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HAZARDOUS MATERIALS CONTAINMENT VIA SPILL PREVENTION AND FAILSAFE ENGINEERING

J. LESLIE GOODIER

Presearch Inc., Arlington, VA 22202 (U.S.A.)

and JOHN M. CECE

U.S. Department of Energy, Washington, DC 20545 (U.S.A.)

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Summary

The enactment and enforcement of regulations related to the release of oil and/or hazardous materials has resulted in the industrial development of a wide range of engineering innovations for spill prevention. An analysis of 1978 and 1979 oil spill data reveals that personnel error, inadequate maintenance schedules, and poor operating procedures are contributing cause(s) of many oil spill incidents. The authors present a synopsis of selected material management and handling procedures which may be useful to reduce the number of spills.

Introduction

From federally accumulated statistics for oil and hazardous substance spills, the authors obtained information on U.S. oil spills for the years 1978 and 1979. Table 1 exhibits a condensation of some of this data as it relates to industrial operations; the information is arranged to acquaint the reader with the various spill "categories" and the number of spills which occurred during the reporting period. Table 2 lists the most common cause(s) of the spills reported in 1978 and 1979. The reader is reminded that these figures are acquired from *reported* spills, and that it is somewhat reasonable to believe that an equal amount of material was spilled, but *not* reported. At an April 2, 1982, hearing before the Oversight and Investigations Subcommittee of the U.S. House of Representatives' Energy and Commerce Committee, the Subcommittee estimated that less than 40% of all serious spills are reported to the National Response Center [1]. Needles to say, the loss of oil products (energy materials) as the result of accidental spillage during transportation, transfer, storage, and processing is tremendous.

Additional review of Table 2, Common Spill Causes, reminds us that many spills result from situations or circumstances whose existence is known by management already. One may conclude that tank overflows, pipe and hose ruptures, personnel error, etc., are accident causes correctable by modest

TABLE 1

On-land oil spill analysis for two-year period (1978 & 1979) (selected categories from U.S. Coast Guard data)

Category	No. of spills	Gallons spilled
Railway cargo transfer	9	3341
Rail vehicle liquid bulk	30	134956
Rail vehicle general cargo	18	39707
Rail vehicle transfer	5	7125
Rail vehicle dry bulk	1	20
Railway fueling facility	19	58641
Highway vehicle dry bulk	23	12728
Highway vehicle liquid bulk	343	519407
Highway vehicle passenger	26	1050
Highway vehicle general cargo	42	2918
Highway cargo transfer	20	6574
Highway fueling	44	18362
Other land vehicle	38	25799
Unknown type of land vehicle	10	11599
Other land transportation facility	138	96576
Power plant	99	46151
Pipeline within non-transportation related facility	36	57489
Onshore pipeline	503	3214233
Other pipeline	34	48855
Onshore industrial plant or processing facility	356	393019
Onshore oil or gas production facility	97	79239
Onshore refinery	56	44803
Onshore fueling	77	18088
Onshore bulk storage facility	213	875125
Onshore bulk cargo transfer	289	4633920
Onshore non-bulk cargo transfer	9	210798
Other onshore non-transportation related facility	260	172939
Other transportation related marine facility	100	219055
Totals	2895	10972497

maintenance improvements or better understandable operating procedures. Certainly, many accidents may be prevented/avoided without a huge capital investment.

It is our observation that there has been no attempt to consolidate, define, and publish information that will guide managers and engineers in the application of spill prevention and failsafe engineering. As an aid to plant engineers and managers. Federal workers, fire marshals, and fire and casualty insurance inspectors, we have prepared this paper as a reminder (and guide) of selected spill prevention techniques.

TABLE 2

On-land oil spill causes for two-year period (1978 & 1979) (Source: U.S. Coast Guard Pollution Reports (POLREPS))

Cause		Number of incidents
1	Pipe rupture or leak	664
2	Other equipment failure	283
3	Tank overflow	279
4	Highway accident	238
5	Unknown cause	177
6	Other personnel error	160
7	Improper equipment or handling	150
8	Tank rupture or leak	140
9	Hose rupture or leak	123
10	Valve failure	104
11	Intentional discharge	100
12	Natural or chronic phenomenon	85
13	Other structural failure	79
14	Transport rupture or leak	77
15	Gasket failure	55
16	Railroad accident	47
17	Pump failure	41
18	Flange failure	19
19	Dike rupture or leak	19
20	Loading arm failure, rupture, or leak	18
21	Manifold rupture or leak	14
22	Aircraft accident	13
23	Container lost intact	10
Total number of on-land incidents during study period		2895

Discussion

Hazardous material transfer

Spill investigations conducted over a period of 34 years (Goodier) indicate a high risk potential for accidental discharges during the transfer of oil or hazardous materials. Some 50% of the spills listed in Table 2 resulted during transfer operations.

