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**A NOVEL METHOD FOR MONITORING PIPE WALL THINNING
Final Report**

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This is the final report of a study which was conducted under a grant from the U.S. DEPARTMENT OF ENERGY, ENERGY RELATED INVENTION PROGRAMS. Part of this work was also supported by a grant from the COMMONWEALTH OF VIRGINIA, CENTER FOR INNOVATIVE TECHNOLOGY.

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EXECUTIVE SUMMARY

This report presents results from eight tasks which were formed to demonstrate commercial viability of a new technology for the early detection of corrosion damage. The tasks produced three products which are deployed to commercialize the technology:

(1) Experimentally verified software package which allows instrument specification for wall thinning detection. (2) Eighteen months of field experience in the installation and monitoring of radioactive tracers for wall thinning. (3) Technology for environmental and process monitoring, which was not developed under this contract but evolved as a natural extension of the subject invention.

Radioactive tracers are deployed to provide early warning of corrosion attack on pipes and tanks. The results of this project clearly demonstrate that these monitors are tailor made for harsh and difficult to access environments. It is believed that no other technology is capable of providing in situ wall thinning data in such environments.

The early warning of wall thinning with radioactive tracers will be commercialized via licensing agreements. Power plants and refineries have the capabilities to deploy the technology which was developed and demonstrated under this project. The attached literature which outlines the advantages of the present technology has been sent to EPRI and API.

Funds from licensing agreements will be invested in the establishment of a service to conduct the actual monitoring. This service will extend beyond corrosion monitoring to include environmental monitoring.

Recent increase in environmental regulation and cleanup of polluted sites has created a market for low cost, in-situ, monitoring. Through its ownership of U.S. Patents 5,187,366 and 5,200,615, which offer the most economical means of monitoring vast areas for toxic compounds, the company is in a unique position to profit from the emerging new market. The attached literature also summarizes the status of the technology.

Negotiations are underway with companies with existing sales and distribution outlets for the formation of joint ventures. A proposals for the ARPA initiative and the DOE/SBIR have been prepared in the area of environmental monitoring.

TASK 1- EXPERIMENTAL FACILITY

The purpose of this Task was to construct an experimental facility for the tests of Task 2. The test rig was constructed at the School of Engineering at the University of Virginia. The complete facility is described in Attachment 1.

TASK 2- EXPERIMENTAL AND MODEL DEVELOPMENTS

The purpose of this Task was to develop a computer model which would allow to scale the test results to other operating conditions. More specifically, the calculational model allows the user to specify the required trace intensity for a given pipe material and size, flow velocities, instrument sensitivity and background radiation.

As discussed in Attachment 1, excellent agreement was obtained between model predictions and experimental data.

TASK 3- MARKET NEEDS

The purpose of this task was to establish contacts with various industrial concerns to provide feedback to Task 2.

During the course of this program, a large number of pipe failures due to internal erosion/corrosion have occurred in nuclear power plants, the corresponding losses have exceeded many millions of dollars. These failures have been attributed partially to the failure of an EPRI developed computer model to properly identify the areas where inspection should be conducted. Also the model does not protect against chemical transients between inspection intervals. EPRI has been aggressively marketing their product to utilities and has not been helpful in the transfer of the present technology to their members.

Another experience gained from this Task was that regulatory uncertainties in obtaining a license for installing tracers may increase the cost of this technology. For example, after arrangements were made with Bethlehem Steel for the instrumentation of several pipes and tanks at their Sparrow Point plant we learned from the State of Maryland authorities that their new policy allows only water soluble tracers. As a result a method was developed to produce solid, water soluble tracers. Although this example may not be typical it does indicate that substantial funds will have to be allocated for contingencies

associated with obtaining government approvals.

TASK 4 - LEAKAGE TESTS

The purpose of this Task was to pressure test 40 different pipe sections to demonstrate that Sentry Plugs will not leak following tracer release. This task was performed primarily by M. CLAR PRODUCT DEVELOPMENT, Rockville, MD.

