The research on Real-time Proactive Safety was conducted by the Georgia Institute of Technology (http://www.rapids.gatech.edu) for the Construction Industry Institute (CII). The PIs were: Prof. Jochen Teizer and Prof. Jimmie W. Hinze.

POWER

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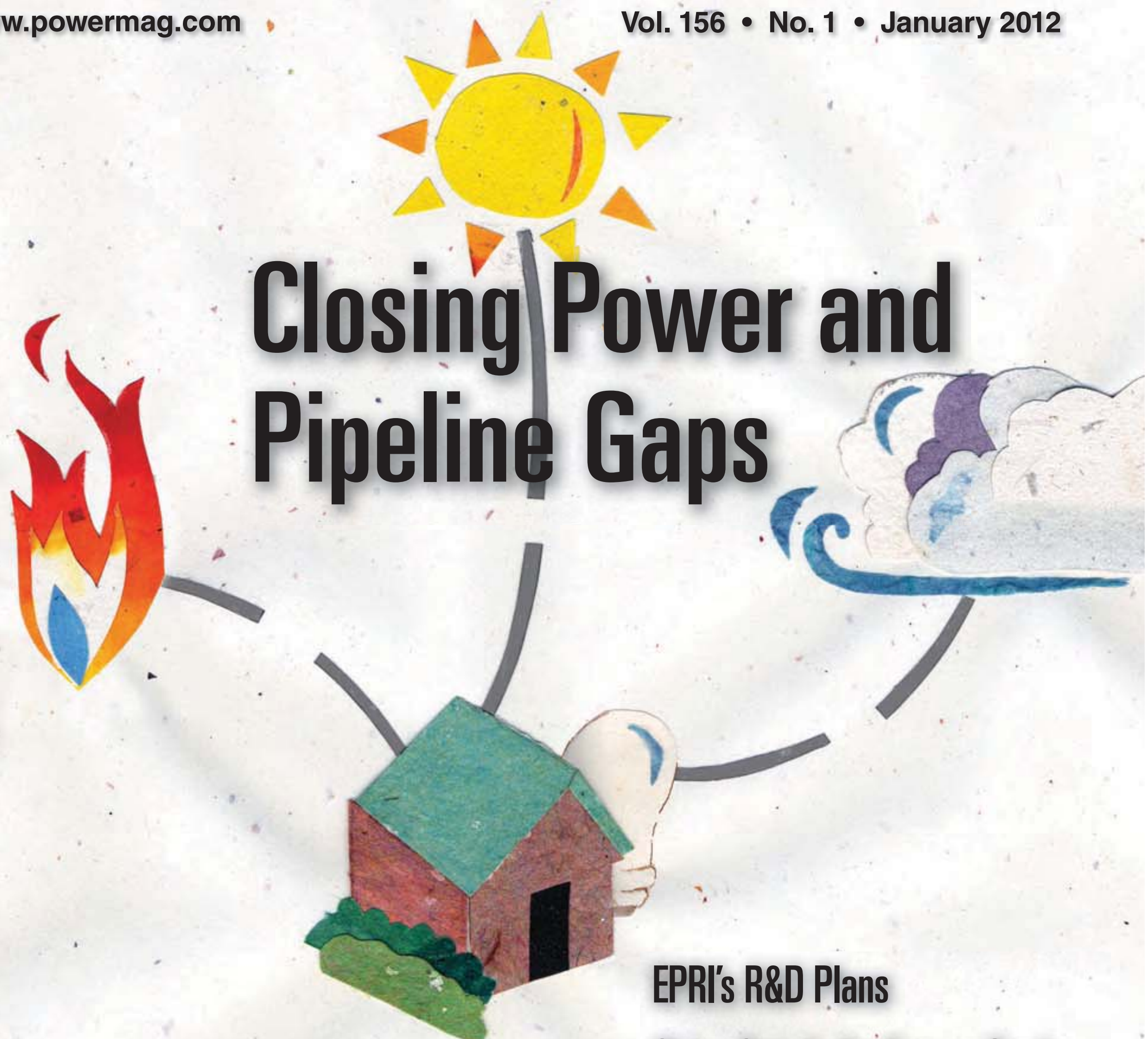
Closing Power and Pipeline Gaps



EPRI's R&D Plans

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New Tech for Job Safety

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Real-time Proactive Safety in Construction

For each of the past 10 years, nearly 1,200 U.S. construction workers have died as the result of injuries received on the job. Of these fatalities, 25% involved heavy equipment—most categorized as struck-by incidents. Remote sensing and visualization technology promises to improve worker situational awareness on congested and busy work sites.

