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SPRING 2000

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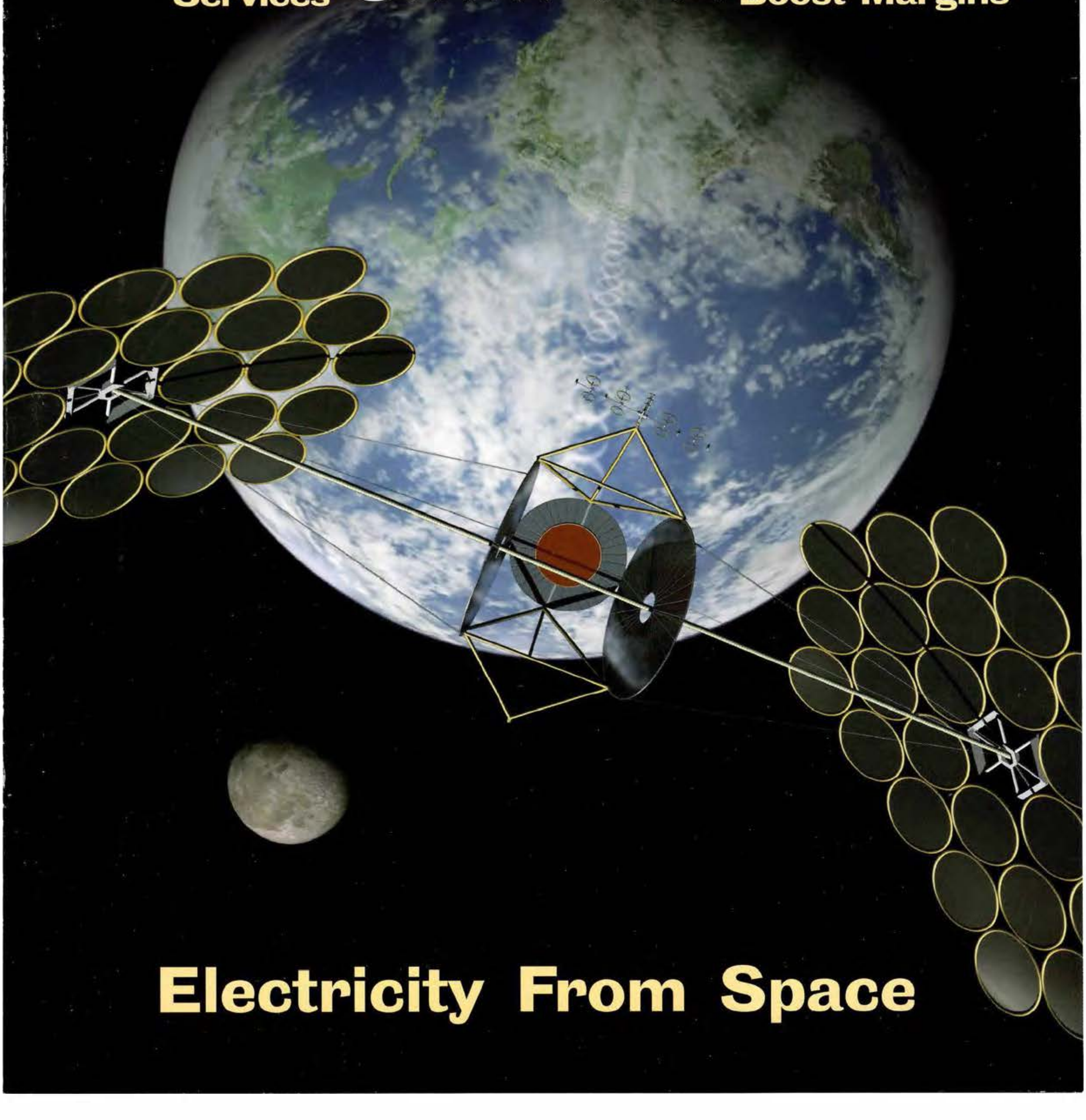
New Urgent-Response Services

Transmission Line Loading
Dynamic Circuit Ratings Boost Margins



Electricity From Space

About EPRI

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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COVER: The Integrated Symmetrical Concentrator and other advanced concepts for beaming solar power from space to Earth promise to greatly reduce costs through the use of ultralight-weight materials and structures. (Artwork ©2000 by Pat Rawlings, Science Applications International Corp.)

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Editorial

Taking the Initiative on Reliability

In his editorial in the Winter 1999 issue of the *Journal*, EPRI President and CEO Kurt Yeager warned about the increasing vulnerability of the North American power delivery system and called for solutions that go beyond simply fixing the problems as they exist today. At the request of a number of utility CEOs, the North American Electric Reliability Council (NERC), IEEE, and other industry organizations, EPRI has launched the Power Delivery Reliability Initiative to pursue such solutions. Work under the initiative seeks not only to identify ways of reducing near-term problems but also to clarify the root causes of recent outages and guide technology development to ensure long-term reliability.

The near-term threat is one of considerable urgency. Interregional bulk power transfers have been increasing exponentially, with some major transmission operators now participating in as many transactions in a day as they used to handle in a week. The limitations of the current power delivery system have already been dramatically revealed by some highly visible outages, such as those in New York and Chicago last summer, and by unexpected wholesale price instabilities.

EPRI's Power Delivery Reliability Initiative will address these problems by conducting separate reliability assessments for each NERC region and for representative utility distribution systems. A workshop of experts is being held early this year to identify actions that can be taken immediately to reduce the risk of further outages; these results will be available for utility use this summer. Analyses of the data from the regional assessments will support the formulation of detailed recommendations for enhancing reliability over the next few years. Many of the solutions are expected to involve the wider deployment of currently available technologies, but insights provided by the initiative will also help guide the long-term development of new power delivery technologies, such as those described in EPRI's Electricity Technology Roadmap.

Conducting this wide-ranging assessment is no easy task. For transmission systems, the rapid increase in bulk power transactions has led to grid operations of such complexity that they are difficult to analyze with traditional methods. As an alternative, the regional reliability analyses are using probabilistic risk assessment (PRA) methods originally developed in the airline and nuclear power industries. These methods have proved particularly effective in analyzing reliability problems arising from the interaction of multiple factors in complex systems. When applied to the NERC regions, the PRA methods are expected to identify actions that can be taken in the near term to reduce the risk of major transmission outages.

Reliability assessment of utility distribution systems is also difficult, in part because of significant differences in system architecture, equipment, and operating procedures across the industry. The initiative will therefore analyze five representative distribution systems to identify weaknesses that are generic to the industry as a whole. The insights resulting from these analyses should prove immediately useful for reducing distribution system outages through hardware upgrades and changes in operations, maintenance, and planning criteria.

For the longer term, EPRI will use results from the initiative to guide its base research program toward the development of new hardware and software to help meet the reliability demands of an increasingly complex power grid and an emerging digital economy. In addition, EPRI and other industry representatives are holding discussions about forming a public-private partnership that could use the initiative results to focus and accelerate the funding of new technology needed for power system reliability enhancement.

So far, some 30 utilities across the country are participating in the Power Delivery Reliability Initiative. Given the central importance of this work to the industry and the nation, it seems only prudent that all utilities commit to this collaborative effort.

Karl Stahlkopf
Vice President, Power Delivery Product Sector

Contributors

Renewed Interest in Space Solar Power (page 6) was written by Taylor Moore, *Journal* senior feature writer.

TAYLOR MOORE joined EPRI in 1982 after working for McGraw-Hill Publications Company as a reporter for *Business Week* magazine. Before that, he was an

Associated Press newsman in Kentucky. Moore received a BA degree in English from Eastern Kentucky University and an MA in energy and resources from the University of California at Berkeley.

Dynamic Ratings Boost Transmission Margins (page 18) was written by Taylor Moore, *Journal* senior feature writer, with technical assistance from Abdel-Aty Edris of EPRI's Science and Technology Development Division.

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in 1992 after 12 years with ABB Asea Brown Boveri in Sweden and the United States. At ABB, he worked on the development and application of reactive power compensators and high-voltage dc transmission. Edris received a BS degree from Cairo University, an MS from Ain Shams University (also in Cairo), and a PhD from the Chalmers University of Technology in Sweden.

Urgent-Response Services for a Fast-Paced Industry (page 26) was written by John Douglas, science writer, with technical assistance from three EPRI staff members.

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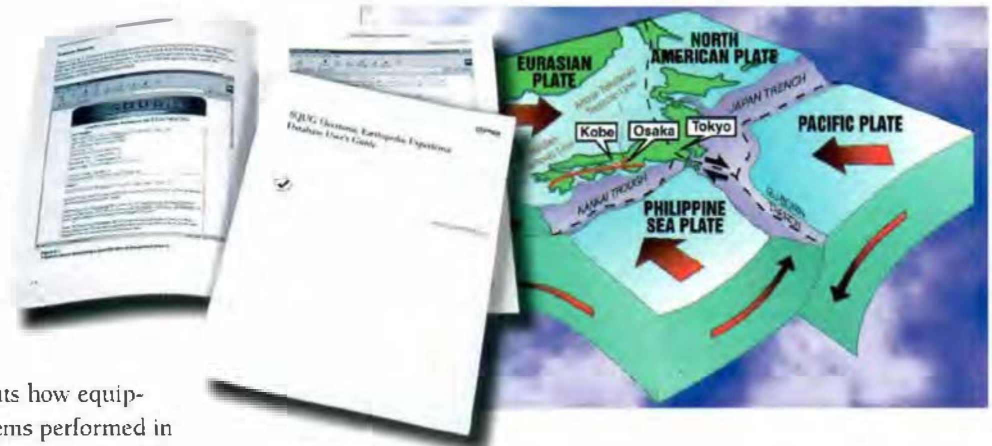


Utility engineers who need to evaluate the seismic adequacy of various electrical and mechanical equipment now have fast, easy Internet access to the Seismic Qualification Utility Group's earthquake experience database, thanks to a new Web site called eSQUG. Available via the EPRI Web site (www.epri.com), the eSQUG database documents how equipment representative of nuclear plant safety systems performed in strong-motion earthquakes at electric power and industrial facilities. Access to the electronic database, which draws on an extensive library gathered by the nuclear power industry since 1981, is restricted to SQUG funders. The user's manual describes the database and explains how to conduct searches and download information, including photographs and slides from surveys of earthquake sites.

■ *For more information, contact Robert Kassawara, rkassawa@epri.com, 650-855-2775. To order the manual (TR-113705), call EPRI Customer Service, 800-313-3774.*

RON MAY

ASAPP2

Both regulatory and economic issues are spurring utilities to track the quantities, locations, and costs of wastes generated and managed at their facilities. EPRI's Accounting Software Application for Pollution Prevention, newly upgraded in version 2, provides a systematic method for collecting, compiling, and reporting data on solid and hazardous wastes, from initial designation to final disposition. ASAPP2 contains significantly improved accounting and data management capabilities and can more closely match an organization's waste management approach and procedures. Intended for use in routine activities, the software can also be applied to support regulatory compliance and to identify opportunities for reducing costs and improving waste management efficiency. It comes with a four-volume manual on setup and use.

■ *For more information, contact Mary McLearn, mmclearn@epri.com, 650-855-2487. To order the software (AP-113711), call EPRI Customer Service, 800-313-3774.*

Turbine Steam Path Damage

Integrating a century of work by hundreds of researchers, designers, and turbine operators, this two-volume hardcover reference summarizes the state of knowledge about problems that occur in the turbine steam path in fossil fuel power plants (including combined-cycle and industrial units) and nuclear plants. The topics covered for each problem include damage features, common locations and susceptible units, mechanisms, root causes, repairs, and long-term corrective actions. Because many turbine problems do not originate in that component, the authors take a unitwide perspective to help the reader understand how to avoid steam path damage. They also link, for the first time, mechanical aspects and chemical environmental factors.

■ *For more information, contact Tom McCloskey, tmcclosk@epri.com, 650-855-2655, or Barry Dooley, bdooley@epri.com, 650-855-2458. To order the report (TR-108943), call EPRI Customer Service, 800-313-3774.*

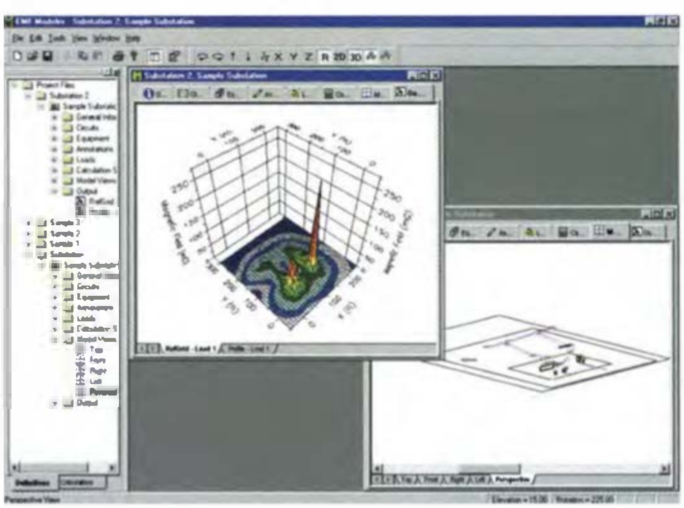
3-D BurnVision 1.0

This easy-to-use computer graphics program has the potential to enhance consistency and standardization in evaluating the clinical status of patients with electrical or other burns. Developed by researchers at the University of Chicago Hospitals Burn Center, 3-D BurnVision generates a three-dimensional body image that is expected to be an improvement over the two-dimensional, hand-drawn charts traditionally used to document surface burns. This image can be viewed from any angle and also can be modified. After medical personnel indicate on the image the extent and depth of the patient's burn wounds, the software computes the percentage of total body surface area burned. Version 1.0 runs on the Windows 95, 98, and NT operating systems. It is not intended that utilities use 3-D BurnVision directly but rather that they donate it to local burn centers as a public service.

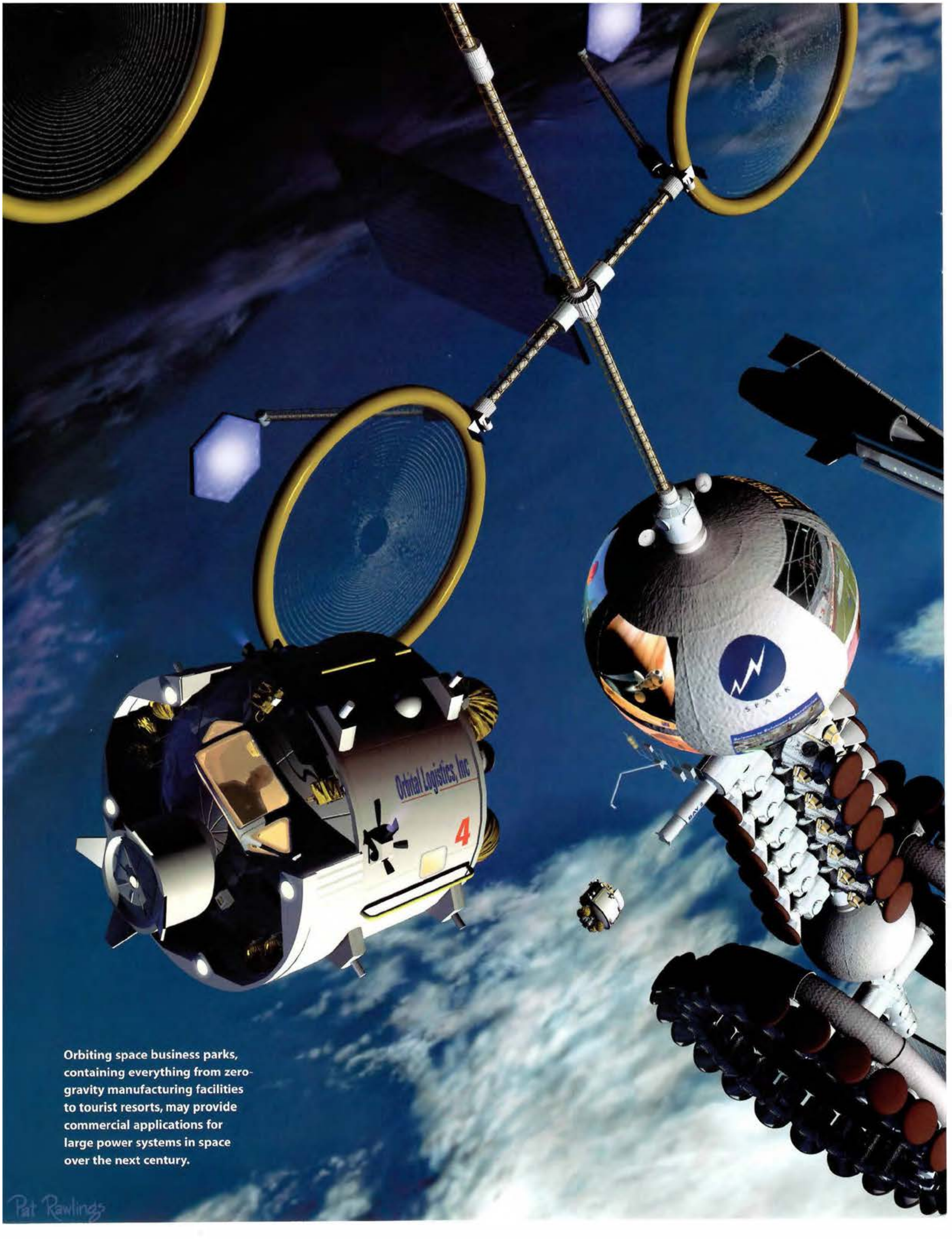
■ *For more information, contact Janice Yager, jayager@epri.com, 650-855-2724. To order the software (AP-113361), call EPRI Customer Service, 800-313-3774.*

EMF Modeler 1.0

Powerful yet simple to use, EMF Modeler is the next-generation software for mapping magnetic fields from substation equipment, transmission lines, and primary and secondary distribution lines. Designed for the Windows 98 and NT operating systems, it combines the best features of its predecessors with such new features as the ability to calculate fields over uneven terrain and the ability to compute induced currents in passive wire loops and lightning shield wires. To facilitate data entry, the developers designed a new user interface with many of the features found in mainstream business programs. Because of the software's flexible simulation capabilities, utility personnel can use it for what-if exercises to assess how various parameters might affect fields at specific locations and to compare potential exposures from various sources. EMF Modeler complements, but is not included in, the EPRI EMF Workstation.



■ *For more information, contact Randall Takemoto-Hambleton, rtakemot@epri.com, 650-855-2248. To order the software (AP-113725), call EPRI Customer Service, 800-313-3774.*



Orbiting space business parks, containing everything from zero-gravity manufacturing facilities to tourist resorts, may provide commercial applications for large power systems in space over the next century.

Renewed Interest in

Space Solar Power

PAT RAWLINGS, COURTESY NASA

THE STORY IN BRIEF

A growing interest in the commercial development of space and a recognized need for noncarbon energy sources are spurring a reexamination of the prospects for generating large amounts of electricity from space-based solar power systems. Technological advances over the past 20 years are casting a more favorable light on the technical and economic feasibility of large-scale space solar power, and continued progress is anticipated. But keeping the effort moving forward for the next several decades will require international public-private cooperation and investment by both the government and commercial sectors. Scientists and engineers have identified a variety of potential applications for solar power in space that could become interim markets for developing and deploying the technology on the way toward an ultimate realization of beaming solar electricity to Earth.

BY TAYLOR MOORE

With little fanfare, an idea first proposed more than 30 years ago for supplying Earth with abundant, zero-carbon electricity from solar energy is being revisited—only this time the perceived need for such a source is greater, and the long-term outlook for its economic feasibility is more favorable. By the middle of this century, some physicists and research engineers contend, a large share of the world's demand for electricity could be met by a constellation of very large space-based solar photovoltaic (PV) arrays. Transmitters connected to these arrays would each beam as much as several billion watts of power to Earth at microwave radio frequencies for collection by wide-area rectifying ground antennas and conversion to electricity.

