New Technology for Saving Lives

Exploring and producing hydrocarbons can be a dangerous business. The industry's safety record is being improved by technical innovations that address driving safety, explosives handling and gas blowouts.

If you believe in Darwin and the survival of the fittest, it's surprising there are any of us left. A baby may have the instinct to suck and seek nourishment, but it completely lacks the instinct not to fall out of its seat or crawl under a lawn mower. Self-protection has to be learned or built into everyday life.

This axiom is not lost on oilfield corporations that bear responsibility for thousands of employees working in hazardous situations worldwide. Prudent corporations recognize the necessity of promoting safety awareness among employees, and they do not stint at developing technology to create a safer workplace.

Ways to promote awareness include training programs, improved reporting procedures, increasing the importance of safety in performance appraisals, and, not least, top management commitment. A technique used in part of the Schlumberger Wireline and Testing group is to issue a "Safety & Environment" passport to every professional (left). The size and thickness of a conventional passport with space on the first page for an identification photo, some personal details and essential medical data such as blood type and allergy information, the passport explains the company's safety/environment philosophy and its accident reporting structure. It then describes major classes of hazardous situations or materials, leaving plenty of blank space after each class to document the employee's record of safety/environment training and achievements (see "Risk Categories," next page). The passport is designed to heighten employee awareness about safety.

Sedco Forex has developed an in-house video department that produces and circulates throughout the company a "Safety Notes" video every two months. These videos are filmed on location at rig sites and report the causes and prevention of acci-

(Schlumberger Wireline and Testing's "Safety and Environment" passport, issued to every employee as a reminder of safety/environment issues and record of training and achievements in the two areas. ESF is an acronym denoting the company's operations outside the USA.)

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idents, safety alerts and warnings, and technical investigations into unsafe equipment or conditions.

Schlumberger's commitment to safety, like that of most oilfield corporations, starts with the CEO. In a February 1990 letter to employees, Schlumberger's chairman Euan Baird wrote that the company's 1989 financial figures (which were satisfactory) failed to "... reflect our growing awareness of problems we are finding in the area of safety and protection of the environment." Dissatisfied with the company's safety/environment record, Baird outlined decisions for improvement and ended by stressing the importance of individual responsibility: "One lapse, by one person," he wrote, "can badly affect the overall performance of the team."

The second option for improving safety is the development of new techniques that directly eliminate or reduce hazard. We will look at three recent examples. The first concerns driving safety, the second relates to premature explosion during perforating, and the third concerns the detection of gas kicks. A fourth area, radioactive safety, where new technology has recently made substantial impact, is described in the accompanying article "Advancing Wellsite Radiation Safety," page 13.

Driving Safety
Driving is undoubtedly the most hazardous activity we undertake, on or off the job, accounting for the majority of accidental fatalities. One way of preventing vehicle

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For help in preparing this article, thanks to Lee Hunt, International Association of Drilling Contractors (IADC), Houston, Texas, USA; Jim Smith, Schlumberger Well Services, Houston, Texas, USA; and Gaun Kimbrell, Sedco Forex, Montmouge, France.

The risk pyramid, with injury and replacement cost criteria. Usually only the worst accidents—the tip of the pyramid—are properly reported. A major challenge is to catch the less serious accidents. This requires management commitment to a no-blame philosophy of accident reporting, assuring employees that they will not be blamed for accidents they report.

Dramatic decrease in serious driving accidents in Schlumberger Wireline and Testing’s Africa/Mediterranean unit following introduction of the Vehicle Accident Prevention System (VAPS). The accident level for 1990 is normalized from reporting to the end of May.
the vehicle's reversing light switch, and an on/off signal from the vehicle's ignition switch (below). These connections are tamperproof. The entire system can be installed in a vehicle in half a day.