The attached sketch shows three different designs to prevent leakage following trace release. The first design, (Top), employs a Number 6 screw which is backed by a 1/8 standard plug. The plug is threaded into a half coupling which is welded to the wall. The critical leakage path is the weld at the pipe wall. The second design employs (Middle) Type 155 A (IRONITE) ductile iron threaded plug with a uniform taper instead the standard plug/half coupling design. The taper plug eliminates the need for welding, it is designed for cast iron and relatively thick wall pipes. The third design, (Bottom), uses a screw with an O-Ring at its tip.

The test fitting ranged in size between 1" and 12", with steel and iron (Class 150 Cast iron, and Class 150 Class 300 and Class 3000 Malleable Iron, Low Carbon steel.)

Three different certified welders, for welding the couplers to the pipe were employed at various times. Since a large percentage of the welds for iron fittings leaked, even after rewelding, it was concluded that the standard plug design will be adequate only for steel. For iron fittings a screw with an 'O' ring or the tapered plug must be used. None of the fitting leaked with the latter design.

TASK 5

The purpose of this Task was to determine whether soluble tracers could be used for downstream monitoring.

If small soluble particles could survive dissolution by the fluid after corrosion had breached their burial place but before the opening was sufficiently large for their release into the flow than they could be used for downstream monitoring in states which do not allow release of insoluble tracers to the environment. The solid tracers are less expensive and are easier to handle.

The polymer polyvinylpyrrolidone (PVP) which is soluble in water, was found to be an excellent binder for Cobalt Nitrate. This binder is produced as a powder but when mixed with the proper amount of water hardens to a stable solid upon drying. This material was employed to establish the feasibility for using soluble tracers for downstream monitoring.

Schematic Of Tracer Sealing Methods

Since it is not possible to reliably predict how fast a pin hole will be enlarged in a given corrosive environment, any dissolution of the trace was considered unacceptable at the outset.

1/16"x1/16" tracers made of the above material mixed with a fluorescent dye were inserted into a simulated transparent pipe wall. The internal surface of the pipe, where the trace was buried, had several pinholes to simulate internal corrosion. The trace was exposed to water flow velocities ranging between 0 and 15 feet/sec. The results of these tests show that velocity had little effect on dissolution when the pin holes were on the order of 0.010 inch in diameter. Dissolution, as seen by the dye, was basically controlled by diffusion through the pin hole. After 24 hours in stagnant water, there was always some dye visible at the pipe surface even for pin holes smaller than 0.005 inch. By coating the trace with a thin layer of silicon no dissolution was detected after two months of exposure to stagnant water. This indicates that it is feasible to use soluble tracers for downstream monitoring. They must, however, be coated with material which prevents dissolution over relatively short time, weeks, but allow dissolution over long periods, months, when released to the environment. When corrosion is measured by monitoring the wall only, without downstream detection, obviously coating is not required.

TASKS 6 and 7 - FIELD DEMONSTRATION

The purpose of this task was to install radioactive tracers in a commercial facility to demonstrate feasibility. Manual monitoring with a hand-held meter, (no downstream detection), was to be used to monitor corrosion. This Task was performed by J.C. Consultants, Chandler, Arizona.

40 sources of Co⁵⁹ were punched out from a 0.040" plate with a 7/64 " die. The plugs were irradiated at the University of Maryland, with a yield of 1 microcurie per source. The sources were shipped to CYPRUS MIAMI MINING, where they were installed in a 9 ft. diameter pipe which carry SO₂. All tracers were installed at weld joints where experience indicates severe corrosion attack. In spite of very severe weather during installation of the tracers, no problems were encountered with any of the procedures. The tracers were installed in April 1991, but it was not until early 1992 that the pipe was put in operation. None of the plugs which protect the tracers were damaged during installation in spite of rough handling.