Because of the potential for release of large amounts of materials (usually into navigable waters), the loading and offloading of barges and tank vessels are particularly important. The transfer of hazardous cargoes is the responsibility of a tankerman and a dockman who work as a team during the loading or offloading operation. The tankerman is a U.S. Coast Guard (46 CFR 12.20) licensed person who can be a company employee or a contractual agent to the barge owner. To be certified, the tankerman must be familiar with the following operational and safety procedures:

- Cargo handling
- Pollution prevention
- General safety
- Firefighting
- First aid

Because of job mobility and the large variety of barges, it is possible that neither the dockman nor the tankerman has seen the particular barge to be loaded/offloaded. Some barges are segmented into as many as six cargo compartments, each of which may carry a different chemical. The compartments are interconnected by piping and valves which may be aligned to permit interconnection or isolation of several or all of the compartments. When a compartment has been filled and isolated, it is possible that material being pumped into another compartment may "short circuit" through an improperly seated isolation valve and cause the filled tank to overfill. Operating personnel are not aware of the situation until the accidental overfill discharges through a vent of the previously filled compartment.

To decrease the probability of this type of tank overflow, spectacle-type blank flanges may be installed in the barge piping system to ensure complete isolation of each cargo compartment (Fig. 1). Because product leakage occurs when the spectacle flange is operated, some tankermen elect not to use the flange and rely on the isolation valve entirely.

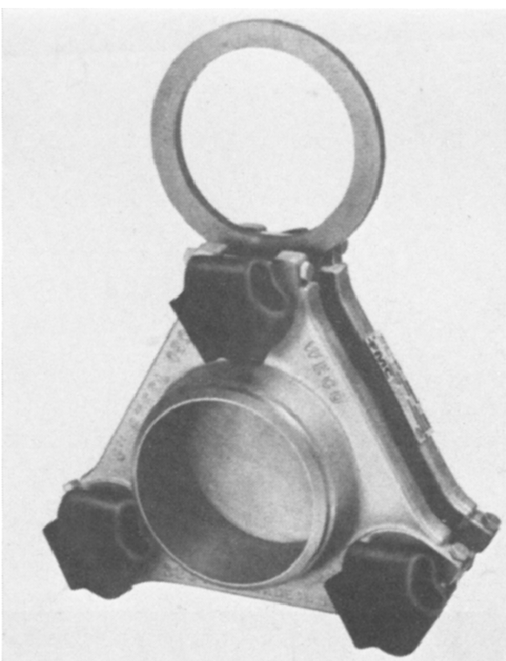


Fig. 1. In-line blank flange AKA line blind valve (FMC Corporation illustration).

Some organizations have enhanced safety by employing a cargo supernumerary (generally a retired deck officer) to supervise the cargo transfer operation. Using a checklist which encompasses deck, dock, and tank field activities, this individual ensures adherence to each step of the transfer procedure. Radio or telephone communication among the work stations may provide additional security.

An additional margin of safety may be attained if remotely operated, quick-closing valves are used. Pantex Valve Actuators (Houston, Texas) and Sentry Systems (Houston, Texas) have developed "Docksentry" and "Spill Sentry" systems, respectively. In case of spillage or fire, each system permits operators of dockside-loading facilities to close loading valves rapidly and from remote locations. The systems may be adapted to accept signals from liquid level sensors in the tank.

The process of coupling and uncoupling heavy cargo transfer hoses is known to be tedious and usually results in the spillage of some cargo. The entire operation may be completed safely and spill-free through the use of automated lifting and manipulating systems and hydraulically operated flange clamps. Additionally, a trend towards replacement of flexible hose lines with hydraulically powered articulated loading and unloading arms has contributed to a decrease in spill incidents.

U.S. Coast Guard regulation 33 CFR 154 defines marine oil-transfer facilities as those marine facilities capable of handling oil; marinas are excepted unless they handle bulk transfers of oil. The regulation requires such a facility to develop and submit an "operations manual" that describes precautions taken to prevent spills. The Appendix to this paper, Basic Content of Operations Manual, is an outline of the contents of the manual.

It is our opinion that any system or program that aids in preventing oil spills will also be applicable to preventing hazardous materials spills. Accordingly, we suggest that chemical manufacturers, users, or handlers involved in cargo transfer operations develop an "operations manual" for their particular situation.

The transfer of hazardous materials to/from tank trucks involves a risk of cargo spillage. This applies specifically to the *loading* of the tank truck. Although this function can be undertaken by company personnel, in many cases loading is conducted by the drivers of the common carrier trucks. At some loading locations the truck capacity is known, and the flow of material is monitored/metered during the loading process. When the load limit is reached the loading process is stopped automatically; this procedure eliminates the chance of spills caused by human error. Additionally this technique eliminates the need for the driver to *sound* continually the truck tank from a position above the fill dome where he could be exposed to hazardous vