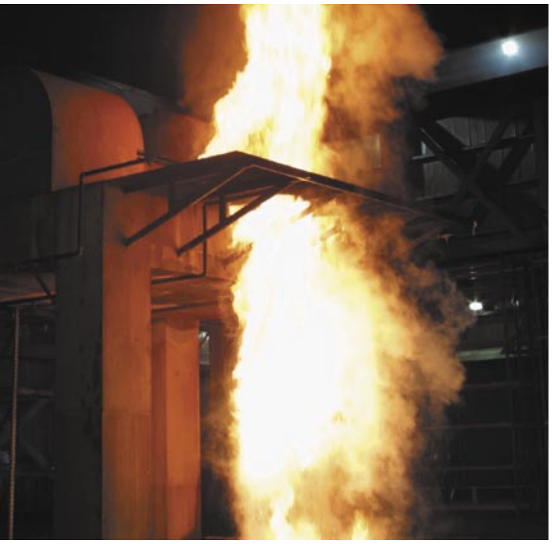
Turbine Generators: a Recipe For a Very Large Fire

What's the "main ingredient" in a turbine generator fire? A few hundred gallons (several hundred liters) of relatively low flash point mineral oil.



Put it under pressure and confine it within piping, seals or removable-opening covers. Then, provide an available "hot" surface—hot enough to ignite mineral oil…nearby steam piping or a turbine casing will do the job. Now, wait until a flange leaks, a pipe breaks, a seal fails or a cover is left off an opening—and you have a "recipe" for one of the largest fires you could ever imagine. And, if the oil is released in a spray, it could be even larger.

Has this recipe for disaster been tested? It sure has. During a recent 15-year period, 17 large turbine building fires resulted in more than US$400 million in gross loss. Lost generating capacity was in excess of 20 million MWh, which is roughly the equivalent of a mid-sized investor-owned utility in the United States. The average loss was US$24 million and the average outage was more than 24 weeks.

Fires involving turbine generators in non-utility facilities like paper mills and combined cycle power plants also were reported. Here's an example of what can happen when oil is released in a spray pattern:

A fire at a process pulp mill began when pressurized oil from a leaking control-oil system pipe sprayed onto hot steam piping. The control-oil line serviced a 37.5-MW steam turbine driving an AC generator. The fire was further fed by the oil that continued to flow, then spread to nearby cable trays. The fire caused extensive damage to critical power cables in the turbine-generator basement. The resulting loss to boilers and other equipment led to a total mill shutdown for more than four days. The gross loss was more than US$13 million, a large portion of which was lost business.

Lack of automatic fire protection in the fire area allowed the fire to spread. Fortunately, manual fire fighting, which is usually delayed due to smoke and heat, was able to prevent even more damage.

Operators also can initiate these types of events. Some of the routine maintenance involves working on pressurized systems—shifting and cleaning strainers, for instance. If the mechanic loses concentration and forgets where he or she is in the procedure, an oil release is possible. This example illustrates human error:

A 620-MW generator driven by a four-flow tandem compound steam turbine at a utility generating station sustained a lube-oil fire. The cause of the fire was failure to shut off, or bypass, the oil flow to the filters of the hydrogen-seal oil system while an employee was changing or cleaning the filters. Five bolts had been loosened on the second filter when the seal ruptured, releasing lubricating oil at 70 to 90 psi (5 to 6 bar). The lubricating oil spewed out of this opening, contacted hot piping and ignited. During the incident, the plant's other turbine generator was tripped and off-site power secured. This caused the operating electric fire pump to shut down.

Extensive damage occurred to the generator, the two LP-turbine sections, steam pipes, oil piping and isophase bus bars. The roof over the turbine generator sagged over a 10,000-ft.^{2} (930-m^2) area, pulling the walls inward approximately 5 ft. (1.5 m). The gross loss was in excess of US$44 million.

