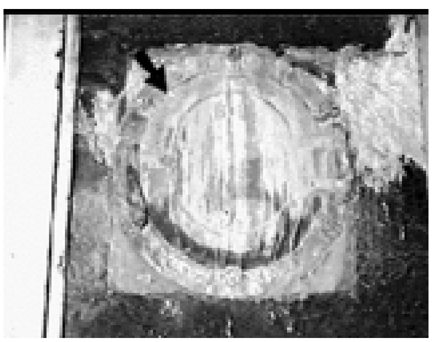

Figure 15: Visual Boiler Manway Cover

Figure 16: Thermal Image

Boiler Insulation Deterioration

The thermal profile of this section of the boiler casing/lagging shown in Figure 17 indicates that there is missing or deteriorated insulation behind the lagging at the spots where the temperatures are the highest. If insulation problems are suspected on a particular unit, IRT can be used in the manner shown in Figure 18 to inspect entire sections of wall, literally in seconds. Deteriorated insulation is not one of the more costly effects on performance; however, high ambient temperatures caused by insulation deterioration can cause local instrumentation problems and an unpleasant work environment and safety hazard.

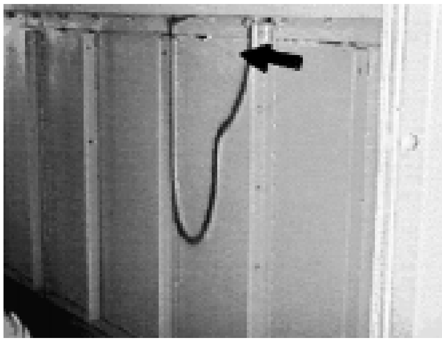

Figure 17: Visual of Boiler Casing

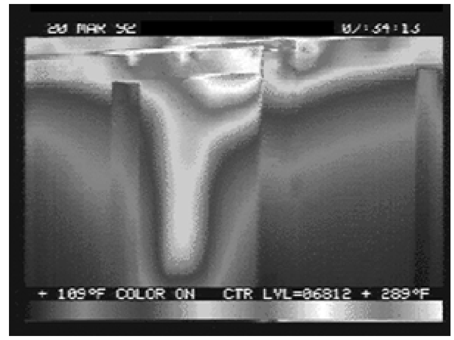

Figure 18: Thermal Image

Boiler Tube Restriction

The thermal image shown in Figure 19 was taken from the inside of a mono-tube boiler during a hydro flush test prior to unit start-up. The picture isolates a section of the water-wall. When the boiler is filled with 200°F (93°C) water during the course of this test, all of the tubes should rise in temperature uniformly from ambient to approximately 200°F (93°C). If there is a restriction that prohibits flow in one or more tubes, there will be an effect similar to the one in the thermal image below. The arrows point to a single cold tube that is unable to fill because of a restriction (probably slag from welds made during water-wall replacement or repairs). A restricted tube will not receive the cooling it needs from the flow of water through it. If it goes undetected, it will probably rupture at a point in time after the unit is brought on line. This would cause unscheduled downtime and associated costs. The tube needs to be cleared and re-inspected prior to unit start-up.

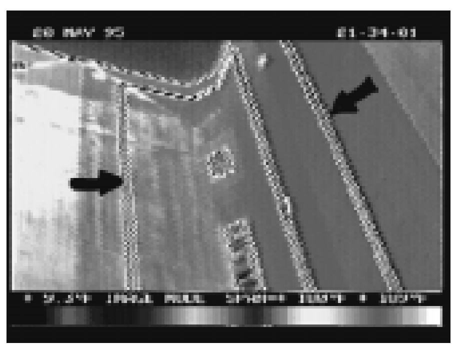

Figure 19: Thermal Image

Obstructed Fuel Line

These four coal fuel lines (coming off of the same pulverizer mill), shown in Figure 20, are carrying pulverized coal for combustion from the mill exhauster to the burners at the boiler. The thermal image, Figure 21, indicates that the 3rd fuel line from the left is cooler than the other three lines by approximately 20-30 Degrees F (-6°C to -1°C). Warm primary air (~160°F or 71°C) is circulated through the fuel system to increase combustion efficiency and will naturally warm the fuel lines. The relatively cool fuel line in this example indicates that there is limited, or completely obstructed, flow in this line. This will prohibit the necessary fuel from reaching the burners. The obstruction could be anywhere in the line, or in a diffuser. The line should be blown clear at the next opportunity.