Monthly surveys with a hand-held detector show that this is an excellent method to monitor internal corrosion at welds, in inaccessible, high temperature areas. Clear readings are obtained at the pipe insulation. In spite of an explosion of an adjacent duct, no damage occurred to the plugs which were subjected to unknown pressure loads.

TASK 8- COMPARISON WITH ANALYTICAL PREDICTIONS

The purpose of this task was to demonstrate that the PREDICTOR model can predict NaI sensor response on an actual system. This comparison was incorporated into TASK 2, pipe diameters in Task 6, were too large for downstream monitoring.

SMART SENSORS FOR NEW REQUIREMENTS

U. S. Patents: 4,779,453, 4,922,748, 5,187,366, 5,200,615

- LEAKS
- CORROSION
- LEVEL
- FLOW

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TECHNOLOGY SUMMARY

SENSOR	FUNCTION	PRINCIPLE	PROTOTYPE/PATENT	STATUS
SENTRY PLUGS	To detect internal pipe corrosion	Radioactive tracers	Field demonstration and lab. data available. Two patents issued.	Available for licensing.
LIQUID LEAK DETECTION PROBE	To detect leaks and distinguish between product and water	Optical. Two sensors: one mechanical the other absorption	Prototype tested. Patent Pending.	Available for licensing
OVERFLOW SWITCH	To signal an alarm when a certain level is reached	Same as above	Same as above	Available for licensing
LEAK DETECTION CABLE (Irreversible mechanical sensors)	To detect and locate liquid leaks over long distances.	Mechanical sensors cut cable. OTDR is used to locate cut	Prototype tested. Field demonstration required. Patent issued	Available for licensing
LEAK DETECTION CABLE (Reversible mechanical sensors)	Same as above	Optical switch	Limited testing done. Patent pending. Confidential Agreement Req'd	R&D is required
ENVIRONMENTAL CABLE (Fluorescent sensors)	To detect trace chemicals	Fluorescent coating on fiber changes intensity when exposed to a specific chemical	Limited testing. Patent issued. Confidential Agreement Req'd	Material R&D and electronic packaging is required.
FLOW SENSOR	To measure flow in small diameter tubes without disturbing the flow.	Tiny optical switches at the inner tube wall are activated by flow.	Feasibility established. Patent pending.	Applied R&D Required
CONTINUOUS LEVEL	To detect liquid level with a long distance to electrical source	Uses many tiny optical switches in series.	Limited testing Patent Pending Confidential Agreement Req'd	Applied R&D Required

A NEW FIBEROPTIC SYSTEM FOR LEAK DETECTION

SUMMARY

The system shown in Figures 1, 2 and 3 is capable to continuously and automatically detect and locate leaks from tanks pipes and landfill liners. The survey of long distances or the coverage of large areas at low cost with simple, off the shelf, components and proven technology distinguishes this system from all other leak detection techniques.

The cost of the system is at least 300% less than the competing electrical leak detection cables and its performance does not deteriorate with time.

The system is intrinsically safe, does not employ wearing parts, all materials have a proven lifetime of at least twenty years and requires no maintenance. Nor does it require costly replacement of the entire cable following exposure to fluids.

The spread of underground plumes, Figure 1, is monitored by a smart fiberoptic cable which is inserted into a network of underground PVC pipes. One side of the cable is connected to a light source (LED, Laser) and the other to a light meter. The smart cable is designed to detect one or a number of different species at the same time by using a daisy chain of sensors. An Optical Time Domain Reflectometer, OTDR, pinpoints the location of the affected sensors by measuring the time it takes a light pulse to travel to and from the activated sensor.

The detection and location of leaks in pipelines and tanks, Figures 2 and 3, is accomplished by placing "smart cables" in the interstitial space or laying the cables in the ground below the pipe or tank.