In this example, the ignited oil flowed downward, engulfing a large area:

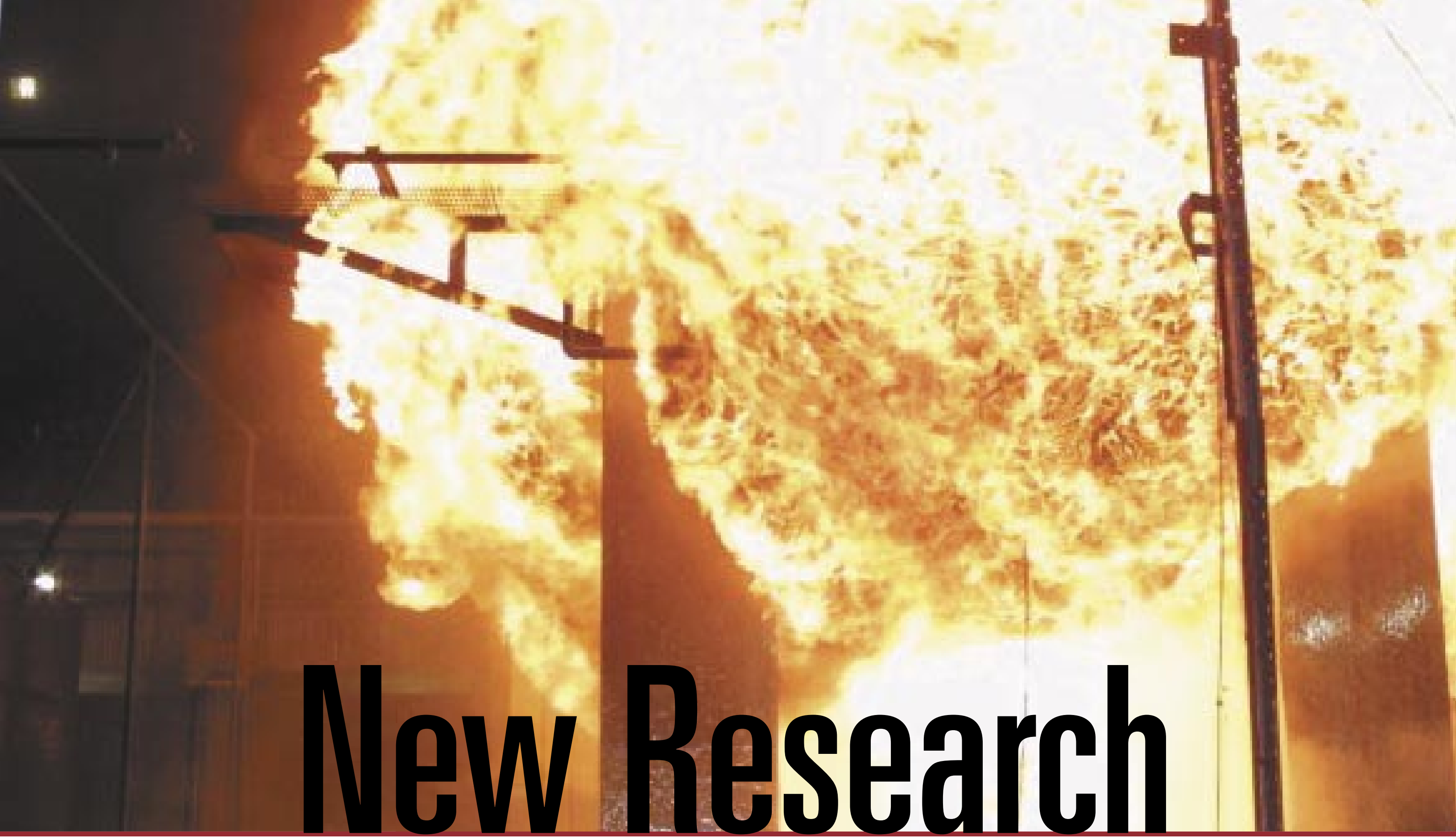
Following repairs to a boiler feed pump hydraulic servomotor, the servomotor cover was left off to check for leakage as the oil line was re-pressurized. A fitting beneath the cover separated, and the oil began to flow out instead of down the guardian pipe as it would normally. The ignited oil found a 9-ft.^{2} (0.8-m^2) floor opening and spread along open cable trays below. The fire burned until all oil was consumed. Damage included walls, I-beams and supports, exterior metal panel walls, cable trays and cables, and the feed pump. Gross loss was more than US$35 million.