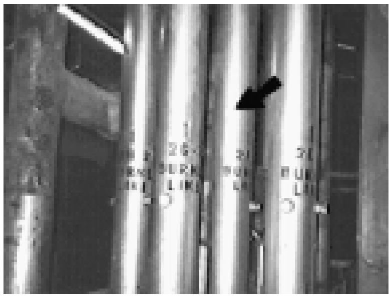

Figure 20: Visual Image

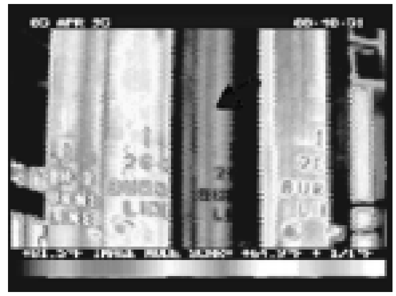

Figure 21: Thermal Image

Steam Supplied Soot Blowing System Popit Valves

The popit valves on steam-supplied soot blowing systems seal off steam flow to the soot blowers (Figure 22). When soot blowers are not activated, the thermal pattern of a normally operating popit valve will indicate a good steam seal in the form of a uniform line of temperature measurement, as in the thermal image, Figure 23. If the popit valve's thermal pattern appears like the thermal image, Figure 24, it is a good indication of a leaking popit valve.

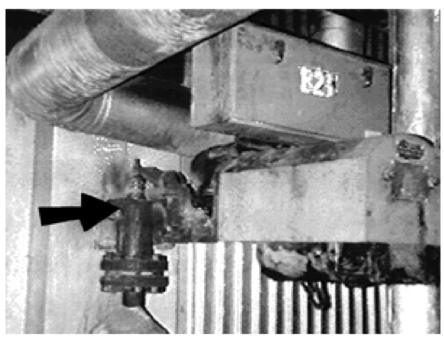

Figure 22: Visual Popit Valves

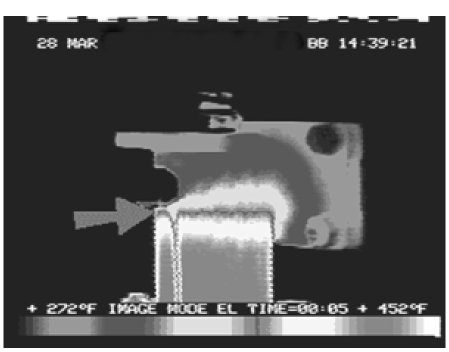

Figure 23: Normal Thermal Pattern

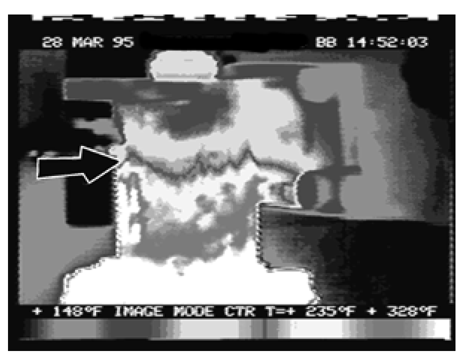

Figure 24: Abnormal Thermal Pattern

8. Steam Path Losses

During the energy conversion process water is also converted to steam; and, the steam process in a power plant involves another myriad of equipment including the turbine(s), piping, heat exchangers, cross-overs, re-heat systems, steam traps, and a host of valves and auxiliary components, all a source of thermal loss.

Here again, IR thermography is being utilized more and more in power plants to determine where these thermal losses (heat and steam) are occurring, and what should be done to correct them. The corrections range from heat insulation concerns to steam leaks from pumps and valves.

In heaters, or re-heaters, in many cases the problem is also more of a performance efficiency loss due to clogged or by-passed tubes, rather than leakages, and does not contribute directly to thermal loss management. However, because the application of IR thermography can reveal these anomalies, it is considered an added bonus to improving the overall efficiency of the plant.

The following are examples of energy losses in the steam path.

The main steam relief valve shown in Figure 25 is normally closed during plant operation. It has two un-insulated outlet headers (see arrows on visual and thermal images). Referencing the color scale at the bottom of the thermal image (refer to Figure 26), the temperatures measured on the left outlet are approximately equal to the ambient temperature (75°F to 100°F or 23.8°C to 37.8°C). The temperatures measured on the right outlet header are consistently hotter. This is an indication of steam passage through the right side of this valve, probably due to a deteriorated valve seat. The valve should be inspected at the next opportunity and repaired as necessary.

