RLAB: A REMOTELY OPERATED LABORATORY FOR IMPROVED MANAGEMENT OF HAZARDOUS SPILLS

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Abstract

Highway spills of hazardous substances expose emergency response personnel and the public at large to the risk of explosion, fire, and contamination. When the spill is of an unknown substance, response personnel must first determine its identity. Problems of human exposure make automated or remotely controlled sampling and analysis a logical approach for this operation. The State of California's Department of Transportation (Caltrans) has sponsored a pair of projects that demonstrate this approach — a remotely operated vehicle (ROV) to sample an unknown substance and a remotely operated laboratory (RLAB) to identify the substance. This paper describes the conceptual design of the RLAB. Key issues include the selection of a method of identifying unknowns, the tradeoff between complexity and functionality, the division of labor between the RLAB and its human operator, the interaction between the ROV and the RLAB, and the possible use of historical spill data to speed the identification of unknowns.

1. INTRODUCTION

Spills of hazardous materials expose emergency response personnel and the public at large to the risk of explosion, fire, and contamination. In 1988, there were over 6000 hazardous materials transportation incidents in the U.S., resulting in 15 deaths, over 150 injuries, and damages exceeding $20 million. All of the fatalities and over 85% of the damages resulted from hazardous

materials spilled on highways. In California alone there were over 300 incidents during 1988, resulting in close to $2 million in damages (1).

The identification of spilled substances is a vital first step in managing a hazardous spill. Identification determines the procedures to be followed in containment and cleanup, and the extent of evacuation required. To effectively manage a hazardous spill, identification, containment, and cleanup must be carried out with minimum human exposure and property damage. Reducing the time required for these activities is critical, particularly for highway spills, where the cost to society due to road closures can be significant.

1.1 Current Practice

Upon arriving at the site of a spill, the first responder (usually Caltrans or the California Highway Patrol) isolates the spill, establishing a safety zone around it. This may require blocking or rerouting traffic. The first responder then attempts to identify the spilled substance. If the substance can be identified by placards, labels, shipping manifests, or interviews with the driver of the transporting vehicle, the first responder can use any of a variety of handbooks, databases, and phone-in services (e.g. 2, 3) to determine appropriate methods for containment, clean up, and disposal.

When an unknown substance is involved – for example, when a substance has fallen or spilled from a vehicle without the driver's knowledge, when a substance is released in an accident that badly damages the transporting vehicle, or when a substance is illegally dumped – the situation must be assumed hazardous until further information is obtained. Additional response personnel are brought in, don protective gear to obtain a sample of the substance, and use a variety of analysis techniques to determine its composition.

In urban areas, although the first responder may be Caltrans or the California Highway Patrol, identification, containment, cleanup, and disposal are carried out by contractors. The first responder will provide the contractor with any information available from a visual inspection of the scene. Depending on the location and time of day, it may take the contractor from 30 minutes to several hours to arrive at the spill site, and another 30 minutes to several hours to identify the spilled substance sufficiently to allow clean up to proceed. During this time, the part or all of the highway is typically closed to traffic. In rural and remote areas, fewer contractors are available, and Caltrans personnel must handle a wider variety of incidents and tasks.

1.2 Identification of Unknowns

At the site of the spill, a qualitative analysis is carried out to identify the unknown. A precise determination of the chemical content of the unknown is not required. Rather, it is necessary to proceed through the analysis only until an appropriate containment and clean up strategy is indicated. In most cases, a more detailed quantitative analysis will be needed prior to disposing of the material. However, this detailed analysis can be carried out in a controlled laboratory environment without the time pressure caused by highway closure.

Three broad categories of equipment and methods may be used in identifying unknowns: field meters, "tailgate" chemistry, and analytical laboratory equipment. Portable hand-held field meters are available to

monitor radioactivity and combustibility, to measure pH, and to detect the presence of a variety of organic and inorganic gases. However, these meters do not provide enough information to determine clean-up procedures for most solids and liquids.

The identification of unknowns in the field is most frequently accomplished by "tailgate" chemistry – working through a sequence of relatively simple tests in which small amounts of an unknown are combined with a series of reagents. Several proprietary systems have been developed to lead response personnel through a testing sequence. Typically, the tests can be divided into two types: screen tests and definitive tests. Screen tests are carried out first to detect properties which indicate that a substance is hazardous. Based on the results of screen tests, a specific sequence of definitive tests is carried out to identify common hazardous materials. In some tests, the reaction of an unknown with a reagent is visually observed. In others, the gas given off as the unknown undergoes a reaction is drawn into a prepackaged tube containing a reagent. A change of color in the tube indicates the presence or absence of a particular material.