But, despite these losses, there is some good news. With proper protection in place, damage can be minimized as evidenced by these two examples:

In the first example, a hot surface ignited lube oil leaking from a hydraulic governor for a steam turbine driving a generator in the powerhouse of a paper mill. Employees manually activated an open-head waterspray system. The waterspray and portable extinguishers put out the fire. The employees were able to coast down the turbine without bearing damage and the fire was extinguished without property damage. The turbine generator was down for six hours. The waterspray system had recently been installed—as recommended by FM Global.

In this second example, oil leaking from a flange of an oil-return line ignited inside a gas turbine generator compartment at a cogeneration facility for a dehydration plant. Lock nuts for the flange bolts had not been used and the bolts loosened. The fire was extinguished by the gaseous suppression system protecting the enclosure, limiting damage to US$20,000.

The bottom line is there is a high likelihood of a fire wherever there is mineral oil under pressure and hot surfaces around to ignite it. If one of the myriad mechanical joints does not fail, operator error could instigate the oil release. So, the best option is to *lower* the severity of the fire by ensuring the best protection scheme is installed, tested and maintained as recommended by your local FM Global engineer. Your business cannot afford the alternative.



New Research Electrifies Industry

Q: What weighs more than a locomotive and spins at 3,600 rpm?

A: The rotor in a large steam turbine generator.

The tremendous forces created by this furiously spinning mass are borne by a series of large bearings. A continuous flow of lubricating oil is forced into these bearings under high pressure. As the turbine shaft accelerates, it is forced up onto a thin film of oil—about the thickness of a human hair.

A large oil reservoir—containing up to 20,000 gal. (80,000 L) of oil—is required to maintain this high-pressure flow. Should this oil flow be cut off for any reason, the spinning rotor shaft would soon make metal-to-metal contact with the inner bearing surfaces—and that could result in catastrophic damage and lengthy downtime.

To avoid this, oil is pumped continually to the bearings of the turbine, generator, exciter and boiler-feed pumps. To ensure oil flow and prevent damage, even if the main pump fails, turbine lubrication systems also are equipped with a battery-powered backup pump.

Much of the world's energy is produced by turbines that depend on this type of lubrication system to keep them running smoothly and efficiently. A break anywhere in this oil supply network spells trouble, not only for the turbine, but also can pose a serious fire hazard.

Oil Fires—a Clear and Present Danger

Inadequate fire protection systems and a lack of proper emergency protocols can lead to serious damage and extended outages in the event of a lube-oil fire. In a recent 15-year period, FM Global found fire protection deficiencies for lube-oil systems were a major factor in 17 large turbine building fires. The property damage alone (not including business interruption losses) totaled more than US$400 million. Lost generating capacity was in excess of 20 million MWh (assumes a base-loaded station with a capacity factor of 86 percent), which is equivalent to the annual generating capacity of a mid-sized investor-owned utility.

The average property loss from these incidents was more than US$26 million. The turbines involved were out of service from 10 days to 48 weeks, with an average downtime of more than 24 weeks. In addition, three turbines were retired following two large fires. By contrast, in six turbine-building fires where recommended protection was installed, the average property damage was US$700,000 and turbines were out of service from one to seven weeks, with an average downtime of less than two weeks. While this still represents a substantial loss, it is far less than those for under-protected facilities.

And, these losses do not take into account the additional costs of business interruption and the possible penalties imposed by contractual obligations such as service guarantees, fuel-purchasing arrangements and the many other factors that an increasingly deregulated power industry faces. Why do these losses continue to occur? One key factor is the lack of definitive research into the specific fire threats faced by the power generation industry. Until last winter, no research organization had ever done full-scale fire tests of actual turbine-hall fire scenarios.

Blazing a New Trail

To help refine its knowledge of the fire hazards faced by power producers, FM Global conducted an ambitious first-of-its-kind test program earlier this year at the company's new Research Campus in West Glocester, R.I., USA.

Three types of fires—spray, pool and three-dimensional spill—are associated with turbine generator hazards.

Additional impetus for the test program came directly from FM Global power industry clients, many of whom urged the company to conduct this type of research and help them better assess the risks in their facilities.

Initially, FM Global intended to merely demonstrate to clients the significant fire risks they faced. However, early in the planning process, the scope of the effort was expanded to include a research component consisting of full-scale fire tests using the Large Burn Laboratory. FM Global Senior Research Scientist Christopher Wieczorek, Senior Engineer Paul Dobson and Engineering Specialist Glenn Mahnken took on the task of researching and designing a mock-up of a turbine, turbine pedestal and lube-oil system.

Wieczorek, Dobson and Mahnken were responsible for the design of the mock-up generator, and worked with others—using actual loss experiences and field observations—to choose three representative fire scenarios as the framework for the research:

- Spray fires
- Pool fires
- Three-dimensional spill fires

Wieczorek, Dobson and Mahnken also worked with Dennis Waters, the manager of the Research Campus, on the final design for a mock-up of a small power generation hall. The design had to be robust enough to withstand an extensive battery of tests as part of the research program, and later serve as a demonstration unit for visitors. The mock-up design included:

- High- and intermediate-pressure turbine housings
- Foundation pedestal
- Grated walkway to simulate an open-floor design
- Lube oil tank and pumping unit
- Dike surrounding lube oil tank

Built To Take It

The turbine-hall mock-up was fabricated from steel, though an actual turbine pedestal or foundation would typically be constructed from concrete; however, the FM Global mock-up needed to be at least somewhat "portable." The pedestal alone measured 15-ft. wide x 20-ft. long x 18-ft. high (4.6-m wide x 6-m long x 5.5-m high), with a 7.5-ft. (2.3-m) grated walkway extending along one edge. To prevent deformation during fire testing, the pedestal was equipped with a water-cooling system consisting of water flowing through pipes in the pedestal legs.

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It Can't Happen Here. . . Can It?

Lubrication, hydraulic, control and seal oil fires occur more often than most utilities let on. In many cases, only fires or other incidents that result in downtime are reported or noted. What is the typical cause of oil release that leads to fires in power generating facilities? According to FM Global statistics, oil releases are most often caused by:

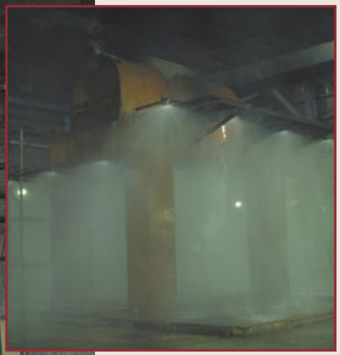
- Electrical failure
- Fitting failures
- Operator error
- Vibration

South Africa: In January 2003, a 600-MW turbine generator at a power plant in Witbank, South Africa, suffered extensive mechanical and fire damage following the onset of severe vibration due to a turbine blade failure. While mechanical failure was the root cause, lube oil continued to flow and feed a fire for more than an hour, despite the fact the turbine stopped abruptly. The cost to rebuild the generator was significant and was scheduled to take about a year to complete. The cost to rebuild does not include the lost power generation revenue from the large generating plant.

Boston, Mass., USA: In October 2002, a 360-MW steam turbine in Boston, Mass., USA, experienced a high vibration excursion that resulted in a leak in the hydrogen oil seal of the generator. The leaking oil ignited and a wall of fire cascaded down to lower levels, creating a three-dimensional spill fire. There was a delay in de-energizing electrical equipment and oil continued to flow for more than an hour. This unit has been permanently retired from service.

From the FM Global archives:
A boiler feedwater pump for a 750-MW steam-turbine generator was taken out of service to repair an oil leak in a steam-control valve. A cover was removed from the guard pipe. When the repair was completed, the hydraulic-oil line was pressurized. The opening in the guard pipe should have been covered. A compression fitting failed. Oil flowed through the opening in the guard pipe and down through the opening in the floor of the enclosure, igniting on a steam pipe. Oil spread across the solid mezzanine floor, damaging switchgear. Burning oil flowed onto the basement floor below. Oil also flowed in cable trays to areas well beyond the initial oil release. The control room was evacuated six minutes after the fire ignited. Quick action by control-room personnel secured lubricating-oil pumps, limiting the discharge of oil to about 600 gal. (2,300 L). The boiler-feedwater pump enclosures were provided with deluge-system protection. No area protection was provided below the operating floor.

A lube-oil fire caused major damage to the roof of a generator, crane and turbine building, causing significant damage and outage. A fitting failed on a 4-in. (102-mm) lubricating-oil line. There was no fixed protection in the area of the fire and no protection for the Class 2 steel deck roof. The roof burned as the fire spread into the boiler building and collapsed onto the turbine. Major structural members came down on either side of the turbine. Operators conducted an emergency shutdown of the turbine; however, lube-oil pumps were not shut off and the spray fire continued until the tank emptied. The pool oil fire on the floor was extinguished by firefighters. Shutting off lube-oil pumps when the turbine was shut down, as well as having fixed fire protection in the area of the leak and at roof level, would have substantially reduced damage.

The turbine-hall mock-up was fabricated from steel, rather than the traditional concrete, to make it more "portable."

According to Jeff Newman, FM Global's director of protection research, one of the key goals of the mock-up design was realism. "Not only did we want to simulate actual fire conditions as accurately as possible, we also wanted to be sure it would look right to industry experts," he said. "Following our test program, our plans included an extensive program of demonstrations for clients, risk management groups and industry experts. The mock-up had to look like equipment they would have in their own facilities."

During January and February 2004, a series of full-scale tests were carried out under the moveable ceiling section of the Large Burn Laboratory using the mock-up of the turbine hall. The series included spray fires, pool fires and three-dimensional spill fires. For test purposes, lube oil was pumped at rates up to 20 gpm (80 lpm). In a very large gas turbine, for example, oil might actually be pumped at up to 800 gpm (3,000 lpm).

Throughout the test program, different sprinkler types and configurations were tested, including:

- Sprinklers with various K-factors
- Sprinkler spacing arrangements of up to 10 x 10 ft. (3 x 3 m)
- Sprinkler densities ranging up to 3.9 gpm/ft.^{2} (159 mm/min.)

Even at the relatively low flow rate of 20 gpm (80 lpm), the researchers were surprised by the ferocity of some of the fires generated by the test apparatus. Some of the spray fires, in particular, generated heat-release-rate bursts of up to 40 MW or more. In fact, the testing required the collective capacity—and then some—of the entire FM Global burn laboratories and the 20-MW fire products collector.

The turbine fire tests produced the most powerful fires yet recorded in the new FM Global burn laboratories. According to Newman, this was the first test program that required the full resources of the burn labs. "The entire facility was dedicated to this test project for more than a month," he said.

"We saw ceiling temperatures during spray fires reach nearly 1,500 F (816 C) without sprinklers turned on and only slightly less than that with just ceiling sprinklers."

— ***Christopher Wieczorek, senior research scientist, FM Global***

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>
> — *Terry Cooper, FM Global’s Industry Engineering Leader – Power Generation*

“This was the first time the entire building here was used as a single massive instrument to measure very large fires. This has never been done before, anywhere.”

According to Wieczorek, the extra capacity built into the burn laboratories came in handy. “We knew the spray fires would be intense. We saw ceiling temperatures during spray fires reach nearly 1,500 F (816 C) without sprinklers turned on and only slightly less than that with just ceiling sprinklers,” he said, adding that temperatures above 1,000 F (538 C) can lead to steel deformation and, ultimately, roof failure.

Revealing Results

According to Wieczorek and Newman, the fire test program revealed or confirmed the following about turbine-hall fire hazards from pressurized-oil systems used in bearing lubrication, seal oil, hydraulics or control systems:

- Spray fires and three-dimensional spill fires cannot be extinguished by sprinklers alone
- Oil flow must be cut off as quickly as possible
- Local protection is required to control spray and three-dimensional spill fires
- Pool fires alone can be extinguished by adequate local fire protection

Prior to the research program and subsequent demonstrations, Wieczorek was surprised that many of those he spoke with in the power generation industry underestimated the fire risks posed by lube oil and other systems. “That was kind of an eye-opener,” he said. “I believe those who see the results of our research and videos of the fire tests, and those who were lucky enough to see our demonstrations in August, have a better understanding of the risks posed by these pressurized-oil systems.”

Soon after the tests were concluded, a videoconference was held for FM Global engineering staff worldwide to discuss the preliminary results and the impact on site assessments and other engineering work.