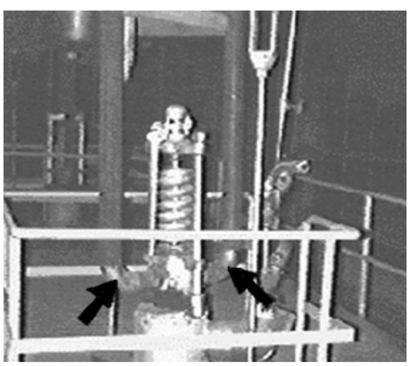

Figure 25: Visual of Main Steam Relief Valve

Figure 26: Thermal Image

A steam trap that exhibits a similar temperature on the heat exchanger side (bottom), and on the outlet side (top), is passing steam (Figure 27). That is the case here, where a temperature in excess of 600°F (315.6°C) is measured at both points (Figure 28). Thermography alone can identify this type of problem. However, in many cases, other diagnostic tests can be used in order to evaluate the overall condition of a steam trap to verify that condensate and air are being vented properly.

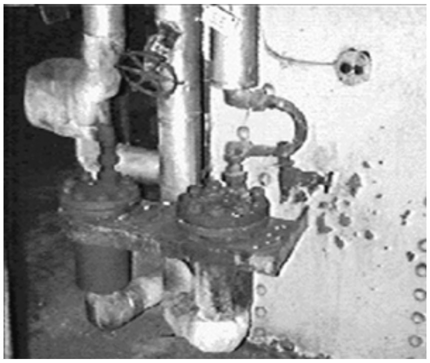

Figure 27: Visual of Defective Steam Trap

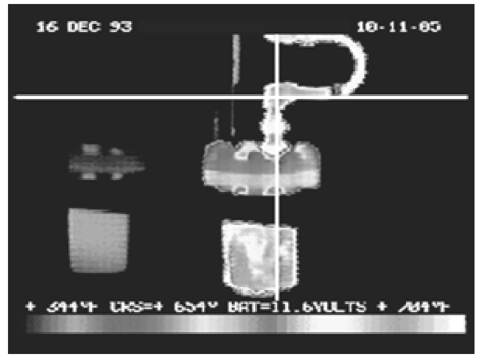

Figure 28: Thermal Image

Visual Image, Figure 29, shows a section of cement floor in a power station. A thermal image of this same section of floor (Figure 30) was taken during an IRT inspection in an attempt to try to determine the approximate location of a steam leak in a header somewhere beneath the floor. It was suspected that the hot spot on the thermal image was caused by heat transfer from the steam leak to the surface. An excavation of the floor revealed a ruptured Y-Joint in the pipe (Visual Image Figure 31). The header was repaired and the floor was replaced. A re-inspection of the floor, performed after the repairs were made and after the unit was put back into service (Thermal Image Figure 32), does not show a hot spot and indicates that the problem has been corrected.

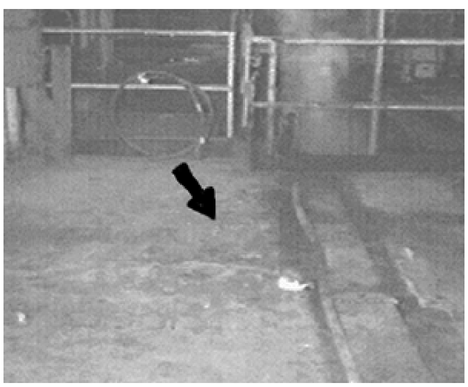

Figure 29: Visual of Cement Floor

Figure 30: Thermal Image of Floor

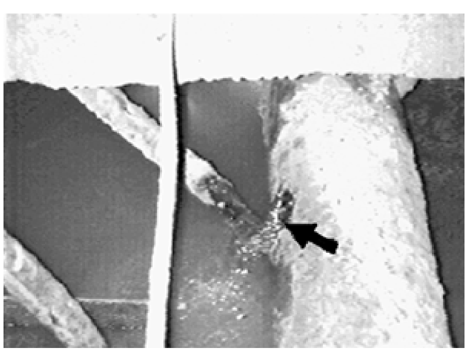

Figure 31: Visual of Ruptured Y-joint

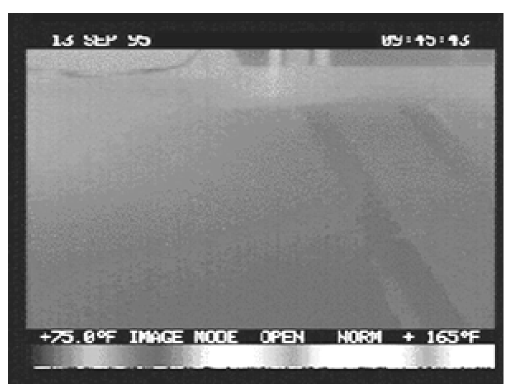

Figure 32: Thermal of Floor After Repairs

9. Condenser Air In-Leakage

The IRT Condenser Air In-Leakage surveys that were part of the Advanced Leak Location-Research Evaluation Demonstration project were strictly qualitative in nature. The study was an investigation of the condenser exterior, its penetrations, and the associated equipment that is under a vacuum.