The physics and the fundamental technology for such a scheme are well known and largely in hand, advocates say, although prodigious engineering development would be necessary to actually build a space power system. The greatest barrier to realizing the potential of power satellites in high Earth orbit is the same as it was three decades ago—the high cost of launching hundreds of thousands of tons of solar arrays and other equipment into space and assembling them. For several reasons, however, the challenge now appears somewhat less daunting than it did 30 years ago. (Another, arguably less significant, barrier remaining from the past is public concern about environmental, health, and safety risks of large-scale space-to-Earth microwave energy transmission. Experts say such risks are exceedingly small; see sidebar, p. 10.)

The most basic idea for space power stretches all the way back to one of the founders of the electric age and the discoverer of wireless radio, Nikola Tesla. "Throughout space there is energy," he told the American Institute of Electrical Engineers in 1881. "If [it is] static, our hopes are in vain; if kinetic—and this we know it is for certain—then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature."

Tesla's prophecy—and his attempts to demonstrate terrestrial wireless power transmission—inspired later visionaries of space solar power. As noted by R. Bryan Erb of the Canadian Space Agency, the Russian Konstantin Tsiolkovsky suggested in 1912 that rocketry would enable the collection in space of solar energy in amounts billions of times greater than available on Earth.

A half century later—with the space age under way—Peter Glaser, a vice president at Arthur D. Little, became an important proponent of space solar power. In the 1960s, in work for the government on spacecraft reentry heat shield materials and other problems confronting the space pioneers, Glaser and other consultants were asked to apply their expertise and their imaginations to emerging energy issues of terrestrial concern. Glaser became acquainted with the resource economist M. King Hubbert, whose seminal work on the depletion of fossil energy resources alerted policymakers to the need for long-term energy planning and R&D.

"Hubbert convinced me that in thinking about energy resources for the long term, we should focus on the resource that, insofar as anyone knows, will probably be around for another billion years—solar energy," recalls Glaser, now retired. "Solar cells, as well as being used in space exploration, were beginning to be used on Earth for various applications; but they were good for only one-shift daily operation on Earth and therefore could not provide base-load power without enormous amounts of energy storage. I came to the conclusion that the best place to collect solar energy was in space, outside Earth's atmosphere, where large arrays can be in direct sun exposure nearly all the time."

Glaser first proposed space power satellites (SPS) in 1968, and in 1973 he received a U.S. patent on a conceptual design for such a satellite. From 1972 to 1982, Glaser conducted technical and economic evaluations of SPS systems for the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE) and its predecessor agency. The inventor of numerous space mission experiments, including some that still operate on the moon, Glaser served as president of the International Solar Energy Society and as editor-in-chief of its journal, *Solar Energy*. He also organized many international conferences on SPS systems.

Sponsored by 16 nations and expected to be completed in the next several years, the International Space Station will be powered by about an acre (4050 m²) of photovoltaic arrays, making it a near-term platform for large-scale solar power development.

Solar power's brighter appeal in space

Emerging around the time of the U.S. Apollo moon landings and U.S. and Soviet development programs that greatly advanced PV technology, the SPS concept can be seen as a logical outgrowth of human space exploration.

In geostationary Earth orbit (GEO) at an altitude of 35,900 km (22,300 mi), a sun-facing solar array receives, on average, some eight times as much sunlight (about 1400 W/m^2, or 130 W/ft^2) as can be obtained at Earth's surface. The factors responsible for the lower terrestrial amount are Earth's day-night cycle (a 50% reduc-

COURTESY NASA

tion), the oblique angle of sunlight to Earth except over the Tropics at noon (a 50% reduction of the remaining amount), and the obscuring of the sun by clouds and atmospheric dust (another 50% reduction). In some areas, sunlight may be almost completely blocked for days on end.

Even when the atmosphere cooperates, various efficiency and conversion losses in today's terrestrial PV technology limit the average power output to 3–4 W/m^2. Technology advances may eventually raise this average to 17–20 W/m^2. In contrast, the microwave-receiving ground antenna of a space solar power system would have an output, per unit area, greater by a factor of 10 to 80.

Glaser conceded in a 1968 article in *Science* magazine that "the use of satellites for conversion of solar energy may be several decades away." And his preliminary calculations indicated that the array needed would be very large indeed. Even using the high PV conversion efficiency (80%) he believed to eventually be possible with certain organic semiconductors, Glaser calculated that an array capable of meeting the 1966 power requirements of the northeastern United States would weigh 150 metric tons (330,000 lb), not counting support structures. The transmitting dish antenna, composed of klystron amplifiers, would be about 2 km in diameter and would generate a diffuse microwave beam that would irradiate an Earth receiving antenna about 3 km in diameter. Solid-state dipole rectifiers in the receiving antenna, called a rectenna, would absorb the microwave energy and directly convert it to dc electricity, which would then be converted to ac for supply to a utility distribution network.

Glaser envisioned that by the time a complete space solar power system could be developed and implemented, prolonged human stays in orbit would be commonplace. Indeed, such a capability would be essential to support the construction, operation, and maintenance in space of very large solar collectors and microwave antennas. "We should not underestimate the development efforts that will be required to construct, launch, and operate the suggested solar power generating satellite," Glaser noted. But he added that "solution of most of the difficulties is expected to be within the projected capabilities of systems engineering, and not to require the discovery or development of new physical principles." At the time of Glaser's writing, however, the necessary technology was insufficiently advanced to permit a detailed analysis of the concept's cost and benefits.

Reference system defined

Through most of the 1970s and into the early 1980s, DOE—with support from NASA and such aerospace contractors as Boeing and Rockwell—extensively evaluated, refined, and elaborated Glaser's original SPS concept. In this work, an SPS reference system design featuring a 5-GW satellite was developed. Operating in GEO or possibly in low Earth orbit (LEO), the satellite would provide power to one or more rectennas. In a key advance in supporting technology, William C. Brown of Raytheon developed a rectenna system for the efficient collection and conversion of a transmitted microwave beam.

The reference system solar array was 5 by 10 km. At one end was a magnetron-based microwave-transmitting antenna that was 1 km in diameter and operated at 2.45 GHz. This frequency is in a band allocated by international authority for industrial, scientific, and medical use and is the same frequency used by today's ubiquitous microwave ovens. The weight of one such SPS was put at 30,000 to 50,000 metric tons.

On the ground or ocean surface, rectennas 10 by 13 km would intersect the microwave beam. Although generated at high power density, at ground level the beam would have an energy density of

The photovoltaic arrays now used to power satellites may be either rigid structures with crystalline PV modules or flexible thin films that can be unrolled in orbit. Those shown here, designed for the International Space Station by Lockheed Martin, consist of thousands of individual solar cells on a flexible backing. Such current-technology arrays are very expensive and provide limited power. To make large-scale space-to-Earth transmission of solar power commercially attractive would require producing arrays of thousands of square meters at greatly reduced costs—more than an order of magnitude lower than today's.

200–250 W/m², or only about one-fifth of the average energy intensity of direct sunlight at the equator at noon. A demonstration of terrestrial point-to-point wireless transmission of microwave energy in 1975 showed that the type of rectenna designed for the reference system could directly convert a 2.45-GHz beam to dc electricity at a remarkably high average efficiency of more than 80%. A coded reference radio signal beamed from the center of the rectenna to the transmitting antenna would be used to ensure the pointing accuracy and safe operation of the microwave power system.

An SPS in GEO could be oriented so that it would be exposed to the sun 24 hours a day for most of the year; the only interruptions would be approximately hour-long eclipses of the sun by Earth for 22 days before and 22 days after the vernal and autumnal equinoxes. The maximum daily interruption would be 72 minutes and would occur near local midnight. According to Glaser, the eclipses would reduce the solar energy received in GEO by about 1% of the total energy available during a year.

"With this year-round conversion capability, an SPS could be used to generate continuous baseload power on Earth with minimal requirements for energy storage," says Glaser. "Furthermore, the absence in space of environmental and gravitational

Microwave Power: Issues and Perceptions

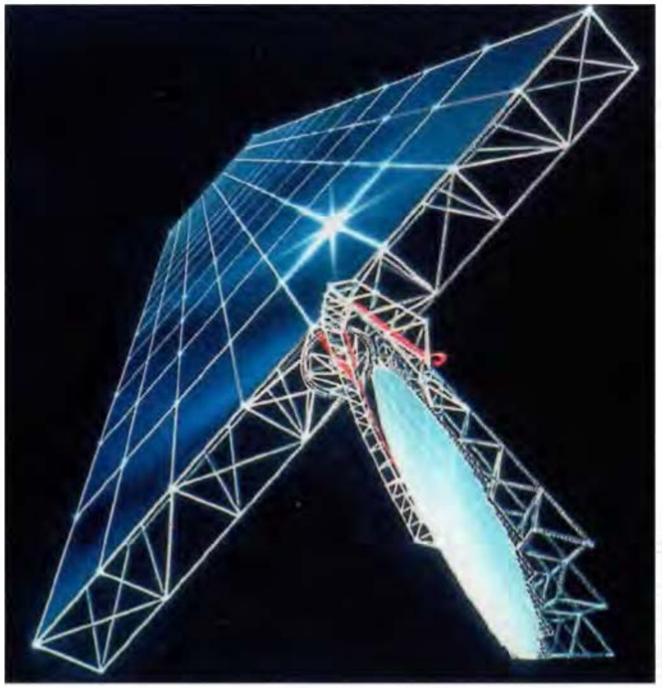
When solar power satellites (SPS) were first evaluated in the 1970s, uncertainties about the health and safety aspects of microwave energy raised concerns in some quarters. Among the concerns were the potential for catastrophic accidents, harm to wildlife, and adverse effects of chronic human exposure to low levels of microwave energy. With the advent of commercial microwave applications subject to standards for safe exposure—such as communications and cooking applications—many of these early worries have been dispelled at the level of scientific understanding. But some believe that the jury is still out on the use of cellular telephone handsets.

By design, an SPS's microwave beam would have a wide diameter to ensure that its energy density always remained low. The beam would have a Gaussian distribution, meaning that its energy density would be greatest in the center and would fall to a much lower level at the edges. NASA's John Mankins says that the concepts now under evaluation would involve beams with an energy density at the center of about 230 W/m² (23 mW/cm²), or about one-fifth the intensity of summer sunlight at noon. At the beam edges, the density would be 1% to 10% of the center level. The ground rectenna would be set in an open area and surrounded by a fence at which any residual energy would be far below the current U.S. microwave safety standard of 1 mW/cm²—and even the most conservative limit (0.01 mW/cm²) used anywhere in the world.

The satellite's microwave transmitter could be designed to make inadvertent focusing of the beam to higher energy densities impossible and to transmit power only when correctly aligned with a pilot radio signal from the rectenna. Airspace restrictions around the beam up to 40,000 feet (12 km) would normally keep aircraft from intersecting the beam, but even in the unlikely event that happened, NASA's preliminary analysis says the energy would be insufficient to cause harm or malfunction.

Despite the reassuring preliminary conclusions, Mankins says NASA is taking very seriously the possibility of perceived and actual environmental, health, and safety issues associated with space solar power and wireless power transmission. "We have activities under way in this year's program to better understand this area—including efforts to better determine constraints on the erection of lightweight, extensive, and contiguous structures would permit the deployment of SPS arrays over large areas in orbit"—at altitudes greater than 1000 km.

In the reference system design work, it was calculated that micrometeoroid impacts would degrade 1% of an SPS array area over 30 years of operation; large meteoroid impacts in GEO were expected to have very low probability. More recently, however, the amount of accumulated debris in Earth orbit, particularly in LEO, has been internationally recognized as a problem for space development—a problem that literally could impact large-surface-area SPS arrays.



The space power satellite reference system design developed in the 1970s featured a rigid solar array measuring 5 by 10 km and a magnetron-based transmitting antenna 1 km in diameter. Ground- or ocean-based rectennas measuring 10 by 13 km would receive the microwave beam on Earth and deliver up to 5 GW of electricity.

The SPS reference concept envisioned that a system sized to meet the U.S. power demand at the time would total sixty 5-GW satellites, each beaming microwave energy to one or more rectennas. Lifting each satellite's 50,000 metric tons into LEO would require a reusable heavy-lift launch vehicle weighing 250 metric tons. At a LEO-based space factory, 300 to 500 trained space workers would be needed over an anticipated 20 years to construct the satellites and send them into higher GEO orbit. Even if the costs of reaching LEO and GEO declined to the lowest levels imaginable, the estimated cost of achieving initial power output from an SPS system would be around $250 billion (in 1996 dollars).

This cost outlook, coupled with other SPS shortcomings and the quite different space application interests of the incoming Reagan administration in 1981, resulted in a low priority for SPS work by DOE and NASA. And in 1984 plunging oil prices evaporated any sense of urgency for developing solar energy in space.

NASA takes a fresh look

In 1995, after a decade and a half of little official interest in SPS, NASA revisited the subject in what came to be called the Fresh Look study. This effort assessed whether SPS-related technologies had advanced enough—and whether other factors had emerged—to significantly alter the outlook on the economic and techni-

what the perceived issues will be and how to address them, whether there are real issues, and, if so, whether they are showstoppers or can be resolved."

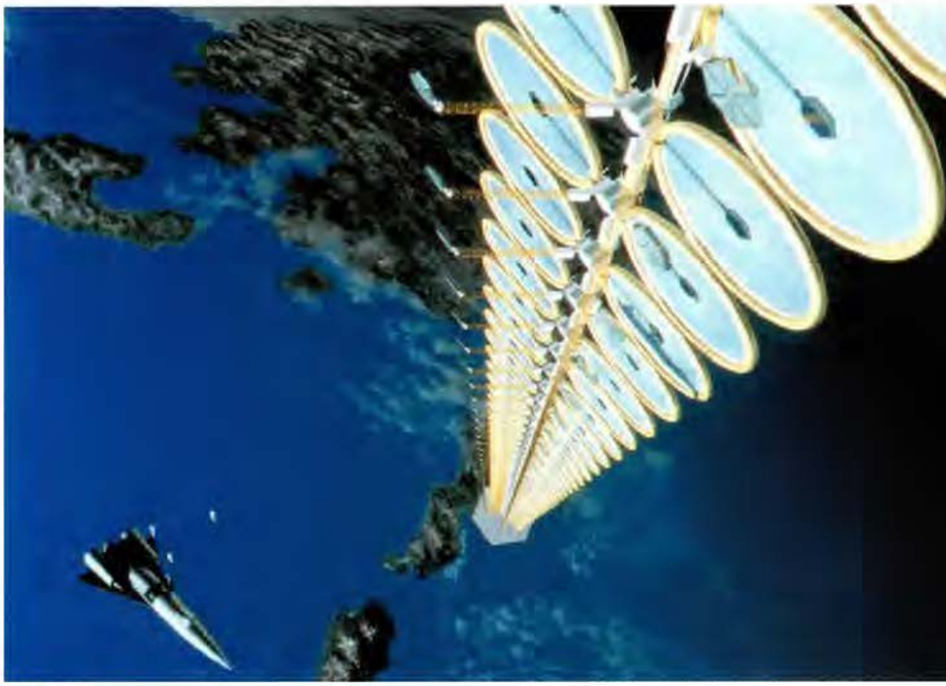
Mankins concludes, "To the best of our knowledge at this time, wireless power transmission confined within fences will be statistically safer to the surrounding population than sunlight—which can cause skin cancer, heat stroke, and so on—not to mention other large-scale energy sources like coal or nuclear. Nevertheless, we intend to work this issue very hard."

John Osepchuk, an expert on microwave technology who has written and consulted extensively about biological effects, hazards, and standards development, says that the earlier DOE-NASA work on an SPS reference system included several studies of potential effects of power beams on birds, bees, mice, and humans. In the only positive evidence of an effect, microwave energy at the reference system's design frequency and its beam power level at the rectenna was detectable by some bird species. This suggests, Osepchuk explains, that "migratory birds flying through the beam may suffer some disruption of their flight plans. Blue jays seemed to experience some thermal stress at 25 mW/cm^2, suggesting that birds of that size or larger may suffer thermal stress at that power density at 2.45 GHz."

Since 1986, Osepchuk has argued that although public fear of microwaves may represent a greater obstacle to the eventual deployment of SPS technology, the most serious technical problem in the near term is that of radio-frequency interference (RFI) and the related issue of frequency allocation. Over the past 20 years, many communications companies have been using frequencies in the 2.4–2.5-GHz microwave band supposedly reserved for industrial, scientific, and medical use, crowding the spectrum in which SSP systems were envisioned to operate. SSP power beams are likely to pose an RFI threat to nearby communications systems that operate in the same frequency band.

For this reason, says Osepchuk, "it appears that NASA now favors 5.8 GHz as the frequency for microwave power transmission, which would probably require new bioeffects studies to be done at that frequency. It is also likely to require ingenious solutions in transmitter and rectenna designs and development. High-efficiency microwave generators—such as magnetrons—that operate at 5.8 GHz are not yet available." Developing them may require the application of advanced high-power electronics. □

Concepts emerging from NASA's Fresh Look study in the late 1990s include the use of large modular elements that could be mass produced and at least partly self-assembled in orbit. The Sun Tower power satellite concept, two versions of which are shown here, incorporates these features. In the version below, concentrating thin-film reflectors would focus sunlight onto multi-bandgap solar modules of about 1 MW each. A multistrand high-temperature superconducting cable would connect the modules. In both this and the version on the right, a phased-array microwave generator at the bottom of the tower would beam energy to Earth-based rectennas. A constellation of 20 such solar satellites could provide a total of 20 to 80 GW divided among multiple rectenna sites.



PAT RAWLINGS, COURTESY NASA

cal feasibility of space solar power. The study found that a great deal had changed.

First, the energy future is constrained by an agreed-on need to limit atmospheric concentrations of carbon dioxide from the burning of fossil fuels. In this context, the imperative of meeting the developing world's demand for energy—specifically, electricity—creates a huge global market for new, noncarbon energy sources. "When we evaluated space solar power in the 1970s, the absence of direct carbon emissions was recognized, but concern about the risk of climate change from carbon emissions was quite embryonic then," says Frederick Koomanoff, who managed that space power assessment and later DOE's climate change research. "We didn't really know whether carbon emissions from fossil fuels were a problem."

John C. Mankins, who as NASA's manager for advanced concept studies oversaw the more recent assessment, says, "Now, major priority is being given to the development of renewable energy resources." He notes that such countries as India and China, where much of the growth in population and energy demand is projected to occur, are very interested in large-scale engineering solutions to electricity supply—for example, China's Three Gorges dam. And according to EPRI's Electricity Technology Roadmap Initiative, new, breakthrough energy concepts must also be implemented in order to provide sustainable energy for the global population of 10 billion expected by 2050.

Second, the cost outlook has brightened. Placing payloads in orbit still costs tens of thousands of dollars per kilogram, not the hundreds of dollars originally considered essential for the SPS reference system concept, but U.S. policy has set a goal for NASA to dramatically reduce Earth-to-orbit transportation costs over the next 20 years regardless of decisions about SPS. Moreover, key developments in such areas as information technologies, autonomous systems and robotics, power generation, and electronics—along with diverse new SPS system concepts and architectures—have revealed avenues for research and technology that promise to reduce the cost of SPS electricity.

"Since the 1970s, there have been staggering advances in composites and other lightweight materials, modular fabrication methods, robotics, and intelligent control systems. All of these—even the emerging reality of superconducting cable—may help bring SPS closer to reality," notes John Maulbetsch. The former EPRI manager for strategic science and technology (now retired) has followed space solar power since he first heard Glaser describe the concept in 1970.

The Fresh Look study identified several promising concepts as alternatives to the SPS reference system—concepts suggesting that order-of-magnitude lower costs might be possible. And even more recently developed concepts now under evaluation point to significantly lower overall system and first-power costs.