Basic sensor design, Figure 4, is a 3/8 inch round spring which incorporates a small blunt edge and a holder for the fiber cable. A polymer insert prevents the edge from touching the fiber. When the leaking fluid reaches the sensor, the polymer immediately becomes soft and allows the edge to break the fiber. Specific sensor designs depend on requirements such as response time and reversibility.

On March 16, 1993 legislation was introduced in Congress to stop leaky fuel tanks. One of the provisions " requires a release detection system for facilities at which tanks are located".

The system described in the following pages represents the most cost effective and reliable technology which can meet the intent of THE SAFE ABOVEGROUND STORAGE TANK ACT OF 1993.

FIGURE 1

SCHEMATIC OF A PERIMETER MONITOR

A LEAK LOCATION/DETECTION SYSTEM FOR ABOVE GROUND TANKS

OBJECTIVE. The objective of this system is to locate and detect leaks below from above ground tanks.

PRINCIPLE. A 200'x 200' site is defined as a reference site. A fiber optic cable with attached leak specific sensors is placed above, or between two layers of a plastic liner. The site is divided into eight 500 sq. ft. areas and a 1000 ft.long, 1/2" corrugated tube which contains the fiber is placed on a 5'x5' grid, Figure 2. Any sensor exposed to the leaking fluid will either cut or will introduce a significant disruption in light transmission. This light attenuation is sensed by a simple instrument known as an OTDR or a Fault Locator.

LEAK LOCATION. A hand held Fault Locator is attached successively to the 16 fiber ends located in the termination boxes along the four sides of the property. The location of the first broken fiber is identified within 60 seconds by the instrument. From the data obtained from all 16 points the location and the extent of the leak can be determined.

LEAK DETECTION. Can be attained by periodic inspection with a flash light for continuity of each of the eight fiber loops. An electronic controller can be added to the system for automatic and continuous leak detection.

SENSOR REPLACEMENT. The capability to locate new leaks following repair of a leaking region is not impaired since only the sensors in the immediate vicinity of the leak are effected. If a large number of sensors is disabled in a given loop the fiber can be pulled through the corrugated tube and reinserted following the installation of new sensors.

FIELD INSTALLATION. No special training is required to lay the corrugated tube along the grid. The Fault locator is a simple instrument and no special skills are required for its use. Some training is required for the attachment of the 16 end connectors to the fiber and the initial calibration of the system. This rugged system can be stepped on during installation. If the fiber is accidently cut by a sharp object it can be easily spliced.

TOTAL DIRECT COST:

Matrix	Direct Material			Direct Labor		Total(\$)
	Sensor	Fiber	Tubing	Assembly (plant)	Installation (field)	
5 x 5	800	1600	1200	800	300	4700
10x10	400	800	600	400	150	2450

LEAK LOCATION FOR ABOVE GROUND TANKS

200' x 200'

The corrugated tubing, containing the fiber and the attached sensors, is delivered to the site in eight 1000' reels. The tubes are taped to the liner with the sensors approximately corresponding to the center of each of the 5'x.5' grid squares. Following installation, each cable is tested with an OTDR and a record is kept for future reference.

LEAK DETECTION/LOCATION FOR DOUBLE CONTAINMENT PIPES

OBJECTIVE: To detect/locate leaks along double containment pipes.

PRINCIPLE: Three fiber optic cables are inserted in the interstitial space of the pipe, Figure 3. Small (3/8" da.), rugged sensors are attached to each fiber at intervals of 5 feet. Some sensors are activated by product only while others are activated by water only. When a sensor is contacted by the fluid the power meter activates an alarm and an OTDR, a fault finder, is used to locate the effected sensor.

SENSOR REPLACEMENT. The Detection/Location capabilities of the system are not disabled by a leak. The detection and location lines continue to function after the leak has been detected. Location capability is lost only in that part of the cable where the leak had occurred. The capability of the detection dedicated line to detect automatically new leaks without sensor replacement depends on the type of sensor employed and the electronic controller.