The areas under investigation included:

- Condenser (box, turbine to condenser boot, and penetrations).
- LP Turbine (LP turbine shell including rupture diaphragms, man-ways, and flanges).
- Steam seals.
- Instrumentation sensing lines.
- Extraction lines.
- Valves.
- Condensate Pump - Suction Side (flanges, shaft seal, instrumentation sensing lines and valves).
- LP Feedwater Heaters (shell side).
- Air Removal Systems (vacuum pumps, steam jet air ejectors, and hoggers).

Study Summary

Condenser air-in leakage, as seen through the IRT camera, appears as a cool area surrounding a void. The void can be found through the convective effects on the surface surrounding the opening, when the surface of the component being viewed has a differential temperature from the ambient. If the component surface and ambient temperatures are similar, the area will go undetected using IRT. One of the characteristics of a vacuum leak is that the amount of air being drawn through the opening will change as the internal processes change. For example, as the condenser water level fluctuates, so will the amount of air infiltration. This change can be seen in motion as the surface area being cooled from the convective effects increases and decreases with the process. However, the change in air flow happens quickly; therefore, in most cases the image averaging mode is required to view the change.

Identifying the condenser air-in leakage requires equipment that can distinguish very small temperature differences (tenths of a degree).

The IR equipment and its specific features that assisted in finding the voids included:

- Color monitoring of the IRT images
- IRT image averaging
- Video tape recording and storage of IRT images

Viewing the IRT images in color provides assistance in finding small leaks, as opposed to trying to distinguish them in shades of gray. In most cases, small leaks could not be seen using the gray scale. Some IRT equipment offers an image averaging mode. This mode permits multiple scans, laying image over image, of the component being viewed and then displays the averaged image on the monitor. When an image is averaged in such a manner, it appears to be in slow motion. This is a unique procedure for viewing and verifying a leak, as were the convective changes affected by the process changes (i.e., condenser water level fluctuations could be seen on the component's surface). In some cases, the process changes occurred so rapidly that the changing could be seen only by using the image averaging mode. Recording air infiltration in motion, therefore, was instrumental in verifying the leak, as well as providing instructional value.

Various distances were used to view the condenser air-in leakage using the IRT camera. In general, the closer the IRT equipment was to the component, the better the results. Items such as valve packing, shaft seals, instrument sensing line fittings, and sight glass fittings would be scanned at a maximum temperature range of 4° to 9°F (2° to 5°C), at a maximum distance of 36 inches (91cm). The suspected area would then be verified using the image averaging mode and placing the camera within inches of the suspected area. For items that were not accessible at a short distance, such as the turbine to condenser boot, the Thermographer should use a zoom lens to get the closest view possible.

Interpretation of Findings

As mentioned previously, the IRT Condenser Air-In Leakage surveys that were part of the Advanced Leak Location-Research Evaluation Demonstration (ALL-RED) Project were qualitative in nature. The surveys verified that the IR techniques applied were effective for locating air-in leakage to the condenser under proper conditions; however, there are limitations. The strengths and weaknesses are summarized as follows:

Strengths

- The method works well for examining large components such as: manways, flanges, expansion joints, shaft seals, and valve stem packing and gaskets.
- The method works well for examining hot areas such as team jet air ejectors, LP Turbine gland seals, turbine expansion joints, traps, and steam piping.
- The method works well for areas that are not easily accessible with either the helium or SF6 methods.
- The thermography technique complements the gas technique well once a general location is identified. Individual components may be inspected without getting false indications from surrounding components.
- The method can be used to confirm leaks found with the standard methods.
- No outside support is required from other departments, as this is a non-intrusive inspection method.
- Some of the identified leaks with this method can be verified by the temperature changes of the void from the system process changes.

Weaknesses

- The application of this method is difficult to apply to ambient temperature components.
- Speed of inspection can be relatively slow for small components. This delay may not conform to the desired plant schedule for the entire vacuum system.

- Due to the physical location of some plant equipment, the inspection can be difficult.
- Some of the identified leaks with this technique required additional leak verification methods.

10. Recirculation System

The recirculation system consists of returning the condensate back to the boiler and adding make-up water, if necessary. This system begins with the condensate pumps, pre-heating the condensate and make-up water with feedwater heaters, and then supplying the water to the boiler feedpumps which then push the highly pressurized water into the boilers to be reconverted to steam. All of these components, plus their associated piping, valves, and drains are the sources of leaks and therefore heat loss.