Third, there is broader thinking about how some of the key technologies and systems needed for SPS could be used in other space applications. Opportunities are envisioned in space science missions, human space exploration, and the commercial development of space (e.g., for manufacturing or tourism). Niche markets for space-generated electricity—both in space and on the ground—may exist at power levels

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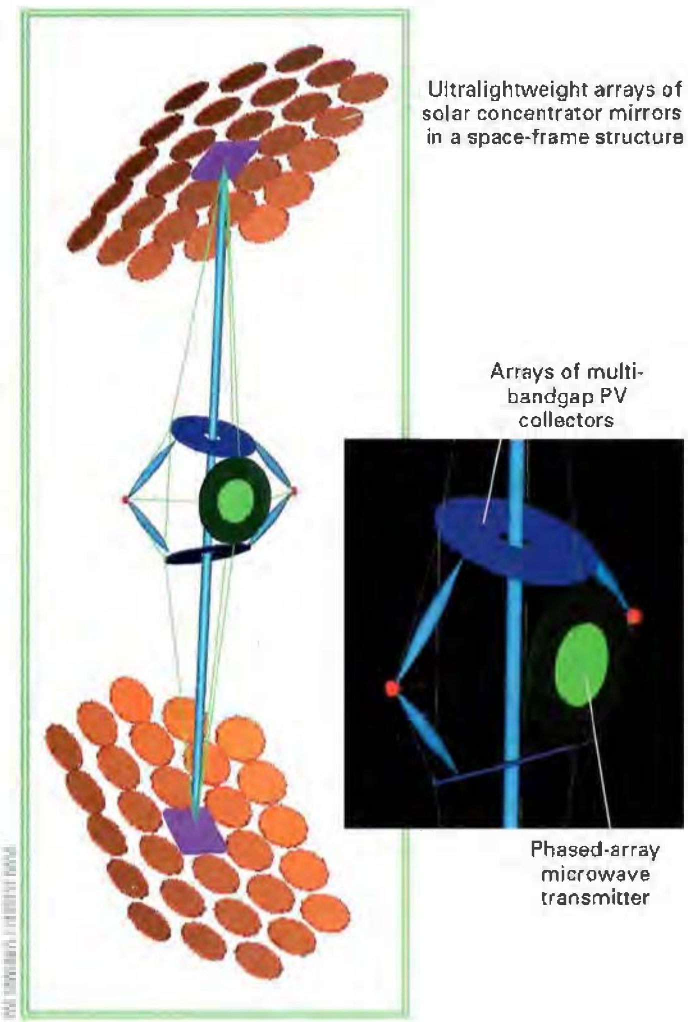
of several hundred megawatts rather than the gigawatts originally considered for terrestrial use.

Finally, there is substantial international interest in and support for the continuing investigation of SPS technology, judging from key technical demonstrations already conducted or planned by organizations in Japan, Canada, Europe, and Russia (see sidebar, p. 16). This interest indicates potential for a long-term international commitment—capitalizing on the collaborative model established for the International Space Station—to obtain a major new source of carbon-free electricity for the planet. Moreover, NASA and the aerospace industry are evolving a new paradigm for relationships in space development and commercialization. This model emphasizes the government's role in R&D for risk reduction and in mission applications and leaves much of the actual development of operational systems to the commercial sector.

The bottom line of the Fresh Look study, which was completed in 1997, was that "space solar power looked a lot more reasonable and a lot more affordable—although still quite high in cost—than it did in 1980," says Mankins. Encouraged by the results, Congress funded a follow-on SPS concept definition study in 1998, led by researchers at NASA's Marshall Space Flight Center. This work explored in greater detail various possible non-SPS applications for large, low-cost space power systems. "These space applications suggest that you don't have to wait 20 to 25 years before you begin to get tangible benefits from an investment in SPS technologies," Mankins explains. "Instead, there can be a continuous stream of government and, potentially, commercial applications for these technologies in space as progress is achieved toward the long-term goal of power from space for terrestrial markets."

As a result of bipartisan support from Congress and the Clinton administration, additional funding for an SPS exploratory research and technology program was authorized for fiscal year 1999 and is continuing in the current fiscal year. "Large power systems are likely to be essential for achieving ambitious space science and exploration goals, including both extra-solar system robotic probes and the development of large, permanent installations on the moon, Mars, or other targets, such as near-Earth and main-belt asteroids," says Mankins.

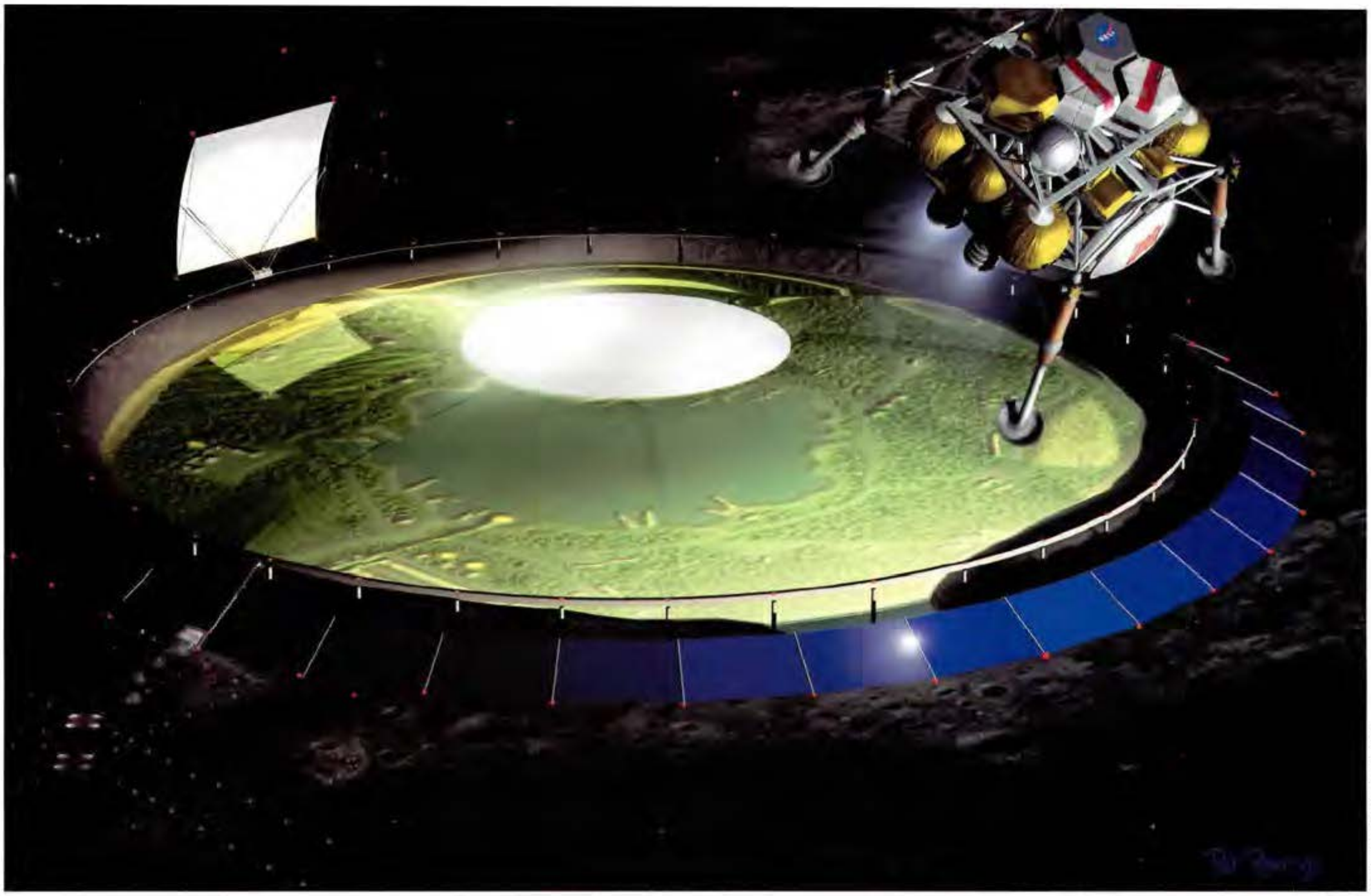
"While no new fundamental science is required, several areas of engineering R&D must be pursued to enable diverse space applications for affordable large power systems," he continues. "These areas include solar power generation, wireless transmission, power management and distribution, thermal management and materials, materials and structures, and space transportation. If the United States and other countries with space development programs could support an integrated, evolutionary scenario for affordable large space power systems over the next several decades, then the many interim space uses of such systems would have the potential to energize strategic investments in the necessary technologies. Such investments could thus make possible the eventual development of very large solar power satellites for terrestrial markets and revolutionary space applications."



In contrast to earlier concepts for space-based solar arrays, advanced concepts now under consideration by NASA—such as the Integrated Symmetrical Concentrator—feature ultralightweight materials and structures that promise to greatly reduce the projected cost of space solar power. In this concept, mirrors would reflect and focus sunlight onto multi-bandgap, thin-film PV arrays located next to a phased-array microwave transmitter.

Space solar power and the moon

For nearly as long as Peter Glaser has been talking about the potential for SPS systems, others have envisioned that the moon will ultimately provide an elegant solution to the heavy mass, launch cost, and orbital



PAT RAWLINGS, COURTESY NASA

PAT RAWLINGS, COURTESY NASA

The moon has been proposed as an ideal site for developing large-scale solar power systems that beam microwave energy to Earth. In one long-term vision (above), up to a million people could be stationed at the moon's constantly sunlit north or south pole in a permanent colony built in a crater and covered by a protective pressure dome with a translucent center. Solar arrays around the rim of the colony would continuously generate electricity, and a curved reflector on a circular track would project sunlight through the dome's center to support greenhouse agriculture. In addition, distributed solar arrays could form a wireless power transmission grid for operations on the surface (left).

debris problems of satellites. The lunar soil could supply silicon for solar arrays and metals like iron and aluminum for support structures, and the moon's vacuum environment and low gravity—only 5% that of Earth—would make it far easier and less expensive to get this material into space. In addition, the moon's surface itself could support enormous expanses of solar arrays. Advocates of lunar solar power contend it is the only way to ensure that solar electricity beamed to Earth will be affordable for its intended beneficiaries.

In a 1975 *Science* article, the late Princeton University physicist Gerard O'Neill proposed that manufacturing facilities in deep space could build SPS from raw materials extracted and brought from the moon, whose space-launch energy requirement is lower than Earth's by a factor of 20. At such a deep-space colony—capable of sustaining 10,000 or more inhabitants—satellites could be constructed and relocated in GEO at a lower cost than if they were built on and launched from Earth, O'Neill said. He noted that if solar satellite power was to have a major impact on the problems of energy resources, "the electricity rates at which [the satellites] operate must be low enough so that they will achieve market penetration" for new generating capacity in preference to terrestrial fossil or nuclear plants.

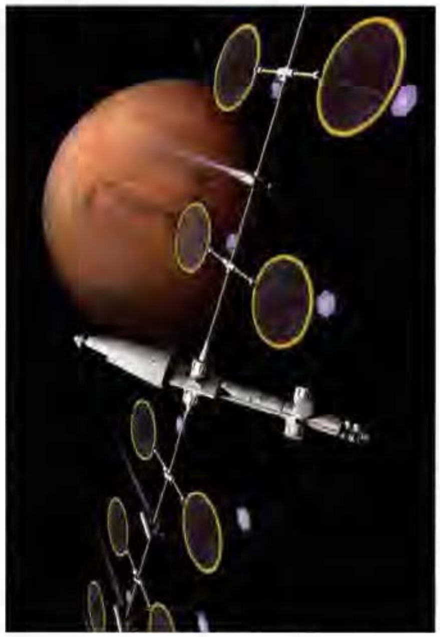
The DOE-NASA investigations of space solar power in the 1970s included research at the Massachusetts Institute of Technology and at General Dynamics on the potential use of nonterrestrial materials for solar array construction and support. The work evaluated four approaches to producing an SPS. Three involved the use of lunar materials, and the fourth was a reference SPS deployed from Earth. The study concluded that 90–96% of such a satellite's mass could be lunar in origin.

General Dynamics conceived of a lunar base supporting about 4500 people, 1000 of whom were directly involved in processing material and producing components for shipment to a space manufacturing facility, where several hundred workers would assemble SPS systems. The costs of the lunar-derived satellites and the satellite launched from Earth were projected to be about equal until the deployment of 30 units, after which the lunar-derived units would be less costly.

For many years, the banner for lunar-based solar power development has been carried by David Criswell, director of the Institute for Space Systems Operations at the University of Houston. In 1970s work for NASA based on samples returned from the Apollo mission landings, Criswell and Robert Waldron analyzed how lunar soils and rocks could be processed into glasses, metals, and other compounds that engineers could use in making a wide range of products. Criswell points out that using the moon as a source of construction materials and as the platform on which to gather solar energy would eliminate the need for extremely large platforms in space, most of the transport and reassembly of components in space, and the need for a space manufacturing facility. For the same rate of capacity installation, the fleet of rockets required for moving people and things around in space would be smaller by at least a factor of 50 than that necessary for SPS deployment from Earth.

"The environment of the moon is very conducive to large-scale solid-state devices such as solar photovoltaics," says Criswell. "It is as close to a perfect vacuum as you can find in the inner solar system; it is totally dry and extremely benign mechanically and seismically; and there is absolutely no weather. All of the things that make solar energy difficult on Earth are absent on the moon. It is reasonable to foresee very large thin-film devices or very large concentrator arrays that are very thin and mass-efficient. Furthermore, all these components and production processes can be fully developed and tested on Earth, as was done with complex devices like the Lunar Rover and the Apollo lunar surface experiments, before a return to the moon."

Criswell says that "there is an absolutely dependable, predictable flow of solar energy at the moon's surface." He envisions two large solar generating bases on the lunar disk's outer edges (called limbs), with some arrays at each base located just over the limbs on the side hidden from Earth. "You could obtain virtually continuous electricity from one or the other base for transmission toward Earth," he says. Microwave relay satellites in Earth orbit would provide load-following power to rectennas on the side of the planet away from the moon.



PAT RAWLINGS; COURTESY NASA

Beyond the next 20 years or so, human space exploration missions of around 1000 days' duration may be undertaken to Mars, to its moons, or to near-Earth asteroids. The Solar Clipper is an advanced concept for using affordable large power systems to provide reliable space transport between a near-Earth staging orbit and distant targets. Such reusable, long-lived systems are considered essential for making long-term space exploration campaigns economically feasible.

According to Criswell, lunar solar power could supply a year 2050 world population of 10 billion people with 20 terawatts (10^{12}) or more of electricity—enough energy to meet all basic human needs—at low cost and with few, if any, of the environmental downsides of other energy alternatives. "The moon is really the only option available for making world energy prosperity possible in this century," he says, "because the lunar approach to large-scale solar electricity would be far less expensive than any other. To enable energy prosperity, we've got to bring the cost of space solar electricity down to where the developing world can afford it, which in my view means a target of 1¢ per kilowatthour. At that level, you could provide everyone in the developing world the equivalent of 2 kW of generating capacity at a cost of approximately $200 a year per person.

"As a platform for solar energy collection, the moon already exists. We could send modular factories there to produce hundreds to thousands of times their own mass in thin-film solar arrays, the primary constituent of which would be silicon and glass refined and manufactured from lunar soil. Some electrical components and housings could easily be transported from Earth. But by manufacturing the arrays and siting the solar power stations on the moon, the cost of space transportation becomes much less important to the overall cost of space solar electricity."

Criswell believes that "installation of lunar solar power bases could begin after as little as 10 years of R&D. A complete system could be installed over 40 years. A lunar solar power system could bring a major source of noncarbon, nonpolluting energy into use—one that would empower humanity to get out of the box of extracting resources from the biosphere and having to ameliorate the effects of burning molecules and nuclei. Once we get away from handling atoms and mass and instead process photons and electrons, we will have the means for cleaning up everything else."

Beginning a journey of small steps

Most ardent believers in the potential for space-based solar power stop short of suggesting that an urgent, capital-intensive development effort should be an objective for the near term. Myriad technical, economic, environmental, legal, and regulatory issues will have to be resolved on an international basis before a consensus to pursue such development can be achieved. Yet any transition from today's carbon-based energy economy to one that is more globally sustainable will entail similar complications. The development of extraterrestrial energy and materials resources in this century would pose formidable challenges indeed—challenges commensurate with the magnitude of the problem being addressed.

Pointing out that every journey is a series of many small steps, supporters of space solar power say that the significant progress achieved thus far in demonstrating the technology and feasibility of wireless power transmission from space makes the case for pursuing continued evolutionary progress.

"The development of power from space for use on Earth is an achievable application of known space technology that can be demonstrated during the next decades," says Peter Glaser. The SPS concept "represents an evolutionary direction for expanding human activities in space and enabling the use of extraterrestrial materials." With proven feasibility and no known showstoppers, Glaser says, SPS could contribute to meeting global energy demand in this century.

Glaser and others have noted that given the risk of global environmental change, it is imperative to consider all possible energy resource options with as clear and consistent an understanding as possible of the health, environmental, and safety concerns each option raises. He quotes Buckminster Fuller and Hiroaki Kuromiya to frame the big picture: "The greatest challenge of history is, how do we make the world work for 100% of humanity in the shortest possible time through spontaneous cooperation, without ecological damage or disadvantage to anyone?"

David Criswell unabashedly favors a major U.S. and international commitment to develop solar power plants on the moon. "The lunar solar approach could be initiated at a fast pace within the current

The Next Steps Toward Space Solar Power

NASA is not alone in pursuing the potential of space solar power. Around the world, a number of other research organizations are working on key technologies necessary for ultimately deploying space power satellites (SPS). Important contributions have been made by scientists in Canada, China, Europe, India, Japan, Russia, and Ukraine.

Many experiments and demonstrations have been conducted in Japan since the 1980s, including work involving the transmission of microwave energy in space from a mother satellite to a small daughter satellite. In addition, researchers in Japan and Canada have demonstrated ground-based transmission of microwave energy for powering model airplanes and airships.

Among the various projects proposed by a working group of Japanese government and academic research scientists is SPS2000, conceived of as an operational test-bed for key SPS technologies, including ground-based rectennas (around 1 km in diameter) for converting beamed microwave energy. The system would feature a 10-MW pilot SPS designed to operate at 1100 km in an equatorial Earth orbit and to provide intermittent power to about 15 rectenna sites in countries located within 3 degrees (about 300 km) of the equator. The satellite would pass over any point in its orbit every 100 minutes and would be capable of transmitting power to any specific rectenna for about 200 seconds. The working group proposed that the project begin in 2000, but the Japanese government has yet to announce whether it will fund the effort.

Patrick Collins, a guest researcher at Japan's National Space Development Agency (NASDA), says he and colleagues have visited 10 of the 11 equatorial countries that have expressed interest in hosting one or more of the planned 15 rectennas. Collins declines to predict whether funding for the pilot demonstration will materialize. But he adds, "I know there is major discussion about what NASA, the European Space Agency, and NASDA should do after building the space station. NASA clearly wants to go to Mars, yet the U.S. Congress wants it to do something with economic value. Compared with the tens of billions of dollars that governments spend every year on civilian space projects and energy development, I believe that even a few billion for an SPS pilot plant is justified and would be very popular with the public."

Meanwhile, researchers at CNES, the French national space agency, are supporting plans for a commercial pilot plant to demonstrate terrestrial wireless power transmission on La Réunion, a French island in the Indian Ocean off the coast of Madagascar. The aim of this effort, known as the Grand Bassin project and headed by the industrial engineering laboratory of the regional university, is to beam microwaves some 700 meters across an ecologically sensitive valley to supply electricity to a remote resort. The project team seeks to demonstrate the environmental advantage of microwave power as an alternative to the construction of overhead transmission lines or underground cables. An industrial prototype system is now under development. If it is successfully demonstrated and the final approvals are obtained, the full system is expected to start up in 2004.