If "tailgate" chemistry does not provide enough information to determine appropriate clean up procedures, a sample of the spilled material must be sent to a laboratory for analysis. Analytical laboratory equipment such as gas chromatography and mass and infrared spectrometers are used to determine the precise composition of the substance. This process is time consuming (especially if there is no laboratory facility close to the site of the spill) and expensive. Skilled operators are required to run the equipment and interpret the results. The results of this quantitative analysis typically provide far more information than is needed to clean up the site and reopen the highway.

The Berkeley Fire Department provides an example of the state-of-the-art in municipal hazardous spill response. They have a trained emergency response team, and have recently purchased a specially equipped response vehicle which serves as a command station. The vehicle contains communication and computer facilities, handbooks, protective gear for personnel, various systems for chemical analysis and identification, a video monitor, and spotlights. A video camera mounted atop the vehicle provides remote viewing of the spill.

2. IMPROVING RESPONSE THROUGH REMOTE CONTROL

Even with state-of-the-art equipment, current practice puts response personnel at risk. Protective clothing may not be adequate; clothing may protect against one chemical, yet be readily penetrated by another. In addition to the human risk, the dollar cost of current practice is significant. Roads remain closed until a contractor arrives at the site, identifies the spilled substance, and cleans up the spill. Supporting equipment and protective gear are costly, and equipment and gear which cannot be decontaminated must be thrown out and replaced.

Problems of human exposure make a remotely controlled system a logical approach. Remotely controlled vehicles have been developed for use in the cleanup of nuclear and other hazardous waste sites. However, these systems are for the most part too large and too expensive to be used on

highway spills. To minimize response time, a system for highway use should be small enough to be stored in a variety of Caltrans vehicles. It should be easily operated by employees whose primary function is not hazardous spill response. In addition, it should be easy to decontaminate, and inexpensive enough to be placed in districts throughout the state and to be discarded when decontamination is not possible. Finally, the system must be intrinsically safe, since many highway spills involve flammable and/or explosive materials.

Identifying an unknown substance can be thought of as a two step process: obtain a sample of the unknown and then analyze the sample. These steps require very different capabilities. The former is primarily physical; whatever is obtaining the sample must get first to the site and then to the exact location of the spill, and must pick up a sample of the spilled substance. Although some initial testing (e.g. for explosivity) may be carried out while obtaining the sample, safety and weight considerations dictate that the bulk of the analysis be carried out at a location slightly removed from the actual spill. The process of analyzing the sample is largely observational. Using existing "tailgate" chemistry procedures, small amounts of the unknown substance and various reagents are combined in a series of test tubes, and the resulting reactions are observed.

Because the requirements for sampling and for analysis are so different, it makes sense to consider the development of separate devices for these tasks. Caltrans has sponsored a pair of projects that demonstrate this approach — a remotely operated vehicle (ROV) to sample an unknown substance and a remotely operated laboratory to identify the substance (RLAB). A prototype ROV has been developed at California State University, Chico, and is described elsewhere (4). A proof-of-concept model of the RLAB is currently under construction. Figure 1 shows how these devices would be used together. Upon arriving at the scene of a spill, Caltrans personnel would deploy the ROV. Using a video camera mounted on the ROV, response personnel would inspect the site, looking for labels or placards, without the need to suit up in protective gear. If no identifying information is found, the ROV would obtain a sample of the spilled substance. At the same time, response personnel would deploy the RLAB in a location slightly removed from the spill, but also removed from people at the site. The ROV would deposit the sample in the RLAB. Testing in the RLAB would be controlled and monitored remotely. Response personnel would not come into contact with the unknown until an appropriate containment and clean up procedure is identified.