Condensate Pumps

Although the suction side of condensate pumps are at low pressures and low NPSH, their discharge pressures and related valves are a source of water leaks. During a survey of condensers and condensate pumps, the M&D Center found the anomalies shown in the following thermograms.

This condensate pump motor, Figure 33, exhibited increased temperatures (173°F or 78.3°C) on the casing (Figure 34) when compared to another motor of the same design and function. An investigation into this anomaly revealed that this motor was being overloaded with respect to its designed amp rating. The motor should either be operated within specification, or replaced with a larger unit designed to handle higher current loads. An internal inspection of the motor should be done in order to assess possible damage sustained by the equipment from being exposed to conditions of excessive heat over extended periods of time.

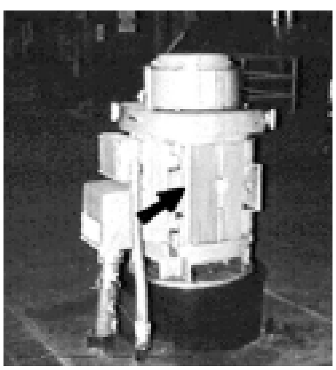

Figure 33: Visual of Condensate Motor

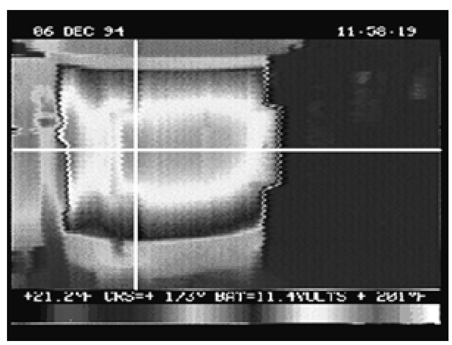

Figure 34: Thermal Image

A baseline thermal image of this Dry Vacuum Pump is shown in Figure 35. Five months after this baseline image was taken (Figure 36), a subsequent inspection revealed the results shown in Figure 37. Hot spots were beginning to develop at areas near the bottom of the pump. Operations reported that they were not receiving the expected performance from this piece of equipment. An investigation into the problem revealed that the pump was becoming clogged with mud and sludge in the cooling water system causing the internal valves to overheat. The system needed to be flushed. After the system was flushed, the hot spots faded and pump performance returned to an acceptable level (Figure 38).

Figure 35: Visual Image Dry Vacuum Pump

Figure 36: Baseline Thermal Image

Figure 37: Thermal Image of Anomaly

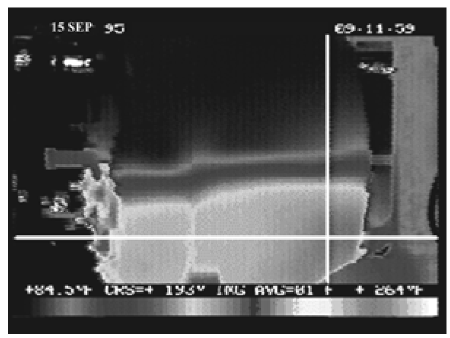

Figure 38: Thermal Image of Corrected Pump

An IRT inspection of an expansion joint, Figure 39, on a large header at the suction side of a condensate pump reveals air infiltration. This is indicated on the thermal image (Figure 40) by the blue areas to the left of the arrow. The color scale on this thermal image is designed to show blue to indicate temperatures that are below the low end scale value (32.9°C or 91.2°F). As mentioned in the example of the boiler, air-in-leakage normally manifests itself as a relatively cool area with respect to the surrounding temperatures.