The computer is switched on as soon as the driver puts the key in the ignition. Then the driver must insert his or her personal memory card. Otherwise the computer issues a high-pitched alarm when the key is turned. With the card inserted and the vehicle in motion, the system begins recording data. But it also sounds a real-time alarm if speed goes too high. There are two speed thresholds. At the lower threshold, the alarm sounds intermittently warning the driver of excessive speed, while at the higher, the alarm sounds continuously forcing the driver to slow down. Two sets of threshold values can be programmed. In Europe, the lower set is used for driving along normal roads, while the higher set is used for highway driving. Speed values can be adjusted to conform to the vehicle type and different countries' driving regulations. In Nigeria, the higher set is used for daylight driving, while the lower set is for nighttime driving. The system automatically switches between the two when the driver turns the vehicle lights on or off.

Real-time warnings help people drive better, but do not permit analysis of poor driving habits. To do that, the system must record selected data on the driver's memory card for analysis at periodic intervals back in the local office. Data compression is necessary because the card has insufficient memory to record every second of driving for a week or a month, typical periods for management review of driving habits.

Every two minutes, the computer samples vehicle speed and adds the sample into a speed histogram that accumulates on the memory card (next page, top). Viewed on a PC back at the office, this histogram tells immediately if the driver is driving consistently fast or in excess of the local speed limit. At first, it was thought that speed would be sufficient to single out the rash driver, but it was soon realized that deceleration data while braking would also be required. This is computed from speed at one-second intervals any time the driver applies the brake.

How the VAPS driving monitoring system fits into a car. All connections and wiring are tamperproof. Installation takes half a day.
Braking characteristics are stored two ways on the memory card. The first is a histogram in which the length of time spent braking is recorded versus deceleration (right). Safe drivers normally do not decelerate at more than 3 meters per second per second (m/s²) [equivalent to 11 km/h per second or 6.75 mph per second]—more than that throws you against the seat belt—so acceptable braking histograms show three vertical bars on the left and practically nothing to the right. Reckless drivers prone to rapid acceleration and sudden braking show bars everywhere.

The second way braking is recorded in the memory card is in speed versus time plots (next page, middle left); these show just the braking periods. The plots' consistency (a series of lines with similar slopes), or lack of it, and steepness allow a quick appraisal of driving style. Generally, a consistently repeating and not too steep braking pattern indicates good driving. Erratic patterns of varying steepness indicate poor driving. Safety officers testify to the ease of interpreting these charts.

The third type of data selection is called the “black box,” like aircraft black boxes that record essential data prior to a catastrophic accident. All the time while driving, the on-board computer stores complete speed and deceleration data for the most recent 50 seconds. Anytime the driver brakes very hard, defined as greater than 6 m/s² [equivalent to 22 km/h per second or 13.5 mph per second]—without a seat belt this would throw you against the windshield—the data are dumped onto the card. These very sharp braking events can be played back later at the office and analyzed in detail (next page, right).

Finally, the employee's overall driving history is recorded in a weekly driving chart, showing when and for how long the driver was behind the wheel (next page, bottom). This serves to monitor vehicle usage and in certain locations has drastically cut personal use of company vehicles.

So far, accident statistics seem to confirm that this system saves lives, injury and lost productivity. But it is still only a system. To
remain effective, the supervisory role of safety officer or manager in reviewing an employee’s driving record cannot be relaxed. The system is expected to evolve. Most likely, the on-board computer will get smaller and more powerful. Driver identification will be with a personalized key rather than personal memory cards. And all data will be stored permanently on the computer and only off-loaded when needed to the office personal computer via a conventional RS-232 transmission link.

**Perforating Safety**

Driving speeds generally give alert drivers time to avert an accident. Explosives, on the other hand, detonate instantaneously and in the case of premature detonation offer no chance of escape. In the oilfield, personal injury due to premature detonation is exceedingly rare—the last fatality in Schlumberger was in 1972. Yet while detonators continue to be manufactured using volatile primary explosive, the exceedingly rare can still happen.

Explosives have two main applications in hydrocarbon exploration and production: as an energy source for on-land surface seismic exploration and for perforating cased wells. The technology to be described eliminates the primary explosive in electrically triggered detonators used in wireline perforating. In principle, it could make any electrically triggered explosives operation safer and logistically simpler.