3. RLAB SYSTEM DESIGN ISSUES

Key issues in the design of the RLAB included the selection of a method of identifying unknowns, the tradeoff between complexity and functionality, the division of labor between the RLAB and its human operator, the interaction between the ROV and the RLAB, and the possible use of historical spill data to speed the identification of unknowns.
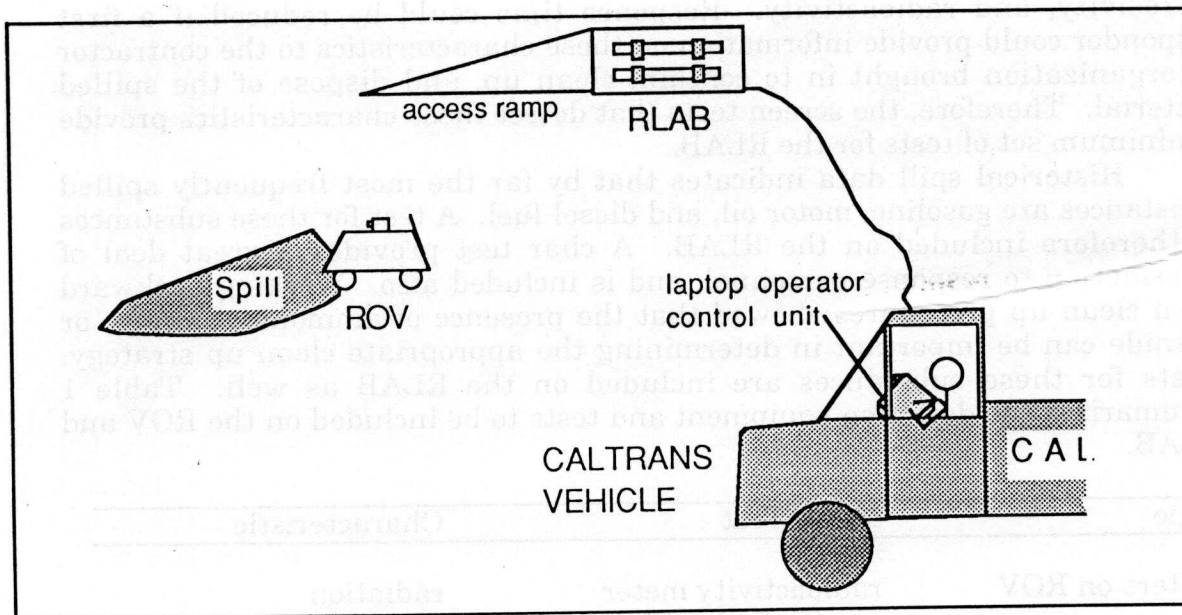
Figure 1. Schematic Illustration of ROV/RLAB Operation.

3.1 Identification Method

The fundamental issue in the design of the RLAB was the method of identification to be used. Current field practice, "tailgate" chemistry carried out manually, could be duplicated in a remotely controlled system. This option was attractive in that, in concept, it would be readily acceptable to field personnel. However, it would have resulted in a very complex and cumbersome system. From a philosophical standpoint, the design of the RLAB provided an opportunity to reevaluate identification methods in the context of increased automation. In the end, two paths were followed. A proof-of-concept model of the RLAB based on a subset of the "tailgate" chemistry tests is being constructed. In addition, specifications are being developed for a new automated testing system that would resemble available laboratory equipment, but would carry out the qualitative analysis required at the spill site. This effort is described in greater detail in Section 4.

3.2 Complexity vs. Functionality

A remotely controlled version of the complete battery of "tailgate" chemistry tests would have allowed the first responder to carry out a complete qualitative analysis of most unknowns. However, the resulting system would have been large, unwieldy, and impractical for placement in many response vehicles. Instead, the RLAB design effort focused on determining a subset of tests that would allow the first responder to provide the follow-up crew with information that would give them a "head start" on identification and clean up.

Discussions with hazardous materials specialists within Caltrans, with local fire departments and contractors, and with the developers of several "tailgate chemistry" systems indicated that the following are important characteristics in assessing the hazards posed by a spilled material: explosivity, volatility, flammability, oxidation potential, water reactivity,

corrosivity, and radioactivity. Response time could be reduced if a first responder could provide information on these characteristics to the contractor or organization brought in to contain, clean up, and dispose of the spilled material. Therefore, the screen tests that detect these characteristics provide a minimum set of tests for the RLAB.

Historical spill data indicates that by far the most frequently spilled substances are gasoline, motor oil, and diesel fuel. A test for these substances is therefore included on the RLAB. A char test provides a great deal of information to response personnel, and is included also. Working backward from clean up procedures showed that the presence of ammonia, amines, or cyanide can be important in determining the appropriate clean up strategy. Tests for these substances are included on the RLAB as well. Table 1 summarizes the detection equipment and tests to be included on the ROV and RLAB.

Type	Meter/Test	Characteristic
Meters on ROV	radioactivity meter	radiation
	organic/inorganic gas meter	various gases
	combustibility meter	offgasing, explosivity
RLAB screen tests	evaporation test	volatility
	combustibility test	flammability
	oxidizer test	oxidation potential
	peroxide test	oxidation potential
	water reaction test	water reactivity
	pH test	corrosivity
	char/ignition test	various substances
RLAB definitive tests	iodine crystal test	gasoline, oil, diesel fuel
	ammonia test	ammonia, amines
	cyanide test	cyanide

Table 1. ROV/RLAB Meters and Tests

3.3 Division of Labor

An unknown spill is a potentially dangerous situation. Because each spill is unique, human judgment is important in assessing the situation and taking appropriate response. In considering a more automated approach to managing a spill, it is important to keep the RLAB operator "in the loop" as much a possible without compromising speed or safety. The physical manipulation of the unknown and various reagents is carried out by the RLAB, with the sequences of action required to conduct a particular test carried out automatically. However, higher level control resides with the operator. The operator initiates all tests from a laptop computer, observes the tests through a camera mounted on the RLAB and a monitoring screen in the vehicle. The RLAB controlling software prompts the operator to enter observations and, in the future, may make recommendations based on interim test results. However, all decision making resides with the operator.