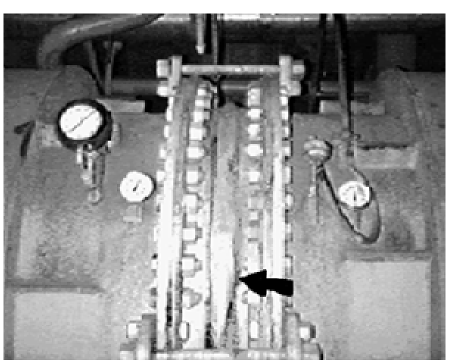

Figure 39: Visual of Expansion Joint

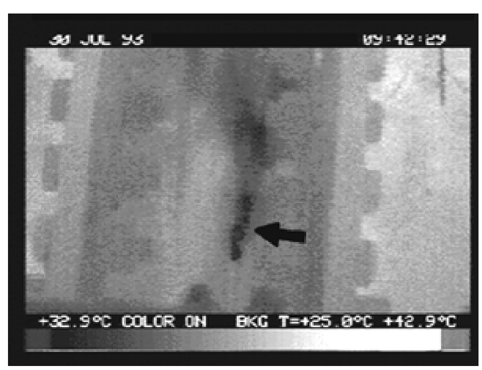

Figure 40: Thermal Image

Feedwater Heaters/Heat Exchangers

Feedwater heaters are used to improve the overall power plant cycle efficiency and to raise the feedwater temperatures to a sufficient level to avoid thermal shock to the boiler metal. Low pressure feedwater heaters actually raise the temperature of the recirculation water before it enters the boiler feedpump; and, high pressure units raise the temperature of the water even further at the boiler feedpump discharge pressures, just prior to entering the boiler.

The heating medium is steam and the pressures can be 3,000 to 4,000 psi (20,670 to 27,560kPa); therefore, the heaters and their auxiliaries are very vulnerable to external steam/water leaks. Leaks can occur due to casing cracks, valves, piping, drains, etc. Typical feedwater heater thermograms follow.

The visual image (Figure 41) shows a feedwater heater relief valve with hot pressurized steam at the bottom, or shell side, and the outlet side on the right. A defect exists which was determined by comparing the temperature of the valve at the shell side (approximately 500°F or 260°C), to the temperature of the valve outlet (394°F or 201°C indicated by the crosshairs). The combination of a 106°F (41.1°C) temperature differential, and an extremely hot outlet temperature (394°F) is an almost certain indication that the valve is passing a considerable amount of steam. In the two thermal pictures, the defective valve is shown in Figure 42. The temperature contrasts between the replacement valve and the defective valve are dramatic. In the thermal image of the replacement valve (Figure 43), the shell side valve temperature is approximately 450°F (232°C). Comparing this with the outlet temperature of 141°F (60.6°C) [refer to crosshairs], the temperature differential is now in excess of 300°F (148.9°C). The temperature differential between the old valve and the replacement valve is over 200°F (93.3°C). This assures that the problem has been corrected. Additionally, the thermal image of the replacement valve provides baseline information for the PDM Group to use to trend this new valve over time.

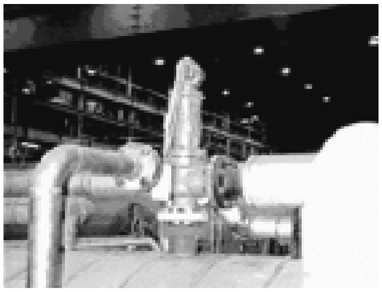

Figure 41: Visual Feedwater Heater Relief Valve

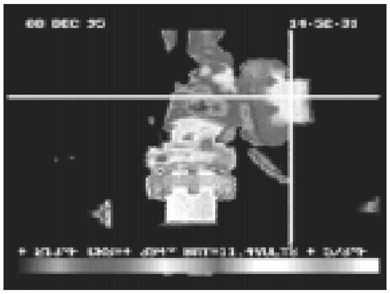

Figure 42: Thermal Image Showing Defect

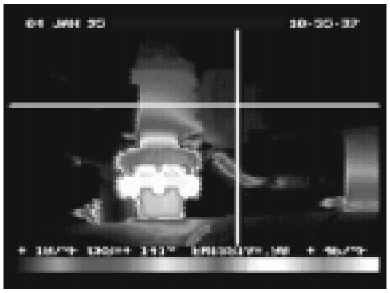

Figure 43: Thermal Image After Correction

Boiler Feed Pumps

Boiler feed pumps (Figure 44), because of their high pressure operation, are subject to seal leaks and piping attachment leaks. Early detection of these leaks have a tremendous impact on maintenance and maintenance planning. Leaks are generally not self-correcting; therefore, the detection of leaks can be made with IR thermography, and sometimes acoustics, long before they are detected by other means such as audio or visual.

An example of a water/steam leak as detected by IR is shown in the following thermogram. The thermal image, Figure 45, illustrates an extremely high temperature on the surface of insulation on a high pressure boiler feed pump. The high temperatures of the water flashing to steam is able to saturate the insulation through to the surface where it is detectable with IRT. The thermal image, Figure 46, was taken after repairs were completed.