If a large number of sensors were exposed to the leaking fluid for prolonged times those sensors will have to be replaced to render the leak detection system its original efficiency. Replacement can be attained by either splicing a new fiber cable or inserting new inserts, Figure 4.

SENSORS . The sensors are characterized in terms of their ability to function following a leak: An irreversible sensor is a sensor which the insert material is not reusable and therefore the sensor must be repaired following a leak. A reversible sensor employs an insert material which is rejuvenated following the leak.

An irreversible sensor which cuts the fiber is used when a leak only seldom occurs. A system utilizes such sensors employ a very simple and inexpensive electronic package. Reversible sensors require more expensive electronics and are used to detect occasional water leaks or condensation.

LEAK DETECTION/LOCATION SYSTEM FOR PIPES

The LEAK DETECTION/LOCATION cable runs along the interstitial space of the pipe (above). The cable contains three lines which terminate in the control box. Sensors are attached to each line at desired intervals.

FIGURE 4

SCHEMATIC OF A CUTTER

TOP: NO LEAK DETECTED.
The knife is prevented from breaking the fiber by two soluble inserts which are wedged between the spring and the inner ring.

BOTTOM: LEAK DETECTED.
The soluble insert loses its strength and thereby allowing the knife to break the fiber.

NOTE: For spring diameters less than 0.5 inch use a soluble solid spring loader without inserts.

FIGURE 6

SCHEMATIC OF GROUNDWATER MONITOR

Functions of sensors (A), (B), and (C):

1. To identify the air/liquid interface, (B).
2. To identify the presence of contaminants at the interface, (A).
3. To measure growth of the contaminated layer (A,C).

All sensors are reversible and respond instantaneously.

THE APPLICATION OF MODIFIED SENTRY PLUGS TO CORROSION MONITORING

INTRODUCTION

Modified sentry plugs employ a proven technology to monitor uniform internal pipe wall thinning from corrosion/ erosion. Sentry Holes drilled to safe depths of pipe walls in selected locations were successfully deployed for many years in the oil industry. Visual observation of leaks from such holes provided a timely warning of potential pipe rupture. The advent of ultrasonic and radiographic techniques together with stricter safety and environmental regulations caused the industry to abandon this "leak before break" method in the 1960's. Several major catastrophies in recent years which resulted from undetected pipe thinning suggest that the phase out of Sentry Holes may have been premature.

Sentry Holes present several advantages over modern corrosion detection methods and when adopted to today requirements their rejuvenation can provide a valuable contribution to plant safety.

The use of hand held UT wall thickness probes during outages is a widely used maintenance tool in modern plants. The main disadvantage of this method is that it is prone to human errors and provides no protection from sudden increases in corrosion rates between inspection intervals. Also, Ultrasonics and Radiographic techniques are expensive and their deployment is limited to accessible areas. To minimize insulation removal before inspection, utilities have been relying in the last several years on an EPRI developed computer model which identifies the key inspection points in their plants.

Major pipe ruptures at a Shell refinery and at several nuclear power plants in the last five years clearly indicate that there is a need for an in- situ, cost effective, and reliable method to warn operators in a timely manner of potential corrosion/erosion problems. The present study shows that augmentation of NDE techniques by a selective use of Sentry Plugs can meet these requirements.

Plugging the Sentry Holes removes the main objection to their use because the pipe will not leak when the holes are exposed to flow. Instead of relying on visual leak detection as an indication of wall thinning, the present method relies on minute amounts of tracers which are embedded in the wall at known locations. The exposure and subsequent removal of these tracers by the fluid when corrosion reached their site forms the foundation to the present technology. The tracers may be radioactive or fluorescent and their removal from the wall can be detected by either monitoring their presence in the fluid or their absence from the wall.

With grants from the Department of Energy, Energy Related Invention

and the State of Virginia, Center for Innovative Technology, the technology for embedding minute amounts of Co-60 in pipe walls and detecting their presence downstream or their absence from the wall has been developed and demonstrated.