3.4 Interaction between RLAB and ROV

The ROV obtains liquid samples with a syringe, and solid (usually powder) samples with a scoop. The syringe and scoop are located at the base of the ROV. To allow gravity to assist in distributing the sample within the RLAB, the ROV should deposit the sample at the top of the RLAB. A lifting mechanism that raises the sample from ground level to the top of the RLAB could be designed, but a simpler solution is to have the ROV drive up a ramp to the top of the RLAB. Once in place over the material delivery system, the ROV releases the sample.

Future modifications of the ROV may allow it to carry out selected containment and clean up operations. To minimize the weight of the mobile ROV, the tools and attachments required for clean up could be mounted to the outside of the RLAB. The ROV would pick up the tools as needed.

3.5 Use of Historical Data

The presence of a computer as the control interface to the RLAB makes it appealing to investigate the use of historical data in the identification process. Different regions of California have different spill histories. For example, in the Imperial Valley, an agricultural area, unknowns frequently turn out to be pesticides. In the Santa Clara Valley, home to computer manufacturers, spills of chemicals used in circuit board manufacturing might be more likely. Additional tests could be added to the RLAB to detect substances that had a historically high spill rate in a particular area.

If extensive spill statistics were available, it might be possible to use them to guide the qualitative analysis. The "optimum" order in which tests should be carried out could be found based on the appearance of the substance, the frequency with which different substances have historically been spilled, and the results of each test as it is carried out. Preliminary consideration of this approach indicated that spill data is too sparse to be useful in this sort of analysis. However, the idea is appealing, and warrants further investigation.

3.6. RLAB Design Summary

The RLAB conceptual design is as follows. The ROV delivers a sample of the unknown to a dispensing system on the top of the RLAB. A carousel houses the tubes in which the tests will be carried out. Depending on the requirements of the test, the tube is either preloaded with a reagent or equipped with a system to dispense a reagent (for some tests, the reagent must be added to the unknown, rather than the unknown being added to the reagent). For several tests, encapsulated reagent tubes are mounted over the test tube. A pump draws a headspace sample into the encapsulated tube. The initiation of each test is remotely controlled by operator; lower level functions (such as the control of the pump) are carried out automatically. A camera mounted on the RLAB allows the operator to view the tests through a remote monitor. Test results are interpreted by the operator with assistance from the operating software.

This design results in a lab that is roughly the size an automobile tire, and requires four actuators (two for the dispenser, one for the char test, one for the encapsulated reagents) and six valves. A proof-of-concept model of the RLAB is current under construction.

4. ANALYTICAL EQUIPMENT FOR QUALITATIVE ANALYSIS

The RLAB conceptual design described above represents one attempt to improve spill response by incrementally improving current practice. A philosophically more appealing approach is to redesign testing technology with automation in mind. The ideal would be a "black box" which would automatically tell the operator the appropriate procedure for containment and clean up of the sample. Standard analytical laboratory equipment can be used to precisely determine the composition of an unknown material. However, such equipment requires a highly trained operator, must be precalibrated based on the anticipated composition of the unknown, and is really designed for quantitative analysis, rather than the qualitative analysis required for containment and clean up of a spill.

Several mobile lab systems have been proposed and are being developed, primarily funded by the Department of Energy. These range in size from a "back pack" to van; anticipated costs range from $150,000 to $1 million. Most of these systems are still under development. For application at hand, these systems are too large, too expensive, and provide more capability than needed.

Conversations with people involved in the development of analytical equipment indicate that the qualitative analysis problem posed by highway spills is one that they have not addressed, but for which there is likely a solution. A survey of Caltrans response personnel is underway to aid in the development of specifications for a portable, field hardened piece of equipment that would automatically carry out qualitative analysis of an unknown.

5. SUMMARY

The ROV/RLAB concept for hazardous spill management has the potential to minimize human exposure and increase response speed while remaining cost effective. Separating response equipment into a mobile ROV and a portable RLAB allows Caltrans to make maximum use of available technology. An RLAB model based on currently used "tailgate" chemistry is being developed. In the future, identification may be automatically carried out by field hardened equipment designed for qualitative analysis.

6. ACKNOWLEDGMENTS

6. REFERENCES

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