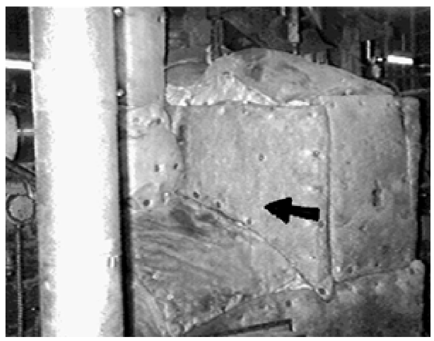

Figure 44: Visual Image of Boiler Feedpump

Figure 45: Thermal Image of Defect

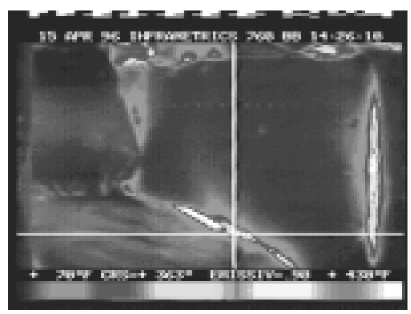

Figure 46: Thermal Image After Corrected

11. IRT Training

Initial quarterly survey intervals should be contracted until IRT equipment is procured and plant personnel are trained. The IRT Technology Owner(s) should be trained in accordance with ASNT Levels I and II Curriculum Training. This training provides a strong knowledge of the technology and will help ensure proper generation and interpretation of IRT reports. The Performance Engineer should also be trained in Levels I and II curriculums to maximize the application of IR Thermography in heat loss (performance) applications. The IRT Technology

Owner(s) should receive 3 to 6 months of On-the-Job-Training (OJT) using an IR camera in the field prior to attending Level I training, and another 6 to 9 months prior to attending Level II training. This allows for the Technology Owner(s) to develop insight about the technology and how it is applied in the field. It is also recommended that trainees use their own utility cameras during the course, to enhance familiarity with the use of their IR Thermography equipment.

12. EPRI M&D Center Courses and Certification

The M&D Center offers Levels I, II, and III IR Thermography courses. It is recommend that students take the Level I course to be eligible for the Level II course, and both Levels I and II before taking the Level III course.

These five-day courses are taught by experts in IR Thermography who have developed unique data acquisition techniques and have accumulated a statistical base of information from almost 10,000 Thermographic surveys. The courses are structured according to the recommended training by the American Society of Non-Destructive Testing (ASNT) for Thermal/Infrared Testing.

They cover the physics, equipment operations, and application knowledge needed to analyze data and recommend solutions. The Levels I and II courses are intended to teach practicing Thermographers what they need for Certification. A self-graded exam is given at the end of each of the courses. The Level III course is designed to instruct the attendees on the qualifications needed for certification of Levels I and II. The attendees passing this course can become certifiers of Levels I and II, if a utility has an IR certification program.

Since the Level I and II courses meet the general training requirements for the ASNT Level II Thermal/Infrared Testing Certification, attendees can receive Certification from their own utility, if available. As an option, the attendees can obtain M&D Thermography Certification at any level by attending the 40-hour course, by passing the test given at the end of the course, and by demonstrating an acceptable level of experience in IR Thermography. There is an additional charge for Certification; and, those interested can obtain a copy of the EPRI M&D Center Certification requirements on request.

13. Cost Benefits

The M&D Center has conducted numerous Predictive Maintenance Assessments for many of the EPRI Member utilities. Follow-on activities currently in process are providing these same utilities with assistance in the implementation of their Predictive Maintenance programs. The financial benefits of PDM programs and the application of PDM technical tools are now recognized as being substantial, and these savings are made more apparent when they are calculated and documented. The reason it is extremely important to document these benefits is because they demonstrate to management the advantages that can be gained by purchasing and applying PDM tools. Documented cost benefits provide the justification for making the decision to invest in PDM, and for management to provide continued support.

Even though vitally important, M&D realizes that the calculations of cost benefits of a PDM program, or of a particular technology such as IR Thermography, are sometimes difficult for technical personnel who are occupied with getting the work done, to find the time to make the analysis. As a result, the M&D Center has developed a computer program to help make the calculations and documentation of benefits much easier. This program is called “Cost Benefit analysis Guide for Predictive Maintenance Program Findings”. It is an MS-Excel Spreadsheet entitled “cba.xls”; and, it is available from the M&D Center on diskette.

IRT Cost Benefit Analysis

The way that the cost benefit program works is that once an anomaly is suspected, verified by thermography, and corrective action has been taken, the IR Thermographer (in these cases) enters the information on the first page which is the Occurrence Assumption Worksheet. The information entered in the first three columns are ‘best estimates’ of what might have happened if the incident had gone undetected and failure actually occurred, for each of the possible severity levels which are: SEVERE, MEDIUM, and LEAST. Definitions of each are:

- (Scenario #1) Most Severe Event – There is no PDM program. The situation goes undetected. The motor fails and is destroyed. There is a 50 Megawatt forced power reduction for 2 weeks in order to have a new motor installed.
- (Scenario #2) Medium Severity Event – There is no PDM program. The situation goes undetected. The motor fails. There is a 50 Megawatt forced power reduction for 1 week in order to complete repairs to the motor.
- (Scenario #3) Least Severe Event – There is no PDM program. The situation is detected by conventional means. The air restrictions were eliminated and minor repairs are made.

Complete details and procedures for using cba.xls and conducting a comprehensive cost/benefit analysis can be found in EPRI publication TR-111916, “Infrared Thermography Anomaly Assessment”.

14. Reporting

The EPRI M&D Center recommends that a published Temperature Differential Severity Guideline be agreed upon up front by all of the PDM Project team members. The M&D Center also recommends that all serious/critical severity ratings should be reported the day they are found on a pre-agreed “Occurrence Report” form, to be followed up by the Comprehensive IRT Report with Thermograms and visual photos within 1 to 2 weeks of the survey.

The standard IRT report should include the following sections:

- “Cover Sheet”, identifying Where the survey was performed, What the survey was performed on, Who assisted and performed the survey, and When the survey was done.
- “Executive Summary or List of High Priority Exceptions”, in which all serious and critical findings can be quickly and easily identified, and which is useful for identifying items requiring immediate attention,
- “Introduction” section, which includes a general severity guideline classification, and definitions of common terms used with respect to infrared technologies,

- “List of Thermal Images” section to identify all thermal images (i.e. Thermograms) taken during the survey,
- “Equipment List” that lists all equipment surveyed (i.e. electrical, mechanical, performance, etc.) during the survey,
- “Data Sheets” which include the thermal and visual images, detailed descriptions of the findings, the probable causes, recommendations, any necessary process data, any comments related to the finding, etc.

15. Infrared Thermography Library

The EPRI M&D Center has developed many applications of IR thermography technology; and, thermal anomalies have been identified in every application and substantial benefits have been recognized. An Infrared Thermography Library is planned which will organize the significant quantities of knowledge and experiences that the M&D Center has acquired since its inception. This Library will feature a technology overview including image interpretation, methods of analysis, and instrument classifications. Specific applications will be included along with thermal and visual images that illustrate these applications. Chronological case histories will document specific anomalies that were detected and the related concerns, recommendations, results, conclusions, and cost benefits. As new IR applications are developed they will be added to the Library, and the updated Library will be available to all participating EPRI Target members.

16. Additional Reading

- EPRI Report, TR-111916, “Infrared Thermography Anomaly Assessment”
- EPRI Report, TR-109529, “Infrared Thermography Developments for Boiler, Condenser, and Steam Cycle”
- EPRI Report, TR-108935, “Infrared Thermography Anomalies Manual”
- “Radiometric Imaging of Internal Boiler Components Inside a Gas-fired Commercial Boiler”, SPIE Thermosense XX Conference, R. Hammaker et al., Orlando, FL, April 1998
- “Infrared Imaging of Fossil Fuel Power Plant boiler Interiors” SPIE Infrared Technology and Applications XX Conference, R. Hammaker et al., Orlando, FL, April 1997
- “An Evaluation of Internal Boiler Components and Gases Using a High Temperature Infrared (IR) Lens”, SPIE Thermosense XVIII Conference, R. Hammaker et al., Orlando, FL, April 1996
- “Advanced leak Location-Research Evaluation Demonstration (ALL-RED) Project”, SPIE Thermosense XVI Conference, R. Hammaker et al., Orlando, FL, April 1994
- “An Introduction to EPRI’s Infrared inspection Technical Evaluation (IRITE) Project”, ”, SPIE Thermosense XV Conference, R. Hammaker et al., Orlando, FL, April 1993
- “Predictive Maintenance Thermography Program Procedure”, Predictive Maintenance Guidelines, R. Hammaker et al., January 1993
- “the Role of Comparative and Qualitative Thermography in Predictive Maintenance Guidelines”, ”, SPIE Thermosense XIV Conference, R. Hammaker et al., Orlando, FL, April 1992

- "Thermography and Predictive Maintenance", 5th Predictive Maintenance Conference, R. Hammaker, Knoxville, September 1992
- EPRI Innovator, IN-101012, "Infrared thermography finds Hidden Defects in Plant Equipment", R. Hammaker, December 1992
- "Eddystone IR Thermography Program Manual", EPRI M&D Center project, ED#155555, R. Hammaker, December 1990
- EPRI Innovator IN-111720, "NYPA's Use of High-Temperature Lenses for Infrared Thermography Leads to Reduced Tube Metal Temperatures", June 1999

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EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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TE-114093

Printed on recycled paper in the United States of America

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