By Larry Green, CSP, DuPont and **Gary Tominack,** Day & Zimmerman

Most large power plant construction projects will consume two or three million man-hours over several years without a contractor experiencing a worker fatality. Contractors for those projects have embraced modern work site safety practices, such as behavioral safety management, onsite traffic flow management, continuous worker training, and policy changes. Despite these apparent safety advancements, the safety record of the entire construction industry lags other industry sectors: about one-quarter of all construction deaths are related to construction equipment and contact collisions (see sidebar).

Safety Best Practices and Technology

OSHA regulations help establish construction site safety policies and procedures. For example, OSHA mandates the use of personal protective equipment (PPE) in particular work environments, including hard hats, safety shoes, goggles, face shields, reflective clothing such as safety vests, heavy or thin (leather) gloves, hearing protection, wet weather gear, and respirators or filter masks. These types of PPE are passive safety devices, because they do not proactively warn or provide feedback to the wearer. A passive approach to safety is not sufficient to prevent the occurrence of contact collisions between workers and moving construction equipment.

Safety education and training are forms of proactive safety that are routinely conducted to increase workers' ability to recognize and avoid construction hazards. However, the behavior of individuals on a construction site is not predictable and is often affected by factors such as fatigue and distractions. Nonetheless, it remains each worker's responsibility to follow the rules, guidelines, and best safety practices. Proactive safety, perhaps better described as a worker having situational awareness, also does not prevent contact collisions.

What happens when the organizational commitment to safety falls short, supervisors and/or employees slip up, and PPE fails? One option is to add an extra level of proactive measures. Proactive, real-time safety programs provide workers on foot and equipment operators in motion with real-time proximity alert devices that can help prevent collision events through an early warning mechanism, a concept recently proven by a trial program sponsored by the Construction Industry Institute (CII, see sidebar). The system includes a technology protective device and a sitewide visualization system that can work reliably in harsh construction environments.

Technology Field Trial Design

The primary objective of the field trials was to test an integrated, proactive, real-time safety technology that increases situational awareness and safety on construction sites. The equipment worn by workers or installed

No. 1 Cause of Construction Injuries: Collisions

Center for Disease Control (CDC) construction accident data for 2009 shows that there were 834 "fatal on-the-job injuries to construction workers," representing 19% of all work-related deaths. That's down from 975 in 2008. CDC data also shows that of 465 vehicle-related construction fatalities (1992 through 1998 data), 318 of the victims were workers on foot, and the equipment commonly involved in the collisions was trucks (60%) and large construction equipment (30%). Of the 465 fatalities, 110 involved equipment operators; the remaining 37 involved supervisors or other workers. Fifty-one percent of the fatalities occurred when a vehicle was operated in reverse.

The Occupational Safety and Health Administration construction worker fatality database for the period 1990 through 2007 reveals similar data. For collisions involving forklifts, skid steer loaders, scrapers, and backhoe loaders, 36% to 88% of the fatalities involved workers on foot.

Although there is no data available that identifies the specific cause of those worker–construction equipment collisions, anecdotal information indicates that collisions are usually caused by either a lack of worker experience, appreciation of the risk factors, or loss of situational awareness caused by construction site distractions.

What Is the Construction Industry Institute?