A perforating gun, used to create ⅛ to 1-inch diameter holes in casing, which permit reservoir fluids to flow into the wellbore,
has three explosive components (above). The shaped charges that make the holes contain stable secondary explosive. This can be handled with ease and poses no immediate danger to personnel. The detonating cord that carries the shock wave to trigger each shaped charge also contains only secondary explosive and is considered safe. The main hazard lies in the third component, the detonator that sets off the detonating cord. In wireline applications, this contains highly sensitive primary explosive that can readily detonate from stray electrical current. Security procedures during a wireline perforating operation are therefore aimed at removing all sources of stray electrical current.

There are three possible sources on a drilling rig. One is from welding, which uses several hundred amperes of current to fuse metal. If the welder’s electrode gets stuck to the rig some distance from the ground, stray currents may be set up. The danger for perforating exists only if the wireline is defective, enabling the current to somehow find its way to the detonator in the gun. Ensuring that this one-in-a-billion combination of events does not happen simply requires the shutdown of all welding equipment—not a problem on rigs or platforms undergoing extensive construction, many welders may be at work and ensuring that all have switched off takes organization and time.

Another source of stray current, particularly in offshore rigs, is a defective impressed cathodic protection scheme (next page, top). This normally protects the offshore rig against corrosion by injecting hundreds of amperes of current into the sea from the base of the rig and collecting it via isolated terminals above the splash line but below deck level. Operated correctly, this poses minimal danger to perforation. But if the isolated terminals are defective, the current may have no option but to return via the rig’s above-deck structure posing a serious risk. Impressed cathodic protection is also applied to completed on-land wells.

The solution of course is to switch off the protection. Operators comply but worry about the consequences. Shutdown of cathodic protection for more than 24 hours requires the system to be recommissioned in steps of 100 amperes every 24 hours, considerably increasing the time the structure lacks protection. Frequent shutdowns create a porous salt deposit on the structure, reducing long-term corrosion protection.

The third source of stray currents is electromagnetic radiation from radio frequency (RF) or radar transmissions. This can conceivably cause premature detonation before the gun is even armed—the two leads of the detonator act like a loop antenna when twisted together and a dipole antenna when untwisted, picking up electromagnetic energy. Once the gun is armed, a faulty wireline can also act as an antenna, this time firing both the detonator and the gun.

As before, the only guarantee that none of this happens is to ensure that all radio and radar transmitters are switched off. When the operator requests a radio exemption—permission to continue using certain RF facilities during a perforating job—guidelines are available for assessing the power of a transmitter and the current it might induce in perforating circuitry. But the estimates are only approximate and the uncertainty poses a risk. Exemptions require the approval of a safety officer.

Transforming these scenarios is a new type of explosive initiator that uses only secondary explosive. Developed at Schlumberger...
Impressed cathodic protection of an offshore rig, working correctly (left) and with a faulty return. In the latter case, hundreds of amperes of electric current flow back to the transformer rectifier through the rig structure, posing possible risk to perforating operations.

berger’s Perforating Center at Rosharon, Texas, USA, this initiator permits wireline perforating operations to proceed safely without shutting down any electrical equipment. The new service results in speedier operations and much less inconvenience for other personnel on busy rigs and platforms. The device has been adapted to work on all of Schlumberger’s perforating guns and has been successfully field tested in Texas, Louisiana and the North Sea (see “Perforating Guns Equipped with EFI,” right).

The new device, called an Exploding Foil Initiator (EFI), was developed from World War II technology. At that time, engineers working on bomb development were concerned with achieving multiple detonations at precisely the same instant, at least within a microsecond. Conventional devices, in which primary explosive is triggered by electrical current heating a wire, detonated at unpredictable times, up to a few seconds after the current was switched on. To achieve perfect timing, they developed a radically new system in which a microsecond pulse of very high current—thousands of amperes—is passed through a thin piece of conducting material. This vaporizes instantly into a plasma and slaps an overlying plastic foil into secondary explosive, detonating it.

Although EFI devices have existed since the war, the original technology was not robust enough for downhole perforating. In perforating, several gun systems are often linked together and fired sequentially, allowing perforation of different zones on the same trip into the well. The shock of firing one gun must not compromise the firing mechanisms on the remaining guns. To ensure ruggedness, the Rosharon engineers therefore had to develop a tough new EFI. They also had to design an unbreakable electronic cartridge, needed to generate the large electrical current for detonation, that would not only survive repeated detonations but also multiple trips downhole.

Their new EFI measures just a few millimeters in diameter and length (above). On receiving a high energy electrical pulse from its cartridge, the conductive bridge forms a plasma inflating the central section of the overlying plastic foil. The foil pushes through the center of a washer and slaps against a small pellet of secondary explosive and detonates it. (This gives the new technique its commercial name of S.A.F.E.* perforating, standing for Slapper-Activated Firing Equipment.) The detonating explosive next shears the center out of a metallic disk, called a flyer, propelling it through an air gap towards a second pellet of secondary explosive, called a booster. This is crimped to the detonating cord and connects ballistically to the whole gun.

If nothing impedes the flyer's progress through the air gap, the booster detonates and the gun fires. But if the gap is blocked by a steel safety pin inserted before the gun is armed at the rig floor and removed just before the gun is lowered downhole, the flyer is stopped in its tracks (next page). Nothing further happens, the gun is in effect safe, and if the first section of the EFI accidentally fires, the only evidence is a barely audible "phut." The safety feature also works if the air gap contains fluid—just one drop of water will stop the flyer. This prevents a leaking carrier gun, which normally contains the detonator, cord and charges at atmospheric pressure, from firing—detonating a leaking carrier gun results in badly damaged perforating hardware and possibly damaged casing.

The cartridge performs three functions. It blocks high frequency RF signals. It also rejects low voltage DC power. But on receiving a high DC voltage, it stores energy in a special capacitor building up to approximately 3,000 volts before discharging to the EFI. Accumulation of sufficient charge takes about 6 seconds. The combined immunity of the cartridge and EFI to all forms of electrical interference has been tested and found satisfactory by an independent authority, Thorn EMI Electronics Defense System Division, based in London, England. The physical ruggedness of the cartridge is ensured by careful packaging of components and vacuum impregnating the entire cartridge in a special compound to absorb shock. In tests, cartridges have successfully withstood over 100 detonations.

The safety improvement offered by EFI technology not only saves the time spent shutting down electrical sources, but also promises to cut the time required to prepare the guns at the wellsite. With the safety pin in place, there is no reason guns cannot be fully armed at the shop before being transported to the well, possibly even by plane or helicopter.

**Kick Detection**

As lethal as explosives can be, gas kicks probably head the list of the oilfield's most feared hazards. Gas kicks occur in seconds, require instant and skillful corrective action, and if not controlled can destroy entire rigs and drilling crews. Reportedly, 22 offshore rigs or platforms have been lost to kicks in the last 30 years, seven of those being lost during 1988 and 1989.

Both human and technological factors count in dealing with kicks. First, there is no substitute for a skillful and attentive drilling crew that can recognize an incipient kick and know just how to kill it promptly. Such a crew has years of drilling experience, for which there is no shortcut, and is motivated to remain alert on the job. All kinds of measures can help keep a crew alert and most can be under management control.

* Mark of Schlumberger
Scallop gun (left) equipped with EFI and power cartridge; also safety pin and installation tool. The cartridge, built to withstand the shock of repeated perforations, draws electric power from the surface through a wireline, charging a capacitor to 3,000 volts. The electrical energy is then shunted through the EFI, detonating the gun. The safety pin is inserted into an air gap in the EFI to prevent premature detonation. It can be screwed into the assembly if the guns need to be transported fully armed, or installed with the tool when the guns are armed at the wellsite.
An example is monitoring drug usage. According to the International Association of Drilling Contractors (IADC), accident rates in the US drilling industry dropped 36 percent between 1984 and 1986, mostly due to introduction of drug screening for job candidates and random drug checks on employees. It was found that 30 percent of job candidates tested positive and that after 18 months of random checks, drug incidence among crews dropped from between 5 and 15 percent to between 1 and 2 percent. It hardly needs saying that alert crews are drug free.

But even the best crew still needs technology to help detect and control kicks. Recently, two Schlumberger companies, Sedco Forex and Anadroll, have combined technical innovations to improve both detection and control. In 1989, Sedco Forex introduced a drilling information and alarm network called the MDS system. This collects and interprets data from sensors on the rig and present the information graphically on rugged color video screens on the rig floor for the driller and in the offices of the Sedco Forex rig superintendent and operator drilling supervisor. These are the key decision-makers in detecting and fighting a kick.