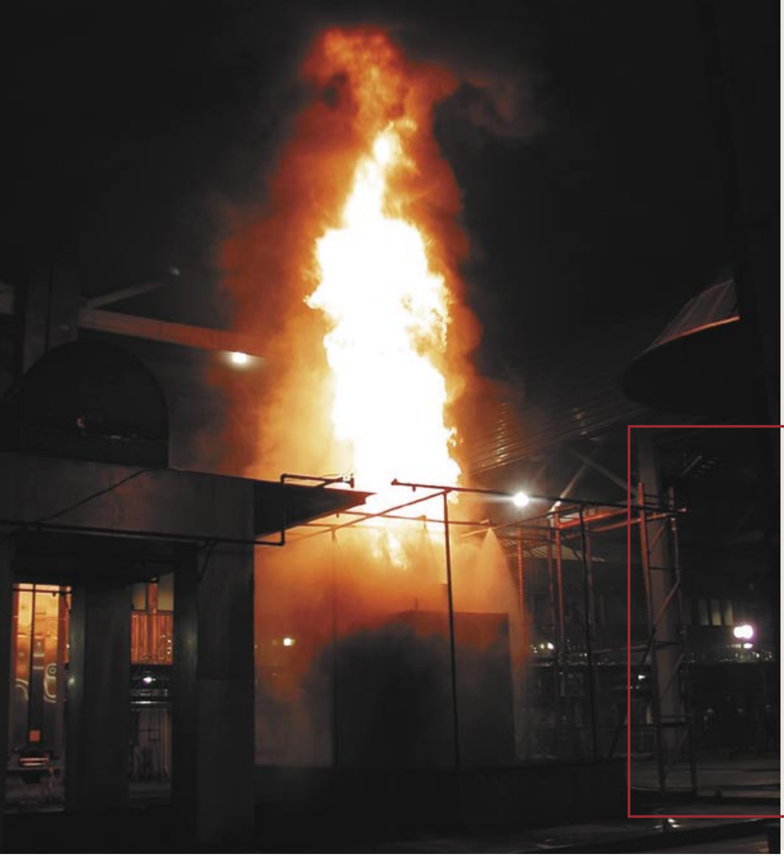
FM Global engineers have already begun to apply the findings in evaluating facilities under construction and existing insured facilities. The information applies to turbine buildings without solid operating floors or in buildings with mixed solid and open-floor designs where there is a potential for an oil fire in the open areas.

The Public Gets a Peek

The turbine mock-up was again set up for tours and demonstrations in August 2004. Approximately 110 visitors, including FM Global clients, power industry risk managers, industry leaders and the press, participated. The program consisted of:

- A presentation of fire research findings from the tests conducted on the turbine hall mock-up;
- An extensive tour of the Research Campus, including hydraulics, natural hazards, materials and burn laboratories;
- Fire demonstrations, including spray and three-dimensional spill fires using the turbine hall mock-up;
- A coal dust explosion; and
- An information package that included a CD of fire test videos and other information.

The tours and demonstrations were hosted by FM Global engineers, research staff and industry leaders, including Industry Engineering Leader – Power Generation Terry Cooper.



Turbine fire tests maximized resources in the Large Burn Laboratory at the Research Campus.

"I think anyone who had doubts about the fire hazards posed by pressurized-oil systems in their facilities was probably surprised by what they saw and learned during the demonstrations," Cooper said. "We are providing our clients and others in the industry with the proof and solutions they need to reduce their fire risk exposures and take steps to avoid forced outages. High availability is critical to the power industry. I think our research shows the risk is real, and we have a much better handle on what protection systems will really work."

. . . Walking the Walk

One FM Global client who witnessed the August fire demonstrations was John Munno, manager of corporate loss prevention for Dominion, one of the largest energy producers in the United States. "I particularly liked the tour of the research facilities. It was interesting to see the company's commitment to this type of research," Munno said. "The fire demonstrations really helped me visualize the fire risk we face, far better than any report or video ever could. And, even the coal dust explosion they demonstrated was very applicable to two of our businesses that use Powder River Basin coal."