The Construction Industry Institute (CII) is a consortium of more than 100 leading owner, engineering-contractor, and supplier firms from both the public and private sectors that have joined together to improve the business effectiveness and sustainability of capital facilities delivery. The CII is engaged in creating and implementing research-based knowledge, developing best practices, and identifying breakthrough strategies that measurably improve project performance, giving members a competitive edge in the marketplace. The CII is based at the University of Texas at Austin. For more information, visit www.construction-institute.org.

in the cab of operating equipment is designed to warn of the presence of potential hazards, particularly heavy equipment, to reduce the percentage of struck-by incidents. These devices are available today from several suppliers but are seldom found in use. The second part of the field trial was designed to combine individual signals from each worker and piece of equipment to form a visual display of the location of all resources on the construction site. By using visualization and predictive software to show real-time movement of equipment and workers, contact collisions can be avoided.

Warning Workers. When workers, equipment, and even materials are too close to each other, this real-time system activates visual, auditory, and vibrating alerts to warn both workers on foot and equipment operators. The field-tested devices—known as equipment and personal protection units—were tested on workers on foot and on operating equipment on the selected job sites.

The in-cab device on operating vehicles was equipped with an equipment protection unit (EPU) that consisted of a single antenna, a reader, and an alarm. The personal protection unit (PPU) consisted of a chip, a battery, and an alarm. The term "personal" was used because post-trial interviews revealed that workers like to identify themselves with the safety devices—they like to "own" them. Although the user can define the signal strength of the EPU for each piece of equipment, the signal is typically transmitted in a radial manner and loses strength with distance. The PPU then intercepts the signal at a user-adjustable distance and automatically returns the signal such that both systems trigger their internal alarms. The operation of sending and receiving information is instantaneous; the whole process occurs in real time. Figures 1 and 2 show the EPU/PPU equipment during field trials.

The PPUs are durable, wearable, and come in different sizes. For a typical PPU, the casing is sturdy and can stand up to the daily weathering that occurs on construction sites. The devices are powered with conventional AA batteries and last for at least two months, depending on the frequency of alerts. Light-emitting-diode (LED) lights indicate when batteries are low on power and need to be recharged.

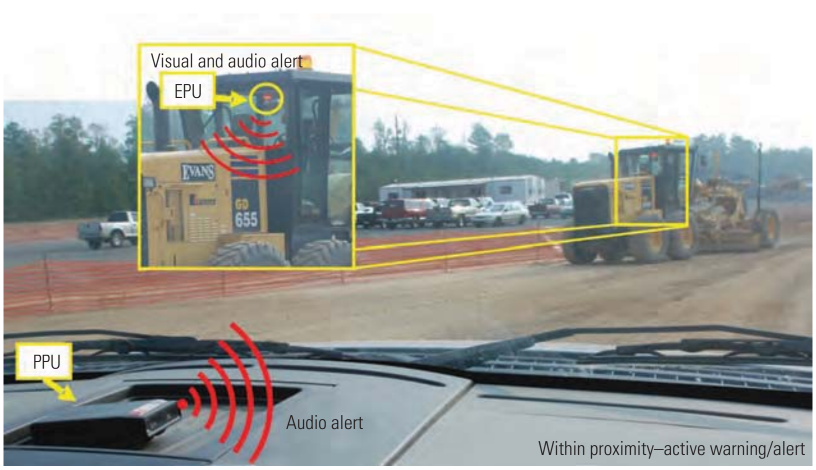
The audible alarm that occurs on both the EPU and PPU is of sufficient strength to get the attention of workers and operators. The alarm emits a unique sound that is different from those common on construction sites. The PPU also has a vibrating alarm so that workers are notified even if wearing hearing protection or when working in an area with loud construction noises. Vibration alerts have the drawback of not working well when workers wear heavy coats in cold weather.

Sitewide Safety Net. These radio frequency–based EPU/PPU devices were then used to develop a sitewide net that recorded accurate location, proximity, and trajectory data of up to 50 construction workers, equipment, and materials in real time. Proximity data of worker locations were automatically processed and put into a visual format to inform equipment operators of the presence of workers not visible or to provide managers with an overall view of site activity.