DESIGN CONSIDERATIONS

Less than one microcurie of Co-60 is inserted into 1/8" inch diameter blind holes sealed with leakproof plugs (1/10 of the activity in a smoke detector). When excessive corrosion of the wall is detected by the absence of one or two tracers the rest of the tracers can be removed before pipe replacement and thereby almost eliminating any release of activity to the environment.

A computer model has been developed and experimentally verified at the University of Virginia. The user friendly program allows operators to specify trace strength as a function of flow velocities, pipe diameter, instrument sensitivity and location.

Sentry Plugs have also been installed in welds of a 10 foot diameter pipe carrying corrosive hot gases. The pipe, fifty feet above ground, has been in operation for more than a year. The tracers are monitored once a month, providing a clear signal through two inches of insulation, it takes about fifteen minutes to survey the 22 Sentry Plugs with a hand-held counter.

ADVANTAGES OF SENTRY PLUGS

- o. Reliability
- o. Design virtually precludes human error
- o. Applicable to remote/inaccessible areas
- o. Continuous pipe protection
- o. Applicable to new pipes or retrofit
- o. Requires no insulation removal
- o. No special skills/training needed to operate equipment
- o. Low initial and operating cost
- o. Localized corrosion can be detected by proper source/film arrangements.
- o. Protects against any chemical or flow transients which may unpredictably increase wall thinning.

DISADVANTAGES OF SENTRY PLUGS

- o. Requires government approval before initial installation.
- o. Requires accounting of tracers.
- o. The use of radioactive substances has an intimidating effect.

LEVEL AND FLOW

Figure 7 shows a schematic of level monitors which are activated by conventional floats or bellows. The main feature of this design is that electric monitors can be located at distances which are far from the sensing device. The low cost optical switch, less than 1/8 inch in diameter, can operate in corrosive environments for large number of cycles. An array of such switches allows for continuous level monitoring.

While the feasibility of the concept has been established the ability to manufacture such optical switches uniformly in large numbers remains to be demonstrated.

FLOW

Because of their small size, low cost and no wearing parts, optical switches can be embedded in small diameter flow lines for process control. As an example, sensors embedded in the inlet and outlet of injector fuel lines could continuously, without disturbing the flow, monitor fuel consumption rates and thereby allow fuel/air ratio adjustments for maximum engine efficiency.

Considerable investment will be required to develop such flow sensors.

FUTURE WORK

The liquid leak sensors discussed above can be produced in sufficiently large numbers to demonstrate the viability of the technology before commercialization. Because of simplicity and the use of off-the-shelf optoelectronic components little technical risk is anticipated.

However, the application of the technology to in situ monitoring of different chemicals in soil/air and in process control requires additional research and development.

Coating the fiber core with very thin fluorescent layers as described in Pat. 5,200,615 is in principle suited for the detection of any trace impurities. Recent advances in materials permits the engineering of coatings to abruptly change their light emitting strength and frequency when exposed to a given analyte. The engineering of Si, which normally does not emit light, is an example of such material.

The concept covered by the above patent allows one to extract in situ large amount of information on the chemical composition of environments from a single fiber in a cost effective manner.

FIGURE 7

SMART LEVEL SWITCH

DISCRIMINATES BETWEEN WATER and HYDROCARBONS

TOP: Polymer swells when contacted by water and shrinks when dry. This design is limited to a distance of 20ft. between sensor and controller

LEFT: This design employs glass fiber and is not limited by distance. In contrast to above, its operation does not depend on blocking the light between opposing fibers.

Water switches must be dried after exposure

FIGURE 8

SCHEMATIC OF FLUORESCENT SENSOR

OPERATING PRINCIPLE: The core of a conventional fiberoptic cable is coated at selected intervals along its length. The coating is engineered to change its light emitting strength and frequency when contaminated with a given chemical specie. By using a network of fibers in situ, this arrangement allows for a very large number of measurements at low cost.

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