Munno has been with Dominion for nearly three years and has worked with many top insurers. "I was impressed FM Global would put up their own money to search for answers," he said. "It demonstrates they want to help clients reduce losses; in fact, reduce industry-wide losses by answering tough questions. They have helped us significantly reduce our risks without a real increase in costs, primarily by increasing our awareness of the risks we face."

Taking It on the Road

Cooper also presented FM Global's research findings in early September to a gathering of 100 utility representatives at a bi-annual meeting at the Edison Electric Institute (EEI). Approximately 40 different utility firms were represented. "When we were done describing the research and summarizing our findings, we opened the floor to questions and answers—we asked them to try to poke holes in our work," Cooper said. "There was almost no dissent. They asked many 'what if' questions to see how these results applied to their particular situations."

According to Cooper, the EEI gathering provided an implicit endorsement—a validation of the research work. "What we had done made total sense to them," he said. "They wanted to know how to evaluate their own risks and protection systems, and learn how to apply this information. This is really a win-win for all concerned."

Cooper explained the efforts to deregulate the power industry in the United States, while it varies greatly from region to region, has had a profound impact on how utilities view risk such as fire and its impact on the bottom line. "In the past, if a utility experienced a loss in service or damage as a result of a fire, it could go to the state utility commission and make a case to justify inclusion of the loss costs into the rate base," he said. "Now, it has become much more complicated and competitive. Independent power producers have sprung up and the new business model demands the highest possible availability.

"Today, the interest in property insurance and time-element (TE) coverage has increased dramatically," Cooper said. "Ten years ago, few utilities purchased TE insurance. Now, 25 percent of the power generation firms we insure for property losses also have TE coverage. They know TE can be double or triple the value of their property losses in the event of an incident or outage. The key to success is availability—unscheduled downtime is unacceptable."

As FM Global's Industry Engineering Leader, Cooper is continually looking down the road. "We have a number of power industry-related projects in the works," he said. "Right now, we're looking at new ways to evaluate the useful life left in power transformers. We're also looking at feedwater controls, maintenance intervals, central station monitoring of gas turbines, and more. This is how we differentiate ourselves in the market. We offer technical knowledge and solutions no one else can provide. In the case of lube-oil fire hazards, we've resolved an issue not only for our clients, but for the entire power generation industry."

Wieczorek said the lube-oil fire tests and fire demonstrations required an intensive effort by all involved, but it was well worth it. "As a relatively new employee," he said, "I was impressed to see the extent we are willing to go to find the answers to tough questions. For those who saw the demonstrations, they got the message—clearly! Now, our job is to spread the word to a wider audience."

To learn more about turbine fire protection, contact Terry Cooper at +1 (1)401 275 3000, ext. 1938, or by e-mail at terry.cooper@fmglobal.com.

What We've Learned

The fire testing conducted on a mock-up of a turbine hall in the Large Burn Laboratory at the FM Global Research Campus in January and February 2004 confirmed some widely held beliefs and provided few surprises. Three fire scenarios were used to frame the research program: spray fire of oils under pressure, pool fires and three-dimensional spill fires.

This last category—three-dimensional spill fires—refers to oil that is sprayed or leaks from a fitting that supplies oil to bearings and the hydrogen-seal oil system on the turbine or generator platform, and then flows down to a lower level (i.e., the ground floor) and burns as a pool fire. The fire may start above or below the turbine platform or floor.

It was no surprise spray fires proved to be a tremendous challenge. Spray-fire tests in the Large Burn Laboratory yielded fires that tipped the scale at 40 MW or more. A spray fire in an actual turbine building could yield a far larger fire. Here's a summary of what we learned:

- Lube oil, hydrogen-seal oil, control oil and hydraulic fluid presents a clear hazard that includes direct heat damage to the roof, crane, turbine and other building contents.
- Spray fires and three-dimensional spill fires cannot be extinguished by sprinklers alone—oil flow must be cut off as quickly as possible in order to extinguish these fires.
- Oil flowing from the turbine or generator pedestal will result in a severe three-dimensional spill fire accompanied by a pool fire on the lower level.
- Due to excessive clearances in turbine halls, ceiling sprinklers alone do not provide adequate fire protection.
- Inadequate sprinkler protection can actually make oil pool fires worse.