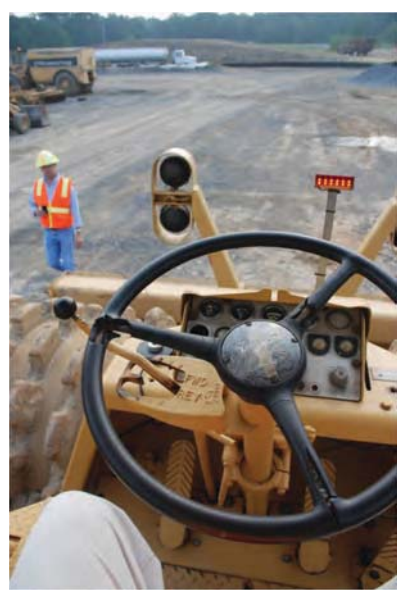
A second advantage of the sitewide safety net is that the data retrieved from these devices can generate information from previously unreported events, such as close calls. This never-before-available information can lead to additional significant changes in orga-

1. Predict collisions. Alert devices were placed on workers and equipment during field trials. *Courtesy: CII*

2. Double safe. Alerts are sent to workers on foot and equipment operators inside the cabin when a set proximity is reached. *Courtesy: CII*



3. Worker-to-vehicle alert. An alert inside the open cabin is shown by the illuminated LED lights in front of the equipment operator. At the same time, the worker receives an audio alert. The equipment protection unit is compact and can fit into an equipment cab without creating any visual or mechanical obstruction. In addition to the helmet, the personal protection unit can be worn on the belt of the worker or around the arm with an arm band. *Courtesy: CII*



nizational safety practices. The technology to collect and analyze this data was developed as part of this project and is not currently commercially available.

Worksite Technology Testing

The system testing occurred at a broad spectrum of construction sites. The team selected 15 construction sites in the southeastern U.S.: five small to large building construction sites; seven small commercial construction sites; two large industrial construction sites; and one union ironworker indoor training facility. The value of the construction work ranged from $2 million to $1 billion, and the number of construction workers employed ranged from 15 to 2,000. The number of pieces of motorized construction equipment used on site ranged from five to 250.

Testing was performed with the proximity warning devices on different types of construction equipment, including wheel loaders, forklifts, graders, forklifts, dozers, excavators, articulated dump trucks, and mobile cranes. Each piece of equipment was directed to travel toward a simulated work crew. The operator was then asked to stop the machine once the audible or visual alert was activated within the equipment cabin (Figure 3). The distance between work crew and equipment was measured, recorded, and analyzed. For each test, the worker on foot and equipment operator were then interviewed. Once familiarity with the equipment was completed, long-term testing was conducted (see table).

Five PPUs of the same configuration were tested in the preliminary field trials. Because each equipment type may require its own unique signal strength, setting the warning and alert distances at a lower level reduces the number of nuisance alerts. The shortest empirical warning and alert distance from EPU to PPU was 2.8 meters (9.2 feet). Cranes, for example, are static and alerts may only be needed when a lift is performed. The operator is able to activate the EPU/PPU alert system only during lifts. In contrast, scrapers can travel up to 37 miles per hour and thus may require earlier activated alerts at longer distances to ensure the safety of nearby workers. All distance measurements included the operator's reaction time and the distance required to stop the vehicle.

The most complex tests of the proactive, real-time proximity warning devices were performed on two large coal power plant projects being constructed by CII members. One of the tests involved large earth-moving equipment and lasted for several months. About 20 workers were provided PPUs, and the 30 pieces of equipment were equipped with EPUs. By the end of the study period, this project had performed 100,000 accident-free work hours.

4. Busy construction site. Movements of a crane, tractor and trailer, and workers on foot on this typical worksite were followed with real-time location tracking. *Courtesy: CII*

Worker Tracking and Data Visualization

The PPU/EPU trials also included a series of location tracking tests. For these tests, the helmets of construction workers were tagged with ultra-wideband, real-time location tracking technology on a typical worksite (Figure 4). Computers recorded the location of tagged resources, and the information was displayed to safety decision-makers in remote locations (Figure 5). Finally, the location of workers, equipment, and materials on a work site were reported in a 3-D virtual display environment (Figure 6).