"Operating a terrestrial wireless power transmission system is one self-sustaining activity in the process of 'terracing' toward SPS technology, as Peter Glaser describes it," says Guy Pignolet, CNES future studies engineer. "No single government or agency is likely to decide to pursue an SPS program at this early stage, so if progress is to be made, intermediate steps with their own short-term rationale must be found. Social acceptability and good environmental integration will be essential for the microwave space power rectennas, and this is the foremost consideration in the Grand Bassin project." □

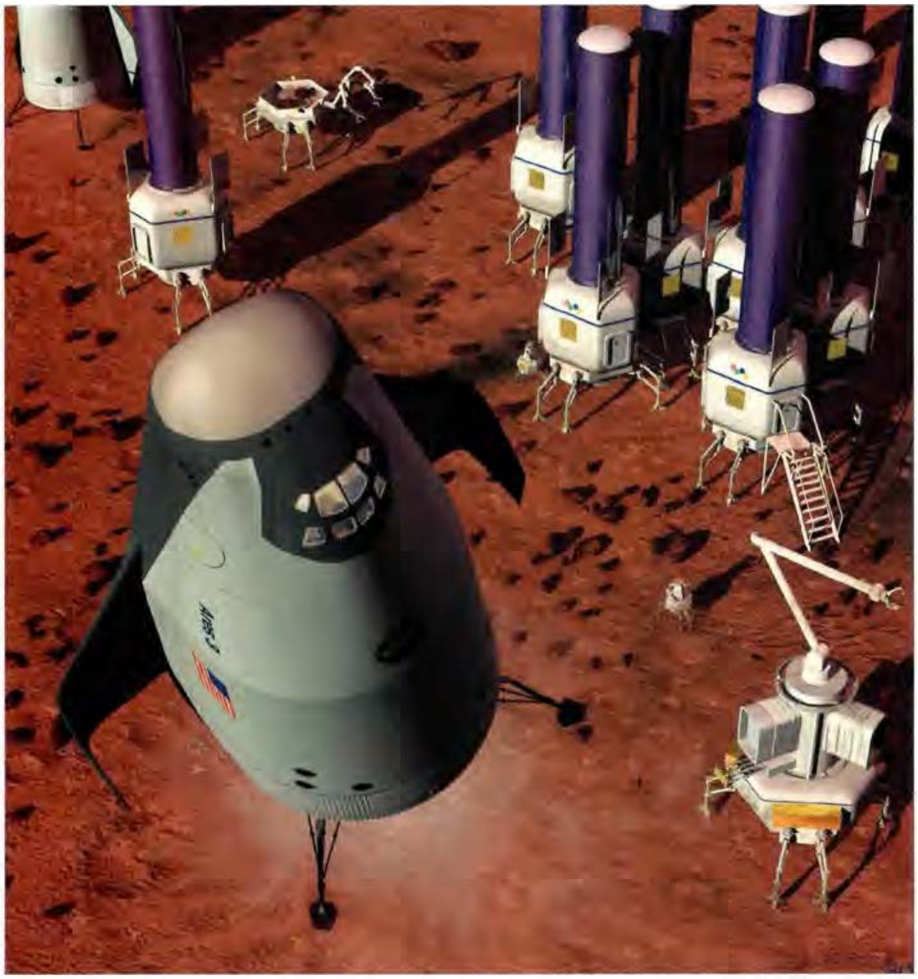
U.S. expenditures on civilian and defense space activities. Private funding would be attracted after power delivery to Earth at commercial levels, say tens of megawatts, has been demonstrated and the essential legal and political commitments have been made. The United States must lead the international community. If the economic growth of developing nations can be accelerated by clean, low-cost electricity, then the world potentially can be a much more attractive place for everyone."

John Mankins of NASA says that the agency's Fresh Look study and continuing assessments have helped dispel perceptions that space solar power is simply beyond the pale of economic feasibility. "Certainly, solar power satellites should no longer be viewed as requiring unimaginably large initial investments in fixed infrastructure before the emplacement of productive power plants can begin," Mankins observed in a 1997 paper. "Moreover, space solar power systems appear to possess many significant environmental advantages when compared to alternative approaches to meeting terrestrial demands for energy—including requiring considerably less land than terrestrial-based solar power systems.

"The economic viability of such systems depends, of course, on many factors and the successful development of various new technologies—not the least of which is the availability of exceptionally low cost access to space. However, the same can be said of many other advanced power technology options."

In a recent interview, Mankins said, "Space solar power may or may not ultimately emerge as a serious candidate among the options for meeting the energy demands of the twenty-first century. But the questions before us now are, what are our options, in terms of both existing technology and new technology, and what should our investment portfolio be to ensure that when we do need new power sources, we will have options from which to choose?"

As emphasized in EPRI's Electricity Technology Roadmap Initiative, solving the "trilemma" of population growth, resource consumption, and environmental cost and providing a sustainable global supply of electricity in the twenty-first century will require "out of the box" thinking. Says Kurt Yeager, EPRI's president and chief executive officer, "To look beyond the planet for a solution is indeed thinking out of the box. While much research and technical effort are centered on the shorter term, the lower risk, and the incremental advance, it is heartening to realize that the energy, enthusiasm, and intellect of some dedicated technologists are directed toward the pursuit of a revolutionary, as opposed to an evolutionary, solution. Whether solar power satellites will eventually come to pass remains to be seen. But much can be learned in an attempt to answer the important questions that accompany such a vast undertaking." ■



PAT RAWLINGS, COURTESY NASA

Advanced concepts for human outposts on the moon, Mars, and near-Earth asteroids include the predeployment of large numbers of identical habitation modules, each with an independent solar power supply. These mobile, "smart" modules could self-assemble into an outpost in advance of the arrival of astronaut-explorers. In the concept here, cylinders of advanced, thin-film solar arrays atop the modules would generate electricity continuously, since some surface area would always be exposed to sunlight.

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Dynamic Ratings Boost

Transmission Margins

THE STORY IN BRIEF

Dynamic thermal ratings for power equipment make it possible to increase the loading of transmission circuits under most weather and system conditions and to reduce the risk of failure under unfavorable conditions. Powerful software now available from EPRI incorporates real-time load and weather data from relatively inexpensive monitoring technology to calculate such dynamic ratings, which are far more realistic than the conservative static ratings normally used. By revealing a circuit's true thermal limit, the software lets system operators move more power with little additional investment in equipment: they not only can seize opportunities to deliver more electricity during high-demand periods but also can avoid unnecessary load shedding when contingencies arise. The software's current version, which incorporates application knowledge developed since 1992, has been verified in extensive field testing by six member companies. **by Taylor Moore**

THE HIGH-VOLTAGE transmission lines that form the backbone of the North American power grid are becoming an increasingly hot property with the advent of competition in wholesale electricity markets. Utilities, their unregulated generating subsidiaries, and independent power producers are relying to an unprecedented degree on the grid's interconnected transmission networks to transfer large amounts of bulk power over greater distances. There is substantial growth in power generating capacity, primarily due to the rise of merchant producers, who typically sell much of their output on the open market. Yet despite the heavy demands on the power delivery system, which are expected to continue to grow, virtually no new transmission circuits are being built.

The DTCR software includes proprietary EPRI thermal models for the three main types of equipment that make up a transmission circuit—overhead lines, underground cables, and transformers. Integrating the models with real-time load and weather data, DTCR calculates and continuously updates dynamic ratings.

The construction of new circuits or even the physical upgrading of existing circuits is problematic, often involving extended public hearings and lengthy delays. This is especially true for overhead transmission lines because of their visibility; in many residential areas, public opposition to lines is nearly certain. Sometimes, the opposition extends even to substations and underground cables.

Moreover, for utilities owning transmission facilities run by an independent system operator (as is now the case in California and Texas and soon will be in other states), there is little incentive to make large capital investments to add transmission capacity that may benefit competing electricity providers. In the brave new world of competition and open access to transmission systems, most companies prefer to pursue small, much less expensive capacity increases that can yield substantial economic advantages. As a result, transmission engineers face considerable pressure to make greater use of existing equipment and facilities while maintaining or improving the reliability of an aging system.

As the electrical loadings on transmission lines increase, the lines are more likely to approach or exceed their static thermal ratings, which are set to avoid equipment failure due to overheating. In such a failure scenario, high loadings, combined with high ambient temperatures, result in the thermal expansion and subsequent sagging of overhead conductors. In extreme cases, this sagging can lead to mechanical failure or an electrical ground fault. However, as transmission engineers are well aware, static line ratings are conservatively based on worst-case weather conditions (full sun, high temperatures, and no wind) in order to maintain minimum line-to-ground clearances for safety. More-realistic ratings would often allow the small capacity increases needed for today's loadings.

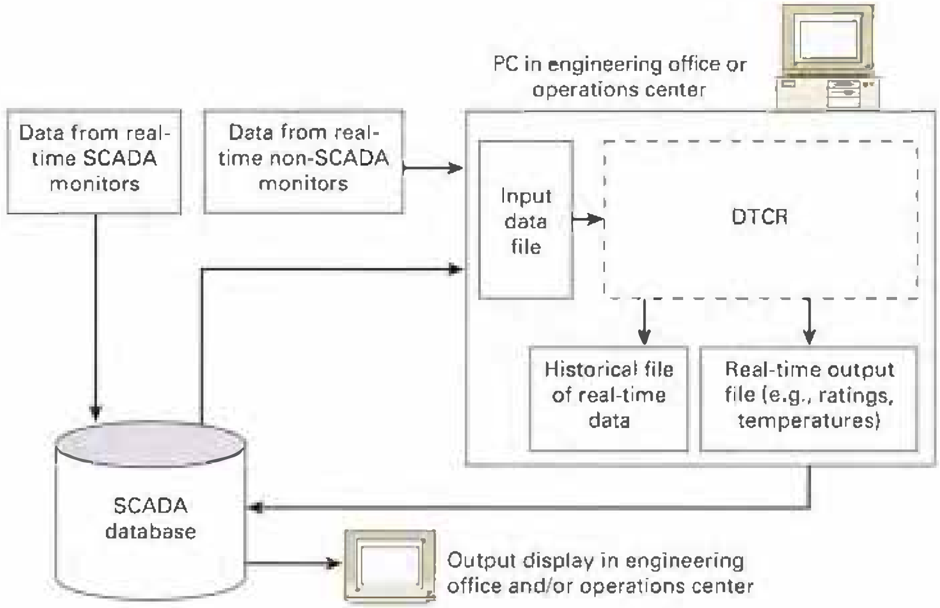
Over most of the past decade, EPRI has been developing a flexible, low-cost technology for increasing the current rating of transmission lines and related equipment on the basis of actual weather conditions and real-time monitoring of equipment temperatures and loading. In most cases, these weather-based, dynamic ratings permit higher short-term loadings than allowed by normal static equipment ratings and do not increase the risk of exceeding thermal limits, which could lead to equipment failure and system outages.

EPRI's Dynamic Thermal Circuit Rating (DTCR) technology combines a powerful calculation engine with a set of EPRI-developed proprietary thermal rating models covering most types of transmission equipment. The engine incorporates real-time weather and other environmental data, along with equipment temperature data, from commercially available monitors and sensors. The monitoring equipment (weather stations, conductor tension and temperature monitors, digital data loggers, and the like) used with the DTCR software can often be installed with little or no outage time and no environmental impact.

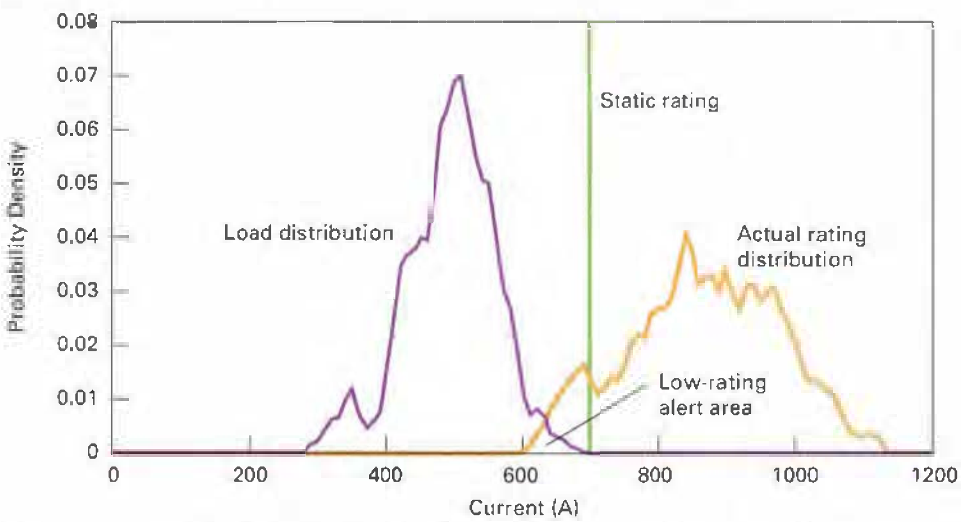
More than half a dozen EPRI member utilities have participated in field tests and demonstrations of the DTCR technology at different stages of development. The field tests verified the reliability of various real-time monitors and communication methods. They also demonstrated that the DTCR technology can monitor and dynamically rate multiple circuits and circuit elements at the same time. Analyses of the field test data indicate that, although dynamic ratings vary widely by system and location, typically they are 5–15% above conventional static ratings for overhead transmission lines, underground cables, and power transformers. Each of the tests revealed periods of high loading when, without real-time monitoring, equipment could have been damaged or public safety compromised.

Version 2.0 of DTCR runs on the Windows 95 and NT operating systems and obtains real-time electrical load and weather data directly from a utility's supervisory control and data acquisition (SCADA) database.

"Our DTCR technology for the real-time rating of transmission and substation equipment is a much-needed development that helps maximize the use of these utility assets without risking equipment damage," says Abdel-Aty Edris, EPRI manager for FACTS (Flexible AC Transmission System) technologies. "The use of DTCR technology on thermally limited circuits could result in modest but economically quite valuable increases in transmission and substation equipment capacity."



Some of the data DTCR uses to calculate dynamic thermal ratings—current-loading data, for example—are already routinely supplied to a utility's supervisory control and data acquisition (SCADA) system or energy management system. Low-cost, commercially available equipment like temperature sensors, conductor tension monitors, and small weather monitoring stations can be installed directly on a circuit to provide additional real-time data. From this input, DTCR's equipment models calculate real-time critical temperatures and multiple dynamic thermal ratings, which become part of the SCADA database for display to system operators and engineers.



A transmission circuit's normal thermal limit is its static rating, calculated once and based conservatively on worst-case weather conditions. In this example, the load distribution is appropriate for the circuit's static thermal rating, since it never exceeds that limit. But a probability distribution of actual thermal ratings—ratings based on temperature and line tension measurements from monitors installed on the circuit—shows that the circuit can safely carry more current under most weather conditions. Such a monitor-based dynamic approach allows operators to increase circuit loading most of the time. They receive an alert when the dynamic rating drops to a level requiring a temporary load reduction.

Development background

Utilities use many different methods and assumptions in calculating the thermal ratings of power equipment. The dynamic thermal models developed for DTCR incorporate the latest available research results. They can be applied at various levels of sophistication and with user-specified equipment parameters and rating limits.

Transmission circuits typically consist of several elements—including conductors, transformers, and switches—connected in series. The thermal capacity of a series circuit is set by the element that has the lowest thermal rating. For parallel-connected circuits, the thermal capacity is a function of the impedances and dynamic ratings of the various equipment combinations.

For circuits in which the thermal rating is determined by relatively inexpensive components, the simplest way to increase the circuit rating is to replace the limiting element with new equipment having a higher static rating. But dynamic rating methods are the preferred option for increasing the thermal capacity of equipment that cannot easily be removed from service or is expensive to replace; they are also preferred for multiple circuits in the same area as a way to increase power transfer limits.

The Empire State Electric Energy Research Corporation, a New York utility R&D consortium, conducted one of the earliest studies of the practicality of dynamic thermal rating methods. Completed in 1987, the ESEERCO study was the first to determine that using real-time methods can result in thermal ratings 5–15% higher than conventional name-plate or worst-case static ratings. It also concluded that real-time thermal ratings based on weather conditions and circuit electrical loads are fairly simple to implement if the measurement of equipment temperatures is not required. The study noted that dynamic rating methods should be applied simultaneously to multiple circuits in order to derive the maximum economic benefit by increasing area power transfer limits.

Building on the results of the ESEERCO study, EPRI began work in 1991 to develop and field-test a personal computer–based software package for calculating real-time thermal circuit ratings with maximum flexibility and minimum cost. The goal was to improve estimates of ratings through the monitoring of weather and soil conditions and electrical loading.

Designed for use by many different utilities with a wide variety of operating conditions and types of power equipment, EPRI's DTCR software and associated monitoring hardware offer portability, low installation cost (in most cases, less than $100,000), simplicity, and flexibility. The software's key equipment thermal models are DYNAMP for overhead lines, PTLOAD for power transformers, and ACE for underground cables.

Georgia Power was one of the first utilities to field-test the DTCR software. Although the limited test did not involve the communication of dynamic thermal ratings to the company's operations center, it did demonstrate the ability of the software to rate multiple power equipment types and circuits simultaneously. The test also highlighted the importance of using simple, commercially available monitors and the need for thermal rating models that do not require detailed data on equipment parameters.

Four other utilities—PECO Energy, Salt River Project (SRP), San Diego Gas & Electric, and Illinois Power—installed the DTCR technology on overhead transmission lines and tested it for accuracy and reliability. PECO Energy and Consolidated Edison Company of New York conducted field tests of installations on power transformers, and BC Hydro applied the technology to the real-time monitoring and dynamic rating of underground cables.

The value of DTCR—and its potential for much greater value—is most apparent in the documented case studies of three of the installations where the technology continues in operation today: at Illinois Power, SRP, and BC Hydro.

Maximizing asset utilization

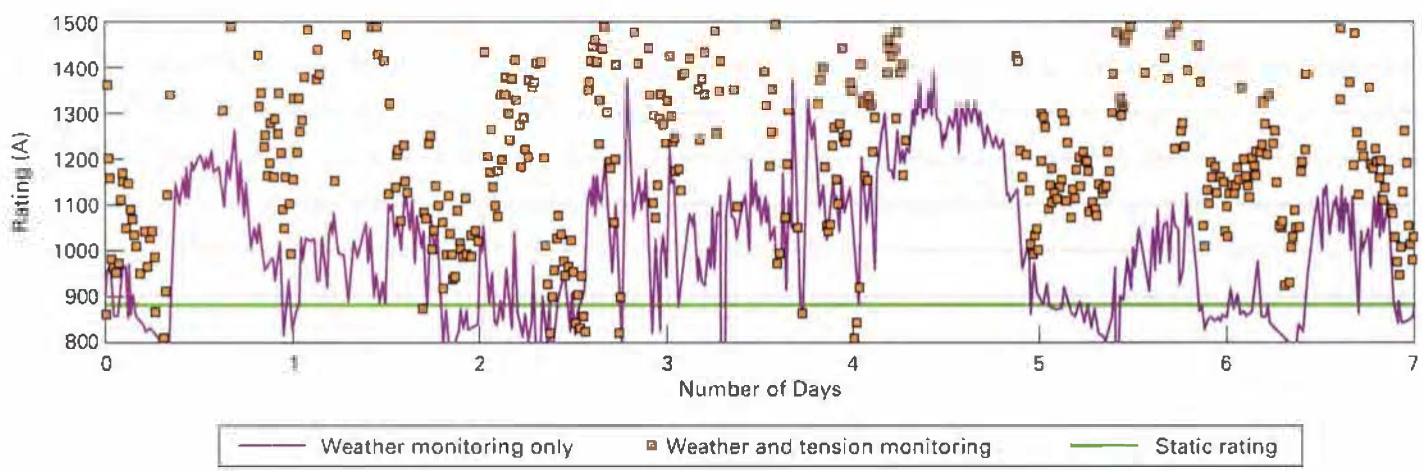
Illinois Power sought an economical way to determine real-time line capacity and achieve more flexibility in line loading. Through a tailored collaboration project with EPRI, it found the solution it needed in the DTCR technology. The utility has successfully applied the technology to two 138-kV transmission lines.

By making it possible to use less conservative static ratings for the lines, the DTCR applications have increased the maximum allowable load flow. Under contingency conditions or whenever the load of a line exceeds the static rating, the DTCR software can, via solar-powered cellular telephone, dial up tension monitors installed on the line and calculate a real-time rating, which is then displayed to the system dispatcher.

The DTCR installations have allowed Illinois Power to defer planned upgrades of both 138-kV transmission lines—upgrades with an estimated total cost of $300,000. Moreover, the utility expects that for one line installation alone, the 5–15% increase in useful thermal capacity resulting from the application of DTCR will increase revenue by about $1 million over the next decade.

"Asset utilization is the battle cry as we head into deregulation," says Frank Ferracane, chief transmission engineer for Illinois Power. "EPRI's DTCR technology enables us to safely and flexibly move more power over existing lines without the cost of line upgrades."