The MDS system helps guide the drilling process, and its software triggers “smart” alarms to give early warning of emergencies such as kicks. Once a kick is detected and the well safely shut in, the influx must be circulated out. For this critical operation, the MDS system presents a special screen displaying crucial data such as drillpipe pressure, choke pressure, pit volume and choke position versus time or pump strokes.

Anadroll’s contribution is the Accu-Flow sensor that measures mud outflow from the bell nipple. Based on an acoustic measurement of the fluid level in the mud return line (next page, bottom), the sensor offers several times the precision of a conventional paddle deflection flowmeter, measuring outflow to within 30 gallons per minute (gal/min) [0.71 bbl/min; 114 liter/min], Typical mud circulation is 1,200 gal/min [29 bbl/min; 4,540 liter/min].

Kicks are detected differently depending on whether a rig is drilling or tripping. During drilling, kicks are traditionally detected by monitoring fluid level in the mud pit—an increase indicates fluid entry downhole. Pit level sensors are quite reliable with a resolution of about 1 barrel (bbl) [159 liters]. Using conventional rig floor gauges, the driller can visually detect a gain of between 10 and 15 bbl [1590 and 2385 liters].

The MDS system collects the pit level data and in real time looks for significant increasing trends with the characteristic of a kick. Using statistical processing, the system rejects random fluctuations that might otherwise be interpreted at kicks and triggers an alarm.


† Mark of Sedco Forex
† Mark of Anadroll

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alarm only when the pit level shows a persistent tendency to increase (right). If the active circulating system is limited to just the mud tanks, the MDS system can reliably flash a warning after significant pit level increases of only 5 bbl. This precision has been proven in an Anadrill test well equipped with gas injection to simulate a kick and in tests on the Sedco Forex 600 semisubmersible currently drilling for TOTAL in offshore Indonesia.

A more sensitive and timely way to detect kicks while drilling was tested by Exxon Production Research Co. in 1985. Called the delta-flow method, flow into the well is compared with flow out. In the absence of a kick, the two flows are equal and delta flow is zero. But if more mud comes out than
Both kick detection methods are automatically deactivated for a few seconds with each change in pump rate to allow the flow rate to stabilize. But when circulation is stopped so a new stand of pipe can be added to the string, some other kind of kick detection that monitors the transient must be used. Adding pipe takes several minutes, enough time for an influx to gain momentum.

In pit level detection, the transient results from the drainage of surface flow lines and lasts up to 5 minutes. Its behavior is observed during the first few connections, and then an average of these behaviors is used as a template to judge data obtained during later connections. An influx due to a kick during connection can thus be discerned. The delta-flow transient is shorter than the pit level transient, around 30 seconds. This is too quick to be measurable by a paddle flowmeter, but it can be measured by the Accu-Flow outflow sensor. To check for an unexpected volume influx while connecting, the MDS system automatically monitors both detection methods.

Kick detection while tripping is an entirely different story, requiring an accurate monitoring of the volume of steel entering or leaving the borehole and comparing it with mud level changes in the trip tank. The MDS system accomplishes this in several ways. First, once the driller has entered specifications of the bottomhole assembly and drillpipe into the computer, steel volume is easily calculated—the length of pipe in the hole is measured automatically with the MDS travelling block altitude sensor. Second, the system applies smart processing to detect deviations from zero difference between steel displacement and mud volume change in the trip tank. Third, the system displays on video screens volume differences and cumulative volume, so trends can be quickly identified. Using a normal trip tank, changes as small as 1 bbl can be detected. The user can define any number of tanks as the tripping volume, but accuracy decreases with increasing tank number.

These and other safety innovations are being developed in an atmosphere of increasing concern about safety issues. The industry recognizes that safety is important for employees and its public relations image—catastrophic disasters make active headlines. The industry also knows that companies operating safely also operate efficiently. In short, safety is worthwhile and technology for safety continues to evolve.

—HNE