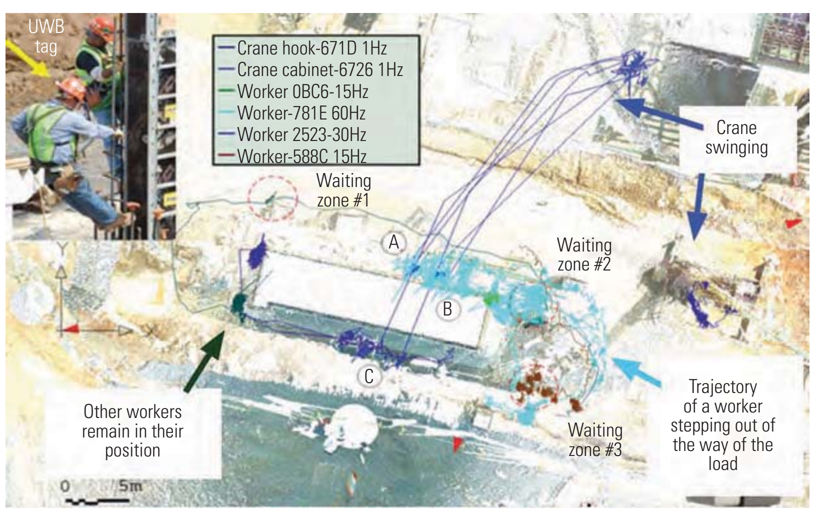
Worker Feedback

At the beginning and end of each field trial, participants were asked their opinions about using the proximity and tracking de-

Field trials test summary. Distance measurements were made for a proactive, real-time proximity alert device with static and dynamic construction equipment in realistic construction environments (with obstructions present). A total of 193 equipment tests at 15 different construction locations covering more than 100,000 accident-free work hours are included in the data. *Source: CII*

Equipment type	Number of trials	Average recorded alert distance (m)	Minimum recorded alert distance (m)	Maximum recorded alert distance (m)
Dynamic				
Personnel mover	4	11.9	10.6	13.6
Loader/forklift	11	17.8	12.7	29.9
Grader and scraper	10	31.5	25.5	50.2
Static				
Dozer	8	24.5	7.8	43.0
Excavator	8	23.4	2.8	38.0
Articulated dump truck	72	35.6	19.0	50.0
Mobile crane	80	34.0	8.9	62.5

5. Real-time rendering. Real-time location tracking of workers, equipment, and material are shown in a plan view of the work site shown in Figure 4. The worker temporarily stepped out of the way while the crane was swinging; other workers continued to work in their positions. *Courtesy: CII*



6. Visualize the data. This is an example of a 3-D immersive visualization interface in which visually obscured workers are made visible to a crane operator on the same work site shown in Figure 4. These work site visualizations can be provided in real time in the equipment cabin or at any other location. *Source: CII*

vices. A total of 143 equipment operators and workers at the 15 sites completed the survey. All equipment operators surveyed volunteered to use the EPU warning devices. Four of the nine equipment operators reported multiple instances when the alarms sounded when they were not aware of possible danger. Although one worker commented on the desirability of making the device smaller, the size of the equipment was not judged intrusive by the remainder. Overall, the equipment operators agreed that they would use the warning devices again, if they were made available by their company.

There were 36 field workers, welders, carpenters, rod busters, and other trades who tested the PPU. Site managers and supervisors were also interviewed. Nearly all reported feeling safer on the site during the trial. Workers stated that there were numerous situations in which the alarms sounded due to materials or equipment passing overhead. Three workers reported discomfort due to the size of the device and its placement on the side of their hardhats. One foreman suggested that it would be better to embed the warning device inside the helmet. All but two workers agreed that they would wear the PPU again.

At one construction site, the contractor decided to purchase the PPU/EPU for every worker on site at the close of the test program. Each PPU cost $400 and each EPU device cost $1,000. The total cost of the warning devices was $120,000 for this project. The contractor reports two potentially serious accidents, perhaps fatal accidents, that were prevented by using the warning devices. The devices are even more cost-effective because they will be reused on many future projects, perhaps saving additional lives. The rate of return on that investment is incalculable.