Ferracane adds that a needed further development is to integrate the DTCR dynamic rating data with utility energy management system (EMS) computers. In order for DTCR to be implemented on all thermally limited circuits in a system, he says, the software's output must be integrated with an EMS that would regularly give dynamic rating information to system operators without their having to deal manually with DTCR.



As this week's worth of DTCR results shows, dynamic thermal ratings—whether based on weather monitoring data alone or on a combination of weather and line tension monitoring data—are usually substantially higher than the flat static rating.

"If applied in its current form to many individual lines, DTCR could present a problem for dispatchers by providing too many inputs to distinguish and process," explains Ferracane. "Integration with EMS computers is a logical next step toward a commercial product that can be applied systemwide."

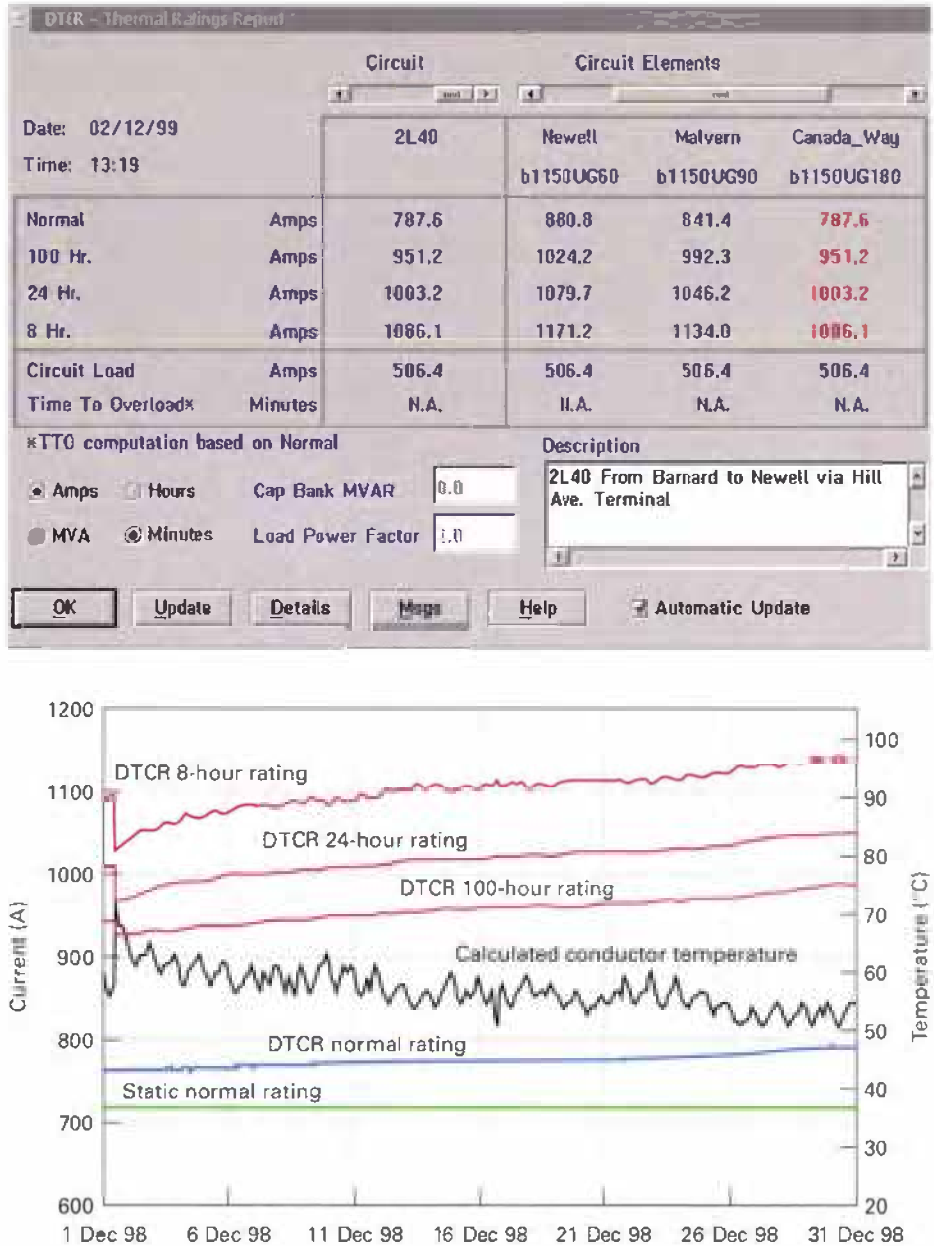
Greater use of a critical path

SRP currently uses the DTCR technology on two key transmission lines to enable short-term loading beyond their static ratings, and the company plans to complete another installation—on a line it operates jointly with Arizona Public Service—by next summer. SRP says the first installation alone is allowing it to defer the construction of a new transmission line for as long as five years, for cost savings of at least $9 million.

That original installation, the product of a tailored collaboration project with EPRI, is on SRP's 230-kV Agua Fria–Westwing line, which carries much of the power the utility imports into the greater Phoenix area. In the fall of 1996, SRP planners asked the transmission design department to find a way to increase the line's power transfer capacity in time to handle expected load increases the following summer. Concern about the line's capacity was driven by unprecedented load growth in the Phoenix area, which was causing dramatic increases in total peak load each summer. Constructing a complementary new transmission line would have solved the problem, but at great expense and with great delay—five years for siting, permitting, design, and construction.

SRP's transmission system designers suspected that the actual weather conditions in the area of the line were more favorable than those assumed in calculating the line's original static rating. If that was the case, the line was operating below its true capacity, and line-to-ground clearances exceeded industry requirements. The utility needed a way to validate these assumptions and derive new, more appropriate ratings that would allow for greater line utilization.

On the basis of information about projects demonstrating EPRI's DTCR technology, SRP contacted EPRI and agreed to a tailored collaboration effort to deploy the technology on its system. The utility had barely five months to complete the installation before the period (June 1 to September 15) when company policy does not permit scheduled maintenance on 230-kV lines because of the high temperatures and stormy weather typical then.



DTCR is helping BC Hydro defer replacement of two 230-kV underground transmission cables installed near Vancouver. By calculating the circuits' actual dynamic capacity, the software allows the utility to maximize use of the existing cables and limit the potential for overload damage until the cables can be replaced. DTCR reports the circuit thermal ratings (top) and can be used to generate output plots (bottom) of short-term and long-term dynamic ratings.

This DTCR installation at SRP was the first to use spread-spectrum radio, which links the tension monitors and meteorological stations to a computer at the Agua Fria substation. Data on conductor tension, wind speed, wind direction, ambient air temperature, and solar gain were all collected in real time. SRP resurveyed the line to produce an up-to-date model of line-to-ground and crossover clearances. The survey showed that at the present conductor temperature limit (75°C), there was ample clearance for all spans, and at 105°C, only five spans had clearance problems. Resolving these clearance issues enabled SRP to increase the conductor rating to 105°C, a very significant gain.

In addition, an analysis of 24-hour weather data enabled SRP to increase the line's original static rating of 1800 amperes. The new ratings are 2200 amperes at night (10 p.m. to 10 a.m.) and 2500 amperes during the day (10 a.m. to 10 p.m.). Strong winds during the day and a previously unrecognized drop in wind speed after 10 p.m. are the reasons for the night-day capacity difference.

Since the DTCR system became fully operational in July 1997, the Agua Fria–Westwing line has operated at the higher line ratings without incident. SRP reported 10% growth in total peak load the first summer. In 1999, it installed monitors and communications links on a second 230-kV line, the Goldfield-Silverking line. The DTCR data for this line are input to the utility's EMS to provide real-time, on-line information to system operators.

By delaying the construction of an additional transmission line on the Agua Fria–Westwing circuit, SRP estimates avoided-cost savings of $1.8 million for each year of deferral. As a result of the expanded system operating options and avoided generation costs made possible by the DTCR system, the utility realizes additional cost savings of between $600,000 and $2.6 million a year.

"The 230-kV Agua Fria–Westwing line is a critical path for economically serving the Phoenix metro area," says Bill Phillips, an SRP transmission design engineer. "EPRI's DTCR technology lets us use real-time information to determine the line rating, and the result is a significant increase in transfer capability without any additions to the line."

Robert Kondziolka, manager of transmission planning for SRP, adds, "DTCR enables us to operate a line closer to its thermal limits without reducing reliability. The technology allowed us to move much faster to address load growth than we could have with other options—and at a much lower cost."

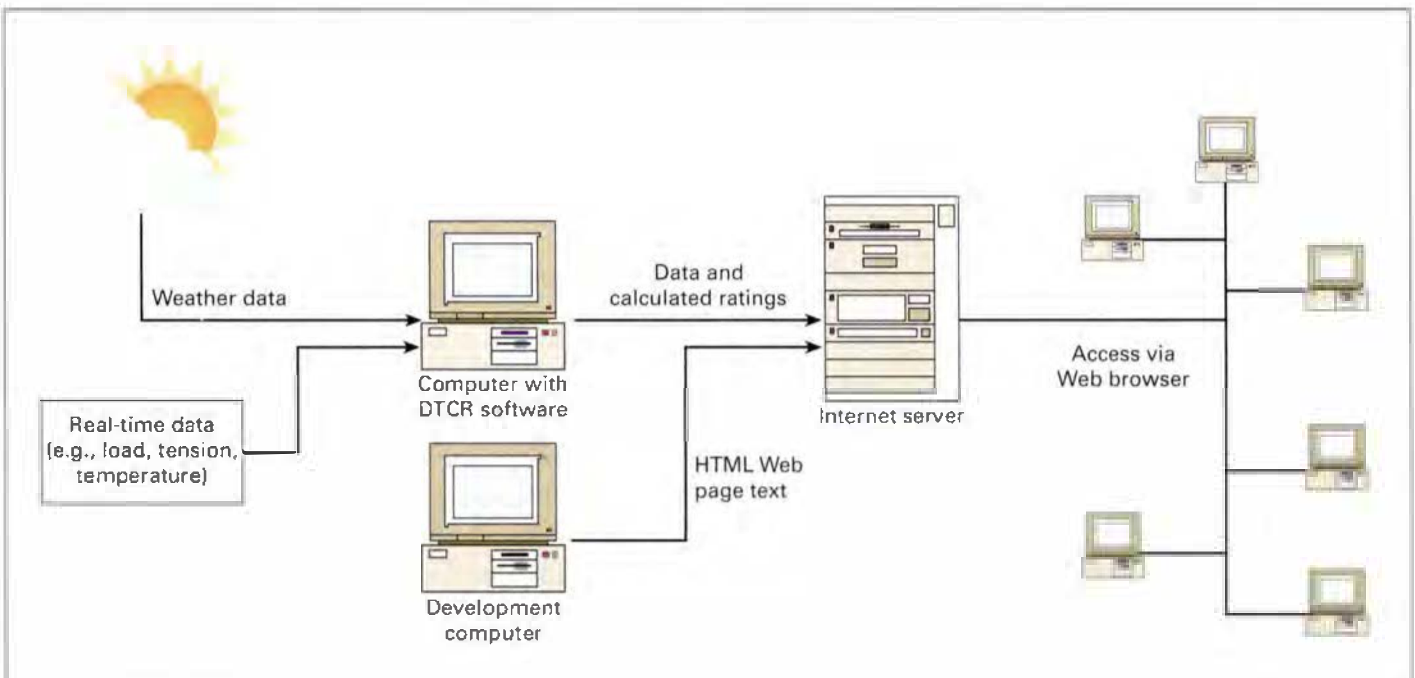
Kondziolka notes that while DTCR allows a line to be operated beyond its static rating in the short term (several hours), the extra capacity that is available cannot be prescheduled or sold for use by others on a firm basis. "At least in today's environment, you can't establish a statistical basis that would enable you to presell the extra capacity. But in the back of our minds, we're considering ways to provide the statistical data necessary to make that possible.

"We are hoping to use the DTCR methodology to build a database that shows the true capacity or rating of a line on an hourly basis and then to demonstrate by calculation what the deviation might be for that basis. If we can provide the appropriate statistical model to our regional reliability council, the Western Systems Coordinating Council, I believe we might be able to actually market the true capability of the line."

For utilities that have thermally limited transmission lines with sufficient line-to-ground clearances and that need immediate short-term capacity relief but do not plan significant line upgrades for at least three years, Kondziolka sees DTCR as "an ideal opportunity and solution."

Taking real-time operation underground

The Canadian utility BC Hydro has installed DTCR on two 230-kV underground transmission cable circuits near Vancouver. According to the utility, which has



Version 2.0 of DTCR was written in programming languages that enable it to run on non-Windows operating systems. These languages—Java for the graphical user interface and C++ for the calculation engines—will also facilitate the future development of an Internet-based server application. Operating on a computer at EPRI, DTCR would receive utility-specific weather and load data for producing and updating dynamic ratings in real time. Transmission system operators and engineers at various locations could review the results simultaneously on an Internet Web site.

over 1.5 million customers in its 948,000-square-kilometer territory in British Columbia, the DTCR technology has helped it defer cable replacement for one year—thereby contributing to one-time savings of about $1 million.

The underground cable circuits, installed in 1957, serve South Burnaby, one of Vancouver's steadily growing suburbs. Given the area's annual population growth of about 2.5% and load growth of about 1.6%, the circuits now frequently carry more load than their original static rating prescribes. Because of the cables' high, age-related maintenance costs and declining reliability, as well as a pressing need to expand transmission capacity, BC Hydro is planning to replace the circuits, one in 2001 and the other in 2002.

Meanwhile, the utility is striving to maximize use of the existing cables and limit the potential for excessive overloading, which could damage cable insulation. When replacement does get under way, BC Hydro will face another challenge: while one circuit is out of service for about six months, the other must reliably carry almost three-quarters of the combined load.

Early in the 1990s, BC Hydro began to look for methods that would help it determine and use the actual—versus the conservative, worst-case—circuit capacity of the cables. Its search soon led it to EPRI, where it became an active member of the DTCR development project review team and a cofunder of several custom modifications that directly addressed its underground cable application needs. After an initial trial in 1995, the utility installed DTCR on three underground circuits in 1997, including the two serving South Burnaby.

By October 1998, the DTCR system was integrated with the company's area control center—a first in utility application. The results of DTCR calculations performed at the control center are immediately available to dispatchers on the SCADA and EMS displays they use to operate the T&D system. This easy access to accurate, real-time line ratings helps the dispatchers to manage the Burnaby congestion by safely maximizing cable use and to make more-confident decisions about handling unanticipated overloads or maintenance outages. According to Allen MacPhail, a specialist engineer in BC Hydro's Transmission and Distribution Engineering Group, the utility expects DTCR to be vital for managing overloads during the extended outage for circuit replacement.

By establishing the control center communications link, BC Hydro has laid the foundation for applying DTCR on other thermally limited circuits and equipment. It already has plans to install the technology on a significant number of power transformers.

MacPhail says that, like SRP, BC Hydro is keenly interested in using DTCR to provide a basis for marketing transmission capacity, which is increasingly in demand by the wholesale power market. "There may be times—when the air is particularly cool or the load is particularly light—when we have extra capacity in our lines, cables, or transformers that has commercial value. On a short-term basis, we could sell that capacity and receive additional revenue."

While competing dynamic equipment rating systems are commercially available, MacPhail says he hasn't run across one that is as generic as EPRI's DTCR or as powerful or as capable of rating multiple lines and multiple elements having different equipment. "It's really quite good in those respects. For general utility application, DTCR appears to be the best of the technologies on the market."

Areas of future focus

While DTCR 2.0 is powerful and robust and has undergone considerable field testing in utility applications, EPRI's Edris says that a number of developments are necessary for the technology to become a fully commercial, self-sustaining product. One is an enhanced ability to make sophisticated statistical capacity estimates beyond the present—for the next day and week. The goal is to enable DTCR to read and use predicted circuit load and weather data for future periods and to present the resulting estimates of future loads and load limits through graphic displays. Another needed development is interactivity, so users can pose what-if questions and modify equipment models in real time.

Better integration of DTCR output with utility SCADA systems is widely agreed to be a priority, adds Edris. "The only way to build confidence in the use of dynamic thermal ratings is through additional field tests and better integration with SCADA. Future field tests should emphasize communication with the utility SCADA database, and DTCR should be modified to facilitate interaction with utility SCADA systems, both in obtaining real-time input data and in providing ratings and other information for SCADA displays. Additional field tests under heavy electrical load conditions are also needed."

To gain acceptance of DTCR by overseas utility affiliates, EPRI is funding the addition of the International System of Units, or SI units, to the software and the addition of other equipment models, such as the CIGRE and IEEE thermal models for overhead lines and the CIGRE transformer model. South Africa's Eskom is collaborating with EPRI in DTCR development by adding a CIGRE model for overhead lines and applying a predictive method for weather conditions. And the Polish Power Grid Company recently finalized an agreement with EPRI to develop and implement DTCR on its system.

Edris's ultimate vision for a real-time, around-the-clock platform for DTCR is to run it on an EPRI server and make it available through an Internet Web site. Member and nonmember utilities could pay usage-based fees for high-security access to the site, where they could observe company-specific weather and electrical load data and dynamic ratings produced by DTCR and updated in real time. Engineers and operators could view the results simultaneously. Real-time input data for this Web application could be obtained from a utility's SCADA database over the utility's computer network, over its intranet, or over the Internet. ■

Further reading

Douglas, D. A., et al. "Dynamic Thermal Ratings Realize Circuit Load Limits." *IEEE Computer Applications in Power*, Vol. 13, No. 1 (January 2000), pp. 38–44.

Development and Field Application of EPRI Dynamic Thermal Circuit Rating (DTCR) Technology. EPRI, August 1999. TR-113391.

Background information for this article was provided by Abdel-Aty Edris (aedris@epri.com).

Urgent-Resp

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THE STORY IN BRIEF Recent power outages in major urban areas have highlighted the industry's growing need for quick technical responses to business-critical problems. Reductions of in-house engineering staffs have made such problems even more difficult to deal with in an emergency time frame, and many utilities are relying more heavily on outside expertise to provide timely solutions. Anticipating this need, EPRI has reconfigured some of its most valuable analysis and troubleshooting capabilities to mobilize urgent-response services for the industry. Much of this assistance will be provided by EPRI's specialized technology centers located throughout the country and by EPRIsolutions—a new service-oriented subsidiary. **by John Douglas**

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Even before August 12, the summer of 1999 had been hard on the American Midwest and its electric utilities. More than 200 people had died from heat-related causes; parts of six states had been declared agricultural disaster areas; and at least 24 power systems, from Georgia to Wisconsin, had set new electricity demand records. But it was the outage of August 12, which shut down part of Chicago's business district, that most shook the electric power industry and suddenly focused attention on the importance of having the highest-quality technical services available at a moment's notice.

Chicago's electric utility, Commonwealth Edison, had been concerned about the state of its distribution system for some time. In March 1999, ComEd had promised the city to spend more than $1 billion on system improvements. Then, beginning in late July, a series of outages climaxed a two-week heat wave in which peak demand records had been broken more than half a dozen times. Over 100,000 customers lost power in those outages.

The immediate series of events leading up to August 12 began about a week earlier, when ComEd removed one of four transformer banks from service at its Jefferson substation, which serves the vital South Loop business district of Chicago. On August 11, the failure of a 69-kV cable knocked out a second transformer bank. At 9:40 a.m. on August 12, another 69-kV cable failure led to the removal of a third transformer bank. To relieve the growing overload at the Jefferson substation, ComEd switched some power to a new spare transformer at its LaSalle substation, but this unit quickly began to overheat because of a problem with its circulation system. Finally, in the early afternoon, ComEd issued a 45-minute warning that power would have to be cut to much of the South Loop while system repairs were undertaken.

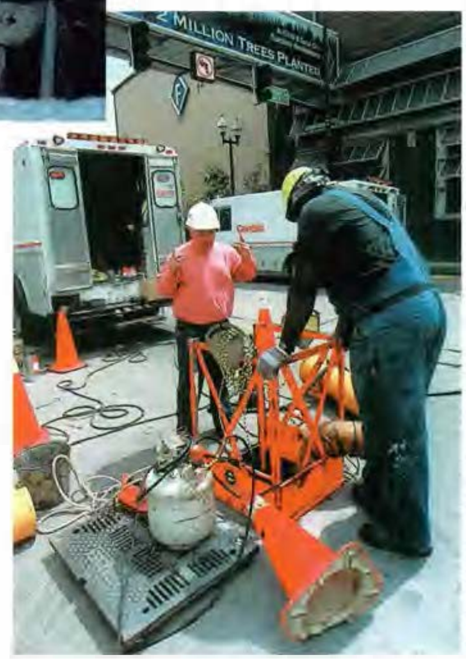
The effects of the outage were widespread. Along with scores of major commercial buildings, the Chicago Board of Trade was forced to close and the Options Exchange halted trading temporarily. Closure of the Dirksen Federal Building affected offices of the FBI and the U.S. attorney and dozens of federal courtrooms. Other customers, including the University of Illinois at Chicago, had to rely on backup sources to meet their power needs. At a press conference that afternoon, a visibly angry Mayor Richard Daley expressed the sentiments of many Chicagoans when he said of ComEd: "We're sick and tired of them, and they had better change."

ComEd acted quickly to undertake a thorough analysis of what went wrong and what changes would be needed to prevent a recurrence. "We must improve our maintenance and inspection procedures," said the utility's chairman, John Rowe. "We are going to do this root and branch. I'm going to get more people involved, including contractors."

To help organize this effort, ComEd officials called on EPRI, whose response team members began to arrive in Chicago the day after the outages. Eventually more than two dozen EPRI staff experts worked on-site for 12 straight days, and support continued for months. Results from the investigation formed the basis of ComEd's formal response to the Illinois Commerce Commission and to the city of Chicago.

The EPRI team worked side by side with six ComEd teams to conduct a comprehensive review of operation and maintenance practices, equipment condition and design, planning procedures, and organizational issues. The teams discovered instances in which alarms on critical equipment had been disconnected, cable and transformer maintenance had not been performed as needed, and both field staff and engineers at company headquarters were unfamiliar with equipment instrumentation. More important, the teams identified several root causes for these failures, including a lack of clear responsibility for ensuring that required maintenance was actually done, a lack of communication between departments, and an overcentralized organization in which management was often detached from events in the field.

The initial results of this assessment were presented to a panel of industry experts in formal sessions on August 26 and September 10. After their comments were incorporated, a final report was submitted to Mayor Daley on September 15—almost exactly a month after the South Loop outage. Describing the results as "sobering, but essential," ComEd Chairman Rowe concluded that "for the first time, we have a clear and complete picture of what and where the problems are. We also have a clear idea of exactly what needs to be done and when."



PHOTOS BY NANCY STONE/CHICAGO TRIBUNE

The failure of underground cables touched off a series of problems that led to a major power outage in Chicago's South Loop business district last August. A quickly assembled EPRI response team of two dozen experts worked on-site with Commonwealth Edison personnel to analyze the sequence of events, identify their root causes, and create a comprehensive plan for avoiding recurrences. ComEd has since launched a two-year, $1.5 billion upgrade of its downtown distribution system.

Need for urgent-response services

More and more, as profound changes sweep the electric power industry, EPRI is providing the kind of urgent technical response just described. At the same time that electricity generation, delivery, and end-use technologies are becoming more sophisticated, many utilities—focused on cutting costs—are reducing in-house technical staffs and maintenance budgets. As a result, utilities are increasingly finding that they lack the internal resources required to handle technologically complex emergencies. Rapid problem solving is especially important in the power delivery area, where failures can impact customers directly and immediately. The ComEd outage was not an anomaly; reliability problems, particularly those related to maintenance, have become more frequent in the industry in the past several years.

For example, on August 26 of last year, Indianapolis Power & Light contacted EPRI for assistance in investigating severe corona discharge activity in the switchyard of its Petersburg power plant. Problems occurring over a two-month period had led IP&L to temporarily shut down 1700 MW of generation and had resulted in the destruction of two generation step-up transformers. The day after the utility's request, EPRI had an investigator on-site to begin a series of detailed inspections, which included the application of a recently developed camera for detecting corona activity in daylight. (See the Winter 1999 issue of the *Journal* for more information on this technology, the DayCor camera.)

The investigator found the problem to be severe contamination of electrical insulation in the switchyard and on the exiting transmission line. The root cause of this contamination was cooling tower effluent, more of which was present than usual because of damaged and deteriorated baffles in the tower. The effluent also had a higher-than-normal concentration of dissolved solids. The investigator recommended a new cleaning program for the insulating material. Longer-term recommendations included the installation of new equipmenr-monitoring procedures and the strengthening of preventive maintenance efforts.

Equipment contamination was also responsible for reliability problems on the 69-kV system of Maui Electric Company. For some time, MECO had been experiencing insulator flashovers, which can result in severe outage conditions. On December 28, 1998, a downpour of about 1.5 inches (3.8 cm) of rain in one hour nearly caused an island-wide blackout. The following week, at MECO's request, an EPRI team conducted site inspections and analyzed insulator performance. The team concluded that the insulators had high contamination levels and required periodic washing. On-site discussions with the utility's substation and line maintenance personnel led to the identification of other system problems. These included the unexplained tripping of double-circuit lines, pole-top fires occurring upon autoreclosure into an existing fault due to unreliable communication between line-end relays, and the misoperation of lightning arresters due to degradation of grounding schemes by vandalism. A report documenting all the findings was provided promptly to MECO for use in hearings with local regulatory bodies.

The need for such immediate technical problem solving is likely to grow substantially as the electric power industry continues to evolve. EPRI is answering this need by providing new urgent-response services based on the unique expertise of its staff. Increasingly, such technical support will be offered through a new service-oriented subsidiary, EPRIsolutions, Inc. (see sidebar, p. 30).

One of the first services to be offered by EPRIsolutions is a power delivery system performance audit designed to prevent the type of costly failures experienced at ComEd, IP&L, and MECO. Such an audit is conducted by a team of EPRI staff members, including personnel from the T&D Engineering and Test Centers in Lenox, Massachusetts, and Haslet, Texas, which are operated for EPRI by EPRIsolutions. Typically a team has a dozen members or so—experts in system engineering, equipment rating and condition assessment, system planning and operations, and maintenance practices and policies. The team works with customer staff—usually for two to three weeks—to identify system weaknesses, propose remedies, and prepare a strategic plan for implementing changes. A similar service will be offered to determine the root causes of problems that have already developed. To date, more than half a dozen utilities have expressed interest in receiving a power delivery system performance audit.

Services by subscription

Another type of urgent-response support is provided by EPRI's Nondestructive Evaluation Center in Charlotte, North Carolina. EPRI members subscribing to the NDE Center can dedicate up to 20% of their funds for Subscriber-Requested Assistance (SRA)—expert assistance with current NDE-related problems at nuclear, fossil, and hydro plants. SRA results are communicated to other subscribers in order to extend the benefits of this work. In 1999, a total of 169 SRA activities were conducted for 39 subscribers.

When South Carolina Electric & Gas, for example, requested help with heat exchanger tube leaks at its V. C. Summer nuclear plant, NDE Center staff conducted an on-site review of outage inspection activities. In analyzing eddy-current data for selected heat exchanger tubes, the EPRI team found evidence of internal pitting, which could have been contributing to the leaks. The removal and destructive evaluation of one tube confirmed the presence of pits.

Another SRA team helped Niagara Mohawk Power assess ultrasonic examination data that seemed to indicate intergranular stress corrosion cracking (IGSCC) in recirculation system welds at the Nine Mile Point nuclear plant. The indications were puzzling, since the type of stainless steel used in the welded joints was considered to be especially resistant to IGSCC. To determine the cause of the ultrasonic examination anomalies, the NDE Center experts performed a detailed review of each weld. They concluded that the irregularities were related to the fabrication of the joints, not to IGSCC.

The Maintenance and Diagnostics (M&D) Center in Charlotte, which is operated for EPRI by EPRIsolutions, also provides urgently needed technical support to utilities. In particular, it helps them avoid problems at fossil-fired power plants through predictive maintenance programs. At the Salem Harbor and Brayton Point plants of New England Power, for example, M&D Center experts worked with plant staff in using infrared thermography (IRT) to anticipate equipment problems. An IRT survey at Salem Harbor during especially hot weather revealed that the only operative auxiliary cooling water pump on one generation unit had a motor lead that was about to melt. It also found that a large (2500-hp) boiler feedpump motor was overheating because of a clogged air filtration system.

In another effort, an M&D Center team helped Cinergy develop a predictive maintenance program for detecting incipient failures in electric motors. The program technologies included IRT, current monitoring, lubricating oil monitoring, electrical tests, and vibration analysis. By following the team's recommendations, Cinergy detected and repaired problems in four large motors, for estimated cost savings of $182,000 over the three-year period during which failures would probably have occurred.

End-use services

Many of the technical problems members bring to EPRI for urgent, expert assistance involve an electrical end-use application at a customer site. In such cases, solutions may be provided either by the EPRI technical development staff or by one of the centers and offices that make up the Retail Technology Applications Network.

When the New York Power Authority (NYPA) had a problem with fluorescent lamps at the World Trade Center, for example, it called on EPRI PEAC Corporation in Knoxville, Tennessee, for technical support. (Formerly called the Power Electronics Applications Center, EPRI PEAC is now a subsidiary of EPRIsolutions.) Earlier, the problem had seemed simple: some compact fluorescent lamps installed by NYPA in the lobby of the twin-tower office complex were flickering and needed to be replaced. The original lamps did in fact prove to be defective, but the new ones also behaved in a puzzling manner: they dimmed each time the complex's HVAC system was switched off for the night. NYPA was concerned not only about fixing the problem but also about finding a way to minimize on-site work and disruptions to the customer's business operations.

PEAC was able to meet both of these needs by simulating the lamps' operating environment in a laboratory at the University of Tennessee. Tests on sample lamps, fixtures, and ballasts revealed that—contrary to initial speculation—light output did not change simply as a result of cooler ambient temperatures. However, further experiments showed that when the lamps were subjected to a cold draft of air, they dimmed dramatically. The investigators concluded that the cause of the dimming problem was the flow of cold air through the lobby's plenum when the HVAC system was turned off.

On the basis of this finding, PEAC staff recommended a surprisingly simple solution—installing inexpensive gaskets over holes in the lamp fixtures to keep out the draft. This solution, which was verified in the test chamber before being put into practice, eliminated the dimming problem and allowed NYPA to avoid the cost of replacing the lamps and fixtures.

Because of its reputation for integrity, EPRI is also in an excellent position to quickly provide customers with objective information about claims made by vendors of end-use equipment. Orange and Rockland Utilities, for example, contacted EPRI's Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC&R) Center in Madison, Wisconsin, for help in determining whether a new residential thermal storage unit would allow homeowners to benefit from the utility's off-peak pricing program. Such units typically consist of electric resistance strips buried inside a large mass of bricks. At night, the bricks are heated by means of inexpensive electricity; then, during the day, they provide heat with the help of a small fan. The product in question, however, claimed to provide these benefits without the need for a massive storage medium, which raised the suspicions of utility personnel who were asked whether they would recommend the product.

Experts at the HVAC&R Center confirmed that the manufacturer's promises were indeed too good to be true. The product turned out to be a simple baseboard electric resistance strip heater, with a layer of insulating material wrapped around it. Even though the device sold

EPRIsolutions: Latest Member of the EPRI Family of Companies

One important side effect of electric power industry restructuring has been a reduction in the human and capital resources allocated for introducing new technologies. In particular, the engineering staffs of many utilities have been cut, and critical maintenance and operations functions have been outsourced. The result is a growing demand for technology-related services, including product customization, installation, and training. As a major source of technological innovation for the industry, EPRI is in a unique position to provide such services, both to members and to nonmembers. Because some of these private-benefit services lie beyond the scope of EPRI's tax-exempt mission to conduct a collaborative R&D program in the public interest, they can best be provided through a new taxable subsidiary—EPRIsolutions, Inc.

"Through EPRIsolutions, EPRI will be able to explore new markets and reach new customers," says Karl Stahlkopf, an EPRI vice president and the CEO of EPRIsolutions. "The primary purpose of setting up the new subsidiary is to increase the satisfaction of EPRI members by offering them a broader range of services than we could before. We also want to serve the needs of other companies—both inside and outside the electric power industry—in order to enhance EPRI's revenue base and to attract new kinds of customers."

EPRI SOLUTIONS

EPRIsolutions is being formed through the merger of two previously existing subsidiaries, EPRICSG and EPRIGEN. Those subsidiaries were created to allow EPRI to conduct proprietary R&D on behalf of individual funders, who would retain rights to the intellectual property involved. In addition to continuing this activity, EPRIsolutions will provide customized technology application and consulting services. EPRIsolutions formally came into being January 1, 2000.

"By helping customers adapt EPRI products to meet their specific needs and by training their staff in how to use these products more effectively, we can enhance the value of the technologies already developed through EPRI's widely respected research program," Stahlkopf concludes. "Our focus is on offering integrated service packages—that is, solutions to everyday business problems—rather than isolated services. In addition, the organizational leanness of EPRIsolutions will help us respond more quickly to meet customers' urgent needs."

For EPRI members, many of the services provided by EPRIsolutions will be coordinated through the planning activities of EPRI's Sector Applications staff. Nonmember customers of EPRIsolutions can tap the expertise of EPRI staff on a contract basis. □

for four times the price of the heater alone, the main selling point was that its installed cost was far less than that of an electric heat pump. What the advertisements did not say was that the heat storage capacity of the insulating material was far too low for this type of application and that the unit would consume two to five times more electricity than a heat pump. Armed with this information, Orange and Rockland decided not to recommend the product to its residential customers.

The New York Power Authority called on EPRI PEAC Corporation for assistance with an intractable lighting problem at a high-profile customer site: the lobby of the World Trade Center's twin-tower office complex. By simulating the lobby's lighting setup and operating environment in the laboratory, PEAC was able to pinpoint the source of the problem and develop an inexpensive solution without disrupting business operations at the center.

EMMANUEL FAURE/SUPERSTOCK INC

Response to environmental challenges

In the environmental area, EPRI staff members spend considerable time each year responding to industry needs for expert testimony on regulatory issues and to requests from individual utilities for help with regulatory compliance. The stakes are often high, and the responses must be timely.

One of EPRI's most important contributions in support of science-based regulation was to provide the U.S. Environmental Protection Agency with information on high-volume combustion ash and sludge from fossil-fired power plants. This information influenced the EPA's determination that the ash and sludge should be regulated as nonhazardous waste. The Utility Solid Waste Activities Group credited this regulatory input for nearly $6.4 billion in benefits. Currently, EPRI experts are working with the EPA on issues critical to the accurate measurement of fine-particulate emissions. In light of this ongoing work, the EPA has decided to postpone its implementation of new fine-particulate standards until after 2002, and Congress has urged the agency to coordinate its research plans with EPRI's.

The type of regulatory compliance assistance available to individual utilities can be illustrated by an air quality modeling effort with Golden Valley Electric Association. GVEA's coal-fired power plant in Healy, Alaska, is located just outside Denali National Park and Preserve, and there was concern that when a new generation unit was added to the plant in 1998, total emissions of sulfur dioxide would exceed ambient air quality standards. The EPA computer code used to model the air quality indicated that SO_2 emissions would violate hourly standards unless an expensive control system was installed. This model was relatively old, however, and was believed to overestimate ground-level SO_2 concentrations for the specific building configuration and meteorological conditions at Healy.

GVEA turned to EPRI, which had been developing a more refined air quality model called PRIME. The two collaborated closely to modify PRIME to ensure its applicability for modeling plume rise and dispersion at the Healy plant. Results from the customized model indicated that SO_2 concentrations near the plant would be only about one-half as high as calculated earlier—meaning that a less expensive control system could be used. When EPA staff agreed that PRIME was the more accurate model in this case, the state of Alaska approved an air quality permit for the Healy plant, with concurrence from the U.S. National Park Service.

Sometimes, EPRI environmental experts can help a utility select a cost-saving new technology that will be useful in attaining regulatory compliance. When Northwestern Public Service was looking for a better way to remediate soil at a manufactured gas plant site, it asked EPRI for advice. Working directly with the utility's environmental consultant to assess the situation, EPRI staff saw a unique opportunity to use a mobile rotary kiln and oxidizer to separate coal tar residues from the soil and destroy them. With this advanced technology, the utility was able to treat almost twice as much soil as originally anticipated while still finishing the job on schedule—and at a much lower cost than possible with other alternatives. As a result, Northwestern received an EPA Region VIII Outstanding Achievement Award for Leadership and Innovation.

Services for a competitive era

EPRI's new service initiative is expected to have a broad impact. Certainly it will enhance EPRI's ability to serve its current members effectively and open up new markets for its technical expertise. And as EPRI President and CEO Kurt Yeager points out, larger issues are also at stake: "Technology holds the key to success in a more competitive electric power industry, but applying advanced technologies is difficult in an era of severe cost cutting. Providing new technology application services, both as part of EPRI's collaborative R&D program and as a commercial business venture through EPRIsolutions, will play an important role in keeping our industry at the cutting edge of innovation in an unprecedented period of rapid technological change." ■

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In the Field

Demonstration and application of EPRI science and technology

Phased-Array Technique for Disk Inspection

EPRI has developed a phased-array ultrasonic technology that provides a better, faster, and cheaper nondestructive examination (NDE) technique for inspecting nuclear steam turbine components. Last fall, Arizona Public Service and Alliant Energy each successfully used the technique during a plant outage to examine turbine disk blade attachments.

Nuclear plant operators have used a variety of surface-sensitive NDE techniques—for example, liquid penetrant, magnetic particle, and eddy-current techniques—to inspect blade attachment regions. For some designs (axial entry), in which certain areas of a blade attachment are exposed, these procedures can be applied with the blades in place. But for the straddle-mount design, in which a blade straddles the entire attachment, surface inspections can be conducted only with the blades removed. To perform inspections on rotors of this design with the blades in place, an ultrasonic technique featuring a broad-beam, fixed-angle transducer set was developed in the 1960s and has been used with little variation ever since. However, the inadequate resolution and sizing capabilities of this approach, along with a propensity for false calls, have made it necessary to remove blades—a time-consuming and expensive procedure—to verify indications.

In 1997, as an alternative to the conventional broad-beam approach, EPRI developed the phased-array ultrasonic technique, which shortens inspections, reduces the rate of false calls, and offers improved depth sizing. The new technique uses a linear array probe containing a series of small individual ultrasonic transducer elements. When the probe is programmed for the blade attachment application, it successively and rapidly generates longitudinal-mode or shear-mode sound beams or both. The beams' angles typically range—in increments of 1 degree or less—from 30 to 80 degrees. In contrast, sound beams from a conventional probe have a single, constant angle.

COURTESY ARIZONA PUBLIC SERVICE CO

The first commercial application of the phased-array technique took place at Arizona Public Service's Palo Verde plant. "The results were as good as or better than we expected," reports Bill Lehman of APS. Because better data were gathered, it was possible to make more-reliable interpretations, he says. The system performed within the allotted time and is expected to reduce the time for turbine disk blade attachment inspections. Speedier inspections will be important in future outages, since outage schedules are shrinking.

At Alliant Energy's Duane Arnold plant, personnel had originally planned to use the new technique only to obtain baseline information before performing a mitigation process that involved removing the turbine blades and machining the dovetail area. When it was discovered that removing the blades could damage them or the rotor, however, phased-array ultrasonic inspection became the only way to assess the condition of the blade attachments.

The phased-array technique provided "good data and an accurate picture of the condition of the dovetail," says Alliant's Mark Huting, adding that it "picked up a small crack through a 4- to 5-inch metal path without blade removal." Fluorescent magnetic particle testing was used to confirm the crack location. The crack was so tight, Huting says, that its location had to be pointed out to the examiner.

Alliant's confidence in the inspection data enabled it to cancel stress corrosion cracking mitigation and thus avoid the possibility of damage to the dovetail during blade removal. The cancellation also reduced the turbine outage schedule by several days. Huting calls the phased-array technique "the most impressive new technology I have seen in a long time."