Much Work Remains

The purpose of this project was to demonstrate the safety improvement potential when using real-time location tracking of workers, equipment, and material on a busy and congested work site. The sensors worked as designed, and the proximity warning, alerts, tracking and monitoring, and remote real-time data visualization tests were very successful. Workers surveyed after each trial said they generally found the PPU nonintrusive. Based on post-trial reports, the equipment enhanced work site safety, recorded previously unreported incidents, and prevented possibly two fatalities (Figure 7).

Further improvements in the operation of the PPU/EPU are possible, particularly with regard to signal propagation in the construction site environment, such as ambient temperature, relative humidity, mounting position and orientation of the devices on workers and equipment, obstacles (metal or wooden) in the construction field, and multipath effects during signal transmission. Further work is required to reduce the size and weight of the PPU and optimize the placement of sensors on workers. The location signals could also be used for accident reconstruction, monitoring confined spaces, keeping workers out of danger areas, and tracking work processes to improve construction efficiency.

7. The field team. A Georgia Tech professor, students, and volunteers performed the field surveys. *Source: CII*

What follows these very successful field trials? We hope the encouraging results will motivate a company willing to invest in further development of the real-time tracking and visualization technology and bring an integrated product to market. It is not overly dramatic to say that lives will be saved when this technology becomes standard practice on every work site. ■

*—**Larry Green** is senior safety, health, and environmental consultant for DuPont Global Operations and Engineering. **Gary Tominack** is corporate director, safety engineering & field services for Day & Zimmerman. Dr. Jimmie Hinze, Holland Professor in the M.E. Rinker, Sr. School of Building Construction and Director of the Center for Construction Safety and Loss Control at the University of Florida, and Dr. Jochen Teizer, assistant professor and director of the RAPIDS Construction Safety and Technology Laboratory, Georgia Institute of Technology, were the principal investigators for this project.*

Members of the Real-time Pro-active Safety in Construction Research Team include: Chanel T. Carter, Bechtel Group Inc.; Dennis Cobb, ConocoPhillips; Clay Gardenhire, The Shaw Group Inc.; Tony C. Palma, Ontario Power Generation; Calvin Price, SNC-Lavalin Inc.; Manny Vahanian, U.S. General Services Administration; and Jason Valliere, SNC-Lavalin Inc. Other organizations and companies that provided assistance on the project were ProTran1, Leica Geosystems, the National Science Foundation, The Shaw Group Inc., XYZ Solutions, VWM Construction Co., Southern Company, and Evans Construction Co.

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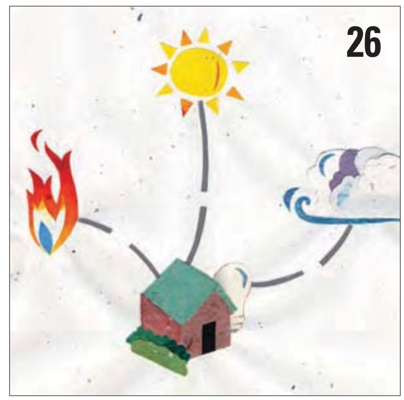
ON THE COVER

The U.S. has plenty of fuel, but the infrastructure needed to deliver it to power plants and electricity users is often absent or gappy. Renewables, including wind and solar, are abundant, but transmission lines don't always exist to carry renewable power to load centers. Estimated reserves of natural gas have increased, fueling hopes of a cleaner alternative to coal, but getting that gas to processors and plants will require new pipelines. Filling these infrastructure gaps is expensive—but could be necessary. *Cover art by Elizabeth C. Johnston, Lizzardbrand Inc.*



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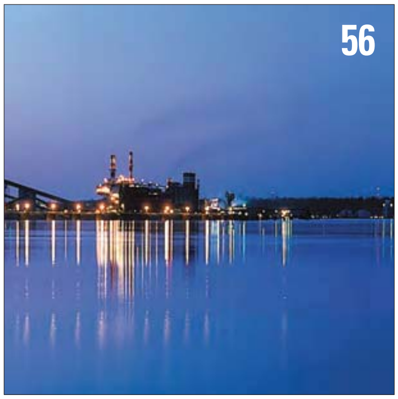

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