The EPRI project's commercialization program provided information on the technique's development to participating inspection companies in order to reduce economic and technical risks and facilitate customization for their applications. General Electric agreed to pursue the technology and subjected it to its Six Sigma Quality Control program, a recognized program for reducing product error.

After the successful completion of that program last September, GE began offering commercial applications. WesDyne International is currently discussing a similar commercialization arrangement with EPRI for applying the technique to axial-entry blade attachments.

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Maintenance Optimization Yields Savings for Nevada Power

In order to meet the growing demand for low-cost electricity, many energy companies are implementing new maintenance strategies to improve equipment reliability, unit availability, and work process flow. Power plant maintenance can be reactive, preventive, or planned—or a combination of the three. Optimal maintenance is the lowest-cost maintenance that achieves the desired level of equipment reliability.

At Nevada Power's Clark–Sunrise–Harry Allen (CSHA) combustion turbine combined-cycle complex, past maintenance strategies mainly entailed time-based preventive maintenance, which was underutilized, and corrective maintenance, which was used aggressively and created a reactive environment. The company decided to develop a condition-based predictive maintenance (PDM) approach. Although some PDM technologies and tools were in place at CSHA, the information provided by those technologies was not being used as effectively as possible to guide maintenance decisions. Nevada Power sought EPRI's help in formalizing a PDM approach. The company wanted its program to integrate all the available data relevant for making timely decisions on equipment maintenance.

To help Nevada Power establish the program, staff from EPRI's Plant Maintenance Optimization Target, Maintenance and Diagnostics Center, Customer Assistance Center, and Combustion Turbine Center conducted a PDM and performance assessment study for 12 gas turbine combined-cycle units at CSHA. The project, which began in 1997, produced a detailed plan and schedule for the development, implementation, and coordination of a PDM program at the complex and all associated support organizations. The plan emphasized the steps to be taken to develop meaningful PDM implementation, performance improvement, and combustion turbine long-term planning and maintenance management programs.

COURTESY NEVADA POWER CO.

The project included PDM level-of-awareness training that required active participation and communication by many plant and central support personnel—critical ingredients for a successful condition-based maintenance program. The final project report to Nevada Power listed the strengths and areas for improvement identified at CSHA and laid out a comprehensive plan for implementing the recommendations. Among the steps recommended were that existing performance information be distributed to operations staff at all levels and that such key data users as plant operators consistently take into account diagnostic and performance information.

Increasing the effectiveness of information management at CSHA resulted in improved unit efficiency and immediate performance gains. For the first six months of the PDM program, Nevada Power estimated net savings of approximately $309,000 for maintenance on turbines, transformers, batteries, and pumps. On the basis of current capacity factors, the company projects total annual benefits of $600,000 to $900,000 from plant maintenance optimization, primarily in the form of reduced costs for maintenance and increased electricity production. "Because of this predictive maintenance project, we're doing a better job of deciding what we should be doing and how often we do it," says Nevada Power's Bruce Humes.

■ *For more information, contact Mark DeCoster, mdecoste@epri.com, 650-855-2541.*

Technical Reports & Software

To place an order, call EPRI Customer Service at 800-313-3774 or 650-855-2121, and press 1 for software or 2 for technical reports. Target funders can download an Acrobat PDF file of a technical report by searching for the report number on EPRI's Web site (www.epri.com).

Energy Delivery

Disaster Planning and Mitigation Technologies: Interim Technology Inventory Report
TR-108972-V4
Target: Disaster Planning and Mitigation Technologies
EPRI Project Manager: R. Bernstein

UPS-Substation™: Evaluation, Conceptual Design, and Generic Specification
TR-111091
Target: Substation Assets Utilization
EPRI Project Manager: S. Eckroad

Femtosecond Communication: Time Multiplexing on an FS Time Scale
TR-111786-V1
Target: Disaster Planning and Mitigation Technologies
EPRI Project Manager: R. Bernstein

Evaluation of Field Diagnostic Techniques for Transmission Cable Accessories
TR-112676
Target: Underground Transmission
EPRI Project Manager: W. Zenger

Integration of Distributed Resources in Electric Utility Distribution Systems: Distribution System Behavior Analysis for Rural and Urban Feeders
TR-112737
Target: Distributed Resources Information and Tools for Business Strategy Development
EPRI Project Manager: F. Goodman

TAG® Technical Assessment Guide, Vol. 5: Distributed Resources
TR-113165-V5
Target: Distributed Resources Information and Tools for Business Strategy Development
EPRI Project Manager: G. Ramachandran

Prototype Intelligent Software Agents for Trading Electricity
TR-113366
Target: Grid Planning and Development
EPRI Project Manager: M. Amin

Estimates of Production Cost Variance Using Chronological Simulation
TR-113395
Target: Grid Planning and Development
EPRI Project Managers: N. Abi-Samra, R. Adapa

Dynamics of Streaming Electrification in Large Power Transformers
TR-113461
Target: Substation O&M
EPRI Project Manager: S. Lindgren

UCA Substation Communication Initiative Demonstration
TR-113480
Target: Substation O&M
EPRI Project Manager: J. Melcher

Remotely Controlled Manhole Cover Removal System
TR-113485
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

GIS/GPS Workshop '99: Applications and Developments for Electric Utilities
TR-113513-CD
Targets: Overhead Transmission; Disaster Planning and Mitigation Technologies; Rights-of-Way Environmental Development and Management
EPRI Project Manager: M. Ostendorp

Optical Sensors: Exploratory Work and Future Research
TR-113533
Target: Substation O&M
EPRI Project Manager: R. Lings

Streaming Electrification Model Tests
TR-113535
Target: Substation O&M
EPRI Project Manager: S. Lindgren

138-kV Maintenance Hole Cover Restraining System Testing
TR-113556
Target: Underground Transmission
EPRI Project Manager: W. Zenger

Issues and Solutions: North American Grid Operations (2000–2005)
TR-113565
Target: Grid O&M
EPRI Project Manager: S. Lee

On-Line Transformer Winding and Dielectric Monitoring: Laboratory and Field Test Results
TR-113650
Target: Substation O&M
EPRI Project Manager: B. Ward

Proceedings: Transformer Reliability—Management of Static Electrification
TR-113741
Target: Substation O&M
EPRI Project Manager: S. Lindgren

Development of STATCOM
AP-113826
Target: Substation Assets Utilization
EPRI Project Manager: A. Edris

Design, Installation, and Operation of American Electric Power ±320-MVA Unified Power Flow Controller
TR-113839
Target: Substation Assets Utilization
EPRI Project Manager: A. Edris

Practical Guide to SF_6-Handling Practices
TR-113933
Target: Substation O&M
EPRI Project Manager: B. Damsky

Transformer Moisture-in-Paper Assessment Method: Field Trial
TR-114075
Target: Substation O&M
EPRI Project Manager: S. Lindgren

Strategic Role of Distributed Resources in Distribution Systems
TR-114095
Target: Distribution Systems
EPRI Project Manager: S. Chapel

Area Investment Strategy Model
Version 1.5 (Windows 95); AP-109730-R1
Targets: Distribution Systems; Underground Distribution Infrastructure
EPRI Project Manager: S. Chapel

MMW: Maintenance Management Workstation
Version 1.1b (Windows 95, NT); AP-112428-R1
Target: Substation O&M
EPRI Project Manager: P. Vujovic

PQ Planner
Version 1.0 (Windows 95, 98, NT); AP-110346
Target: Power Quality for Improved Energy Delivery
EPRI Project Manager: A. Sundaram

SDWorkstation: Substation Design Workstation
Version 2.0 (Windows 95, 98, NT); AP-114649
Target: Substation O&M
EPRI Project Manager: B. Damsky

SEPIA: Simulation of Complex Systems for the Power Industry With Adaptive Agents
Version 1.2.3 (Windows 95, NT); AP-112816
Target: Grid Planning and Development
EPRI Project Manager: M. Amin

■ TIM Oracle: Transmission Inspection and Maintenance System
Version 2.4 (Windows 95, NT); AP-114634
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Environment

Evaluation of Implementation of Contained Recovery of Oily Waste (CROW™) Enhanced Recovery at a Manufactured Gas Plant Site
TR-111714
Target: MGP Site Management
EPRI Project Manager: A. Jain

Numerical Evaluation of 60-Hz Magnetic Induction in the Human Body in Complex Occupational Environments
TR-112460
Targets: EMF Health Assessment; Occupational Health Assessment
EPRI Project Manager: R. Kavet

Land Application Uses for Dry Flue Gas Desulfurization By-Products: Phase 3
TR-112916
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: D. Golden

Review of Sediment Removal and Remediation Technologies at MGP and Other Contaminated Sites
TR-113106
Target: MGP Site Management
EPRI Project Manager: A. Jain

Soil Compaction: A Comprehensive Literature Review (With Interpretations for Transmission Rights-of-Way)
TR-113158
Target: Rights-of-Way Environmental Development and Management
EPRI Project Manager: J. Goodrich-Mahoney

Soil and Crop Response to Power Line Construction Traffic and Shallow and Deep Tillage in New York State
TR-113159
Target: Rights-of-Way Environmental Development and Management
EPRI Project Manager: J. Goodrich-Mahoney

Determination of the Effectiveness of Herbicide Buffer Zones in Protecting Water Quality
TR-113160
Target: Rights-of-Way Environmental Development and Management
EPRI Project Manager: J. Goodrich-Mahoney

Rights-of-Way Stability: A 15-Year Appraisal of Plant Dynamics on Electric Power Rights-of-Way in New York State
TR-113191
Target: Rights-of-Way Environmental Development and Management
EPRI Project Manager: J. Goodrich-Mahoney

Vegetation Dynamics Along Utility Rights-of-Way: Factors Affecting the Ability of Shrub and Herbaceous Communities to Resist Invasion by Trees
TR-113377
Target: Rights-of-Way Environmental Development and Management
EPRI Project Manager: J. Goodrich-Mahoney

GIS/GPS Workshop '99: Applications and Developments for Electric Utilities
TR-113513-CD (see listing under Energy Delivery)

Environmental Asset Management Study: Case Study Report for Sierra Pacific and Nevada Power
TR-113521
Target: Environmental Assets Management
EPRI Project Manager: P. Radcliffe

Safety and Health Asset Management Study: Case Study Report for Sierra Pacific and Nevada Power
TR-113522
Target: Environmental Assets Management
EPRI Project Manager: P. Radcliffe

Environmental Asset Management Study: Case Study Report for Alliant
TR-113580
Target: Environmental Assets Management
EPRI Project Manager: P. Radcliffe

A Framework for Hedging the Risk of Greenhouse Gas Regulations
TR-113642
Targets: Power Markets and Risk Management; Generation Asset Management and Valuation; Least-Cost Options for Meeting Greenhouse Gas Emission Reduction Requirements
EPRI Project Manager: T. Wilson

Survey and Characterization of Utility Vault Waters and Sediments
AP-113730
Target: T&D Soil and Water Issues
EPRI Project Manager: N. Goodman

Non-PCB Capacitor Fluids Used in the Power Industry: Chemical Composition and Dissolution Characteristics
TR-113974
Target: T&D Soil and Water Issues
EPRI Project Manager: M. McLearn

■ D-MCM: Dynamic Mercury Cycling Model
Version 1.0 (Windows 95, NT); AP-114715
Targets: Air Toxics Health and Risk Assessment; Water Quality Criteria and Toxics in Aquatic Environments
EPRI Project Manager: L. Levin

■ MANAGES™: Management and Evaluation of Groundwater Monitoring Data
Version 2.5 (Windows 95, 98, NT); AP-113593
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: K. Ladwig

■ NO_x Market Assessor
Version 1.1 (Windows 95, 98, NT); AP-114716
Target: Tropospheric Ozone and Precursors
EPRI Project Manager: G. Hester

Fossil and Renewable Generation

TAG® Technical Assessment Guide, Vol. 3, Rev. 8: Fundamentals and Methods—Electricity Supply
TR-100281-V3R8 (see listing under Retail and Power Markets)

Predictive Maintenance Guidelines, Vol. 4: PDM Best Practices
TR-103374-V4
Targets: Plant Maintenance Optimization; Predictive Maintenance Program Development and Diagnostic Tools
EPRI Project Manager: R. Pflasterer

Continuous Emission Monitoring Guidelines: 1999 Update
TR-111165
Target: Continuous and Predictive Emissions Monitoring
EPRI Project Manager: C. Dene

Mitigation of Fireside Corrosion in Low-NO_x Boilers: State-of-the-Art Assessment of Materials Solutions
TR-112823
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: W. Bakker

Kingsnorth PF (Pulverized Fuel) Flow Meter Demonstration Trials
TR-113033
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: R. Brown

Conceptual Engineering and Cost Estimate for 100-MW and 20-MW Nominal Capacity CASH Plants
TR-113360
Target: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: A. Cohn

Repair Technology for Stub Tube-to-Header Creep Damage
HW-113512
Target: Fossil Repair and Replacement Applications Center
EPRI Project Manager: D. Gandy

1999 EPRI Fossil Plant Maintenance Conference
TR-113534-CD
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Guidelines for Upgrading Electrostatic Precipitator Performance, Vol. 1: Optimizing an Existing ESP
TR-113582-V1
Target: Primary Particulate Control
EPRI Project Manager: R. Altman

Using Environmental Solutions to Lubrication at Hydropower Plants
TR-113584-V1
Target: Hydropower Operations, Relicensing, and Environmental Issues
EPRI Project Manager: M. Blanco

Rehabilitating and Upgrading Hydropower Plants
TR-113584-V2
Target: Hydropower Operations, Relicensing, and Environmental Issues
EPRI Project Manager: M. Blanco

R&D/Technology Management Best Practices Study, Vol. 1: Executive Summary
TR-113606-V1 (see listing under Retail and Power Markets)

NO_x Control Field Test Results on Coal-Fired Cyclone Boilers (CNCIG Programs)
TR-113643
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: D. O'Connor

Guidelines for Inter-Control Center Communications Protocol (ICCP) Implementation: Plant Controls to Dispatch Computer
TR-113652
Target: I&C and Automation for Improved Plant Operations
EPRI Project Manager: R. Shankar

Revised Guidelines for Makeup Water Treatment
TR-113692
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: B. Dooley

Corrosion of Cu-Ni-Zn Alloys in Water-Ammonia Power Plant Environments: Development of High-Temperature Potential-pH (Pourbaix) Diagrams
TR-113697
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: B. Dooley

Assessment of the Laser Welding Process for Superalloy Gas Turbine Blade Welding
TR-113748
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Managers: V. Viswanathan, J. Scheibel

Development and Assessment of Advanced NO_x Catalysts
TR-113775
Target: Postcombustion NO_x Control
EPRI Project Managers: K. Zammit, R. Chang

Biomass Cofiring: Field Test Results (Bailly and Seward Demonstrations)
TR-113903
Target: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: E. Hughes

Combustion Turbine/Combined-Cycle Monitoring Platform: ORAP LINK and Combustion Turbine Reliability Analysis
TR-113984
Targets: Combustion Turbine and Combined-Cycle O&M; New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: J. Scheibel

Interim Guidelines for In-Situ Inspection and Monitoring Techniques for Steam Turbines, Vol. 1: Overview of Remote Visual Inspection
TR-113996-V1
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: T. McCloskey

Strategic Analysis of Railroad Rate, Cost, and Service Prospects: Conflict or Cooperation?
TR-113999
Target: Fuel and Power Supply
EPRI Project Manager: J. Platt

Guide for Building a High-Performance Generation Plant: A Systematic People-Based Approach
TR-114002
Targets: Plant Maintenance Optimization; Work Process Improvement Guidelines and Techniques
EPRI Project Manager: R. Pflasterer

On-Line Detection of Shorts in Generator Field Windings
TR-114016
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: J. Stein

Combustion Turbine Design Evolution and Risk: Pedigree Matrices for ABB, General Electric, Siemens Westinghouse, and Siemens Power Advanced Machines
TR-114081
Target: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: J. Scheibel

■ NO_x LOI Predictor
Version 2.1 (Windows); AP-113803
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: J. Stallings

■ TURBO-X™, Level 2 Modules: Casting and Thick Sections; Generator (Mechanical); Pressure Blade; Rotor Bore/Periphery
Version 1.0a (Windows 95, 98, NT); AP-114290
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: T. McCloskey

■ UMBRELLA: Software for Assessing NO_x Control Technology Combinations
Version 1.0 (Windows 95); AP-113807
Targets: Coal Boiler Performance/Combustion NO_x Control; Postcombustion NO_x Control
EPRI Project Managers: R. Himes, G. Offen

Nuclear Generation

Area and Process Radiation Monitoring System Guide
TR-104862-R1
Target: Nuclear Power
EPRI Project Manager: W. Johnson

Application Guide for Motor-Operated Valves in Nuclear Power Plants, Vol. 1, Rev. 1: Gate and Globe Valves
TR-106563-V1
Target: Nuclear Power
EPRI Project Manager: K. Brittain

Alternative Method for Performing Regulatory Guide 1.154 Pressurized Thermal Shock Analysis
TR-107128-R1
Target: Nuclear Power
EPRI Project Manager: R. Carter

Guidelines for Leading Indicators of Human Performance: Preliminary Guidance for Use of Workplace and Analytical Indicators of Human Performance
TR-107315
Target: Nuclear Power
EPRI Project Manager: J. Haugh

Basis for the Regulatory Decision on Calvert Cliffs License Renewal Application
TR-107542-CD
Target: Nuclear Power
EPRI Project Manager: J. Carey

Carbon-14 in Low-Level Waste
TR-107957
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Hornibrook

Cost/Performance Evaluation of Advanced Low-Level-Waste Liquid Processing Technologies: PWR Liquid Processing
TR-107977
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Hornibrook

EPRI Liquid Processing Test Facility: Surry Nuclear Station, Phase 1
TR-108099
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Hornibrook

Cooperative IASCC (Irradiation-Assisted Stress Corrosion Cracking) Research Program: CIR-CD Version 99.12
AP-108557-R4-CD
Target: Nuclear Power
EPRI Project Manager: L. Nelson

EPRI SMART chemWORKS, Vol. 2: Implementation Roadmap
TR-108739-V2
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

Decommissioning Standard Review Plans and Risk-Informed Decommissioning Regulation: Selected 1999 Industry/NRC Decommissioning Licensing Interactions
TR-109460
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Wood

EPRI BWR Iron Control Monitoring Final Report
TR-109565
Target: Nuclear Power
EPRI Project Managers: N. Torigoe, P. Frattini

Generic Qualification of the ABB Common Qualified PLC-Based Platform for Safety-Related Applications
TR-110045
Target: Nuclear Power
EPRI Project Manager: J. Naser

PWR Axial Offset Anomaly Guidelines
TR-110070
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Effects of Morpholine on the Surface Charge Properties of Magnetite
TR-110082
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Proceedings of the 1999 Nuclear Asset Management Workshop
TR-110115
Target: Nuclear Power
EPRI Project Manager: G. Sliter

Decommissioning Low-Level-Waste Management and Reduction Guide
TR-110234
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Hornibrook

Secondary Degradation of Defective Fuel Rods: Simulation Test at Halden Reactor
TR-110440
Target: Nuclear Power
EPRI Project Manager: B. Cheng

Robust Fuel Program Technical Requirements for Nuclear Fuel Performance
TR-110689
Target: Nuclear Power
EPRI Project Manager: O. Ozer

Assembling Bolted Connections Using Spiral-Wound Gaskets: Sealing Technology and Plant Leakage Reduction Series
TR-111472
Target: Nuclear Power
EPRI Project Manager: J. Jenco

Basis for the Regulatory Decision on Oconee License Renewal Application
TR-111570-CD
Target: Nuclear Power
EPRI Project Manager: J. Carey

Piping System Failure Rates and Rupture Frequencies for Use in Risk-Informed In-Service Inspection Applications
TR-111880
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Poolside Examination Data on High-Duty BWR Fuel Exposed to 52 GWd/MTU: Limerick 1
TR-112048
Target: Nuclear Power
EPRI Project Manager: O. Ozer

Methodology for Decommissioning Project Management: Trojan Nuclear Plant
TR-112143
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Wood

HVAC Fans and Dampers Maintenance Guide
TR-112170
Target: Nuclear Power
EPRI Project Manager: M. Pugh

Capacitor Application and Maintenance Guide
TR-112175
Target: Nuclear Power
EPRI Project Manager: W. Johnson

Shaft Alignment Guide
TR-112449
Target: Nuclear Power
EPRI Project Manager: R. Knipschield

Data Needs for the Robust Fuel Program
TR-112572
Target: Nuclear Power
EPRI Project Manager: O. Ozer

Influence of Radiolysis and Hydrogen Embrittlement on the In-Service Cracking of PWR Internal Structures
TR-112593
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Evaluation of Neutron Irradiation Embrittlement for PWR Stainless Steel Internal Component Supports
TR-112718
Target: Nuclear Power
EPRI Project Manager: J. Carey

Comparison of Decommissioning Dose Modeling Codes: RESRAD and DandD
TR-112874
Targets: Nuclear Power; Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Hornibrook

Proceedings: Hazardous Waste Material Remediation Technology Workshop
TR-112875
Target: Decommissioning and Shutdown Plant Technology
EPRI Project Manager: R. Thomas

Proceedings: Site Characterization and Final Release Technology Workshop
TR-112876
Target: Decommissioning and Shutdown Plant Technology
EPRI Project Manager: R. Thomas

Experience in the Testing and Application of the EPRI Decontamination for Decommissioning Process
TR-112877
Target: Decommissioning and Shutdown Plant Technology
EPRI Project Manager: C. Wood

Routine Preventive Maintenance Guidance for AK and AKR Type Circuit Breakers
TR-112938 (supersedes NP-7410-V1P2)
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

Source Book on Limiting Exposure to Startup Oxidants
TR-112967
Target: Nuclear Power
EPRI Project Manager: A. McIlree

Optimizing Site-Specific ALARA Assessments: PWR Methodology Development
TR-112992
Target: Nuclear Power
EPRI Project Manager: H. Ocken

An Analysis of Loss of Decay Heat Removal Trends and Initiating Event Frequencies (1989–1998)
TR-113051
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Bearing Technology Topics, Vol. 1
TR-113059-V1
Target: Nuclear Power
EPRI Project Manager: M. Pugh

Comparison Between Electricité de France and EPRI Methods of Pipe Inspection
TR-113315
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Condensate Demineralizer System Evaluation of Pilgrim
TR-113369
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Initiation of Intergranular Stress Corrosion Cracking in Type 304 Stainless Steel and Alloy 600
TR-113458
Target: Nuclear Power
EPRI Project Managers: B. Syrett, L. Nelson

BWR Vessel and Internals Project: In-Core Uniaxial Constant Load Tests for Evaluation of Stress Corrosion Cracking
TR-113482
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Irradiation Creep Behavior of High-Purity Stainless Steels and Nickel-Base Alloys
TR-113484
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Technical Aspects of ALWR Emergency Planning
TR-113509
Target: Nuclear Power
EPRI Project Manager: E. Rodwell

BWR Vessel and Internals Project: Analysis of Crack Growth Rate Data From IFA-586, IFA-605, and IFA-611 at the Halden Test Reactor
TR-113517
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Cold Demonstration of a Spent Nuclear Fuel Dry Transfer System
TR-113530
Target: Nuclear Power
EPRI Project Manager: A. Machiels

Investigation of Unreinforced Branch Connections on Elbows: PWR Materials Reliability Project
TR-113544
Target: Nuclear Power
EPRI Project Manager: R. Carter

Nondestructive Evaluation of the Oyster Creek Top Guide Samples
TR-113548
Target: Nuclear Power
EPRI Project Manager: L. Nelson

EPRI MOV Performance Prediction Program: Friction Coefficients for Non-metallic Butterfly Valve Bearing Materials
TR-113561
Target: Nuclear Power
EPRI Project Manager: J. Hosler

SQUG Electronic Earthquake Experience Database User's Guide: eSQUG EPRIweb Site
TR-113705
Target: Nuclear Power
EPRI Project Manager: R. Kassawara

An Approach to Risk-Informed Changes to Physical Security
TR-113787
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Proceedings of the 1st International Conference on Sealing Technology and Plant Leakage Reduction
TR-113859
Target: Nuclear Power
EPRI Project Manager: J. Jenco

BWR Vessel and Internals Project: Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules
TR-113932
Target: Nuclear Power
EPRI Project Manager: R. Carter

EPRI MOV Performance Prediction Program: Use of Static Closure Data for Determining the Stem-to-Stem Nut Coefficient of Friction at Unwedging
TR-113989 (Addendum 4 to TR-103237-R2)
Target: Nuclear Power
EPRI Project Manager: J. Hosler

Proceedings: Radiation Exposure Control Seminar, 1999
TR-114003
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Qualification of Siemens Power TELEPERM XS Safety System: Compliance With EPRI TR-107330 (Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications)
TR-114017
Target: Nuclear Power
EPRI Project Manager: J. Naser

U.S. Nuclear Industry Approaches to Address Gate Valve Pressure Locking, Thermal Binding, and Related Issues
TR-114051
Target: Nuclear Power
EPRI Project Manager: J. Hosler

CASS™: Corrective Action Selection System
Version 1.0 (Windows 95, 98, NT); AP-107308
Target: Nuclear Power
EPRI Project Manager: J. Haugh

chemWORKS™: BWR Chemistry Simulator
Version 3.0 (Windows 95); AP-109560-P7R1
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: CREVSIM
Version 1.0 (Windows 95); AP-109560-P9
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: MULTEQ
Version 2.24 (Windows 95); AP-109560
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: Primary System pH Calculator
Version 2.0 (Windows); AP-109560-P2R1
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: PWR Secondary Chemistry Simulator
Version 3.0 (Windows 95); AP-109560-P11R1
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

WL-MWM: Waste Logic—Mixed-Waste Manager
Version 1.0 (Windows 3.1, 95, 98, NT); AP-112919
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Retail and Power Markets

TAG® Technical Assessment Guide, Vol. 3, Rev. 8: Fundamentals and Methods—Electricity Supply
TR-100281-V3R8
Target: TAG—Technology-Based Business Planning Information and Services
EPRI Project Manager: G. Ramachandran

Proceedings: Vision at Low Light Levels (EPRI/LRO Fourth International Lighting Research Symposium)
TR-110738
Target: Commercial Building Lighting
EPRI Project Manager: J. Kesselring

Creating New Business Opportunities With Smart Appliances: A Market Assessment
TR-111604
Target: Information and Energy Management Services for Commercial and Industrial Customers
EPRI Project Manager: C. McAllister

Pulsed Power Technology and Applications: North America
TR-112565
Target: Power Electronics
EPRI Project Manager: C. Arzbaecher

Assessment of Current Knowledge of Hybrid Vehicle Characteristics and Impacts
TR-113201
Target: Transportation Energy Storage Systems
EPRI Project Manager: E. Heim

Residential Gateways and Controllers
TR-113247
Target: Opportunities in Networked Home Services
EPRI Project Manager: C. McAllister

Fuel Cells as Power Quality Solutions
TR-113469
Target: Customer Power-Conditioning Solutions
EPRI Project Manager: B. Banerjee

Fast-Charging Demonstration at Buffalo Rock Bottling Company
TR-113490
Target: Nonroad Electric Vehicles
EPRI Project Manager: G. Krein

Flywheel Battery Commercialization Study
TR-113541
Target: Customer Power-Conditioning Solutions
EPRI Project Manager: B. Banerjee

All-Electric Wendy's Restaurant Demonstration Project
TR-113542
Target: Foodservice Facilities Solutions
EPRI Project Manager: J. Kuegle

Identifying, Diagnosing, and Resolving Residential Shocking Incidents
TR-113566
Target: Power Quality for Satisfied Residential and Commercial Customers
EPRI Project Manager: M. Grossman

Application of Adjustable-Speed Drives to Induced-Draft Fans at NSP-SHERCO Power Plant
TR-113576
Target: Power Quality for Improved Industrial Operations
EPRI Project Manager: B. Banerjee

Spurious Alarms Remediation: Beaver Valley Power Station Power Quality Investigation
TR-113578
Target: Customer Power-Conditioning Solutions
EPRI Project Manager: B. Banerjee

FREE ZONE RB-276 Chiller Monitoring Project
TR-113589
Target: Chiller Application Software
EPRI Project Manager: B. Lindsay

R&D/Technology Management Best Practices Study, Vol. 1: Executive Summary
TR-113606-V1
Target: TAG—Technology-Based Business Planning Information and Services
EPRI Project Managers: G. Ramachandran, H. Mueller

A Framework for Hedging the Risk of Greenhouse Gas Regulations
TR-113642 (see listing under Environment)

Market Assessment of Power Quality Problems and Mitigation Options in the Telecommunications Industry
TR-113706
Target: Customer Power-Conditioning Solutions
EPRI Project Manager: B. Banerjee

How Effective Are "Off-the-Shelf" Segmentation Tools for Selling Energy Products?
TR-113754
Target: Promoting Energy Products for Mass Markets
EPRI Project Manager: J. Kesselring

Power Quality Applications Guide for Architects and Engineers
TR-113874
Target: Power Quality Basics
EPRI Project Manager: W. Moncrief

Application of Written-Pole Motor in Rural Irrigation: A 30-HP Single-Phase Motor Used for Irrigation on a Georgia Dairy Farm
TR-114076
Targets: Power Quality for Satisfied Residential and Commercial Customers; Power Quality for Improved Industrial Operations
EPRI Project Manager: B. Banerjee

Tariff Study for the Polish Electric Power System
TR-114082
Target: Power Markets and Risk Management
EPRI Project Manager: C. Clark

Maximize Process Energy Efficiency: Pinch Screening Analysis—Marathon Ashland Petroleum LLC, Catlettsburg, Kentucky
TR-114085
Target: Chemicals, Petroleum, and Natural Gas
EPRI Project Manager: A. Amarnath

Personnel Protection Devices for Specific Applications: Special Considerations for Conditions-of-Use Constraints
TR-114090
Targets: Infrastructure Deployment and Electric Vehicle Benefits; Nonroad Electric Vehicles
EPRI Project Manager: G. Krein

Understanding Energy Customer Profitability Potential: The Customer Portfolio Management System
TR-114123
Target: Enhancing the Success of Innovative Customer Technologies
EPRI Project Manager: B. Kalweit

Commercial Desk Book™
Version 2.0 (Windows 95, 98); AP-114421
Target: Residential and Commercial Business Development
EPRI Project Manager: D. Rigney

IVSI: Industrial Voltage Sag Investigator
Version 1.0 (Windows 98, NT); AP-114115-CD
Target: Power Quality for Improved Industrial Operations
EPRI Project Manager: S. Bhatt

Power Quality Database
Version 2.0 (Windows 95, 98, NT); AP-114120-CD
Target: Power Quality Software
EPRI Project Manager: S. Bhatt

PQ Planner
Version 1.0 (see listing under Energy Delivery)

PQ Solution Package™ for High-Tech Commercial Customers
Version 1.0 (Windows 95, 98, NT); AP-113982-CD
Target: Power Quality for Satisfied Residential and Commercial Customers
EPRI Project Manager: S. Bhatt

Product Mix Model
Version 1.0 (Windows 95, 98, NT); AP-113198-P5
Target: Producing Successful Retail Products and Services
EPRI Project Manager: A. Faruqui

Profit Manager
Version 4.0 (Windows 95, 98, NT); AP-110631-R1
Targets: Retail Business Strategy; Retail Commodity Service Design; Value-Added Service Design
EPRI Project Manager: B. Kalweit

Refrigerator/Freezer Selection Guide
Version 1.0 (Windows 95, 98); AP-113943
Target: Residential and Commercial Business Development
EPRI Project Manager: J. Kesselring

Residential Desk Book™
Version 3.0 (Windows 95, 98); AP-114187
Targets: All targets in Residential area
EPRI Project Manager: J. Kesselring

SST: Supermarket Simulation Tool
Version 2.5 (Windows 95); AP-111112-R3
Target: Retail/Supermarket Establishment Solutions
EPRI Project Manager: M. Khattar

Strategic Science and Technology

Turbine Steam Chemistry and Corrosion: Generation of Early Liquid Films in Turbines
TR-113090
Program: Strategic Science and Technology
EPRI Project Manager: B. Dooley

Investigation of Electrophysical Effects in the Turbine Exhaust Upon Steam Flow and Power Output
TR-113091
Program: Strategic Science and Technology
EPRI Project Managers: B. Dooley, T. McCloskey

Interfacial Crack Propagation During Compressive Failure of Thin Protective Oxides and the Fracture of Iron Oxide Scales
TR-113501
Program: Strategic Science and Technology
EPRI Project Manager: B. Dooley

High-Temperature Bolting Life Prediction and Life Assessment
TR-113529
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

Small Punch Testing of 3–3.5 NiCrMoV Turbine Disk Steel for Toughness
TR-113646
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

Corrosion Control Using Regenerative Biofilms in Power Plant Service Water Systems: Development of Field Test Systems
TR-113713
Program: Strategic Science and Technology
EPRI Project Manager: B. Syrett

The Wavelet Transform and Feature Extraction of Power Quality Disturbances
TR-114175-V1
Program: Strategic Science and Technology
EPRI Project Manager: S. Bhatt

Wavelet-Based Power Quality Event Identification System
TR-114175-V2
Program: Strategic Science and Technology
EPRI Project Manager: S. Bhatt

EPRI Events

April

18–21
Selective Catalytic Reduction Workshop
Memphis, Tennessee
Contact: Paige Polishook, 650-855-2010

25–26
Power Quality Interest Group Meeting
Kansas City, Missouri
Contact: Marsha Grossman, 650-855-2899

26–27
Motor Rewind Seminar
New Haven, Connecticut
Contact: Jim Oliver, 909-735-5239

26–28
Enterprise Infrastructure Security Workshop
Orlando, Florida
Contact: Paige Polishook, 650-855-2010

May

1–3
Agriculture and Food Technology Alliance
Denver, Colorado
Contact: Charles Sopher, 703-737-0401

1–12
Ultrasonic Examination: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

2–5
Machinery Alignment
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

3–5
Generation Asset Management Workshop
Durham, North Carolina
Contact: Peggy Prater, 650-855-2638

3–5
Service Water Engineer Training
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

8–11
Microbiologically Influenced Corrosion
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

9–11
Introduction to Distributed Control Systems
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

9–12
Advanced Air-Operated Control Valve Application, Maintenance, and Diagnostics
Sugarland, Texas
Contact: Sherryl Stogner, 704-547-6174

9–12
Motor Monitoring and Diagnostics
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

15–18
PQA 2000 North America Conference
Memphis, Tennessee
Contact: Paige Polishook, 650-855-2010

16–18
Fluid Film Bearing Diagnostics
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

22–26
CEM Users Group Meeting and Tutorial
San Antonio, Texas
Contact: Barbara McCarthy, 650-855-2127

24–26
2nd International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components
New Orleans, Louisiana
Contact: Susan Otto-Rodgers, 704-547-6072

31–June 2
Management of Former MGP Sites
New Orleans, Louisiana
Contact: Connie Bryan, 504-553-5576

June

3–9
CHECWORKS Users Group
Jackson Hole, Wyoming
Contact: Barbara McCarthy, 650-855-2127

4–9
10th Annual Joint ISA POWID–EPRI Instrumentation and Controls Conference
San Antonio, Texas
Contact: Ramesh Shankar, 704-547-6127

5–9
Introduction to Distributed Control Systems: Short Courses (ISA Conference)
San Antonio, Texas
Contact: Sherryl Stogner, 704-547-6174

5–14
IGSCC Detection
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

6–7
Protective Coatings
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

6–8
Preserving Equipment Qualification
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

6–9
Joint Emergency Diesel Generator Owners Group Meeting
Denver, Colorado
Contact: Linda Parrish, 704-547-6061

7–9
4th International Conference on Welding and Repair Technology for Power Plants
Naples, Florida
Contact: Brent Lancaster, 704-547-6017

9–16
22nd Annual Meeting of the Bioelectromagnetics Society
Munich, Germany
Contact: Leeka Kheifets, 650-855-8976

12–15
Aging Workforce and Educational Infrastructure Conference
Charlotte, North Carolina
Contact: Brent Lancaster, 704-547-6017

12–16
Heat Exchanger Testing for Service Water Systems
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

13–16
Fossil Plant NDE
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

18–22
4th International Conference on Arsenic Exposure and Health Effects
San Diego, California
Contact: Janice Yager, 650-855-2724

19–21
6th Annual Conference on Balance-of-Plant Heat Exchanger NDE
Scottsdale, Arizona
Contact: Kenji Krzywosz, 704-547-6096

19–21
Steam Turbine–Generator Customer Service Seminar
Saratoga Springs, New York
Contact: Paul Sabourin, 704-547-6155

19–21
Technology Management Workshop
Lake Buena Vista, Florida
Contact: Paige Polishook, 650-855-2010

19–23
Visual Examination: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

20–22
Predictive Maintenance Program Development and Implementation
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

21
Water and Energy Conference
Minneapolis, Minnesota
Contact: Kim Shilling, 314-935-8590

22–23
Electromagnetic Interference Qualification of Digital Equipment
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

22–23
Municipal Water and Wastewater Program
Minneapolis, Minnesota
Contact: Kim Shilling, 314-935-8590

26–28
Condensate Polishing Workshop
Annapolis, Maryland
Contact: Barbara James, 707-829-3500

26–29
ABB Circuit Breaker Users Group
Cleveland, Ohio
Contact: Linda Parrish, 704-547-6061

26–30
IGSCC Sizing
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

26–30
Operations for Nonoperators
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

27–29
6th International Conference on Cycle Chemistry in Fossil Plants
Columbus, Ohio
Contact: Barbara McCarthy, 650-855-2127

27–29
Transmission Line Inspection Training
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

July

6–7
Containment Inspection: Visual Examination, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

10–14
Ultrasonic Examination: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

11–12
Adjustable-Speed Drives for Power Plant Applications
Peoria, Illinois
Contact: Jan Stein, 650-855-2390

11–14
Infrared Thermography: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

17–19
ASME-EPRI Radwaste Workshop
San Antonio, Texas
Contact: Cindy Layman, 650-855-8763

17–21
Advanced Structural Analysis and Design Methods for Electric Power Lines
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

17–21
Digital Instrumentation and Controls Upgrade Training
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

17–21
NDE Technical Skills Training: Level 3 Basic/Specific
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

18–20
Introduction to Computer-Aided Power Plant Control Systems
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

18–20
Nuclear Utility Procurement
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

18–21
Infrared Thermography Users Group
Chattanooga, Tennessee
Contact: Paul Zayicek, 704-547-6154

19–21
International Low-Level-Waste Conference
San Antonio, Texas
Contact: Cindy Layman, 650-855-8763

24–25
Service Water System Reliability Improvement Seminar
Branson, Missouri
Contact: Brent Lancaster, 704-547-6017

24–28
Visual Examination: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

26–27
6th International Energy Pricing Conference
Washington, D.C.
Contact: Barbara McCarthy, 650-855-2127

26–28
Terry Turbine Users Group
Williamsburg, Virginia
Contact: Linda Parrish, 704-547-6061

31–August 2
International Conference on Fatigue
Napa, California
Contact: Susan Otto-Rodgers, 704-547-6072

August

7–10
Weld Overlay Examination
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

8–11
Generator Monitoring and Diagnostics
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

8–11
Pressure Relief Valve Application, Maintenance, and Testing
Orlando, Florida
Contact: Sherryl Stogner, 704-547-6174

14–16
Air-Operated Control Valve Application, Maintenance, and Diagnostics
Orlando, Florida
Contact: Sherryl Stogner, 704-547-6174

14–18
NDE Instructor Training
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

20–24
EPRI-AFS International Symposium on Catadromous Eels
St. Louis, Missouri
Contact: Doug Dixon, 804-642-1025

20–24
EPRI-AFS Symposium on Biology, Management, and Protection of Sturgeon
St. Louis, Missouri
Contact: Doug Dixon, 804-642-1025

21–24
Cooling Tower Seminar and Conference
Jackson Hole, Wyoming
Contact: Brent Lancaster, 704-547-6017

21–25
Infrared Thermography: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, 704-547-6174

22–24
On-Line Generator Monitoring
Groveport, Ohio
Contact: Jan Stein, 650-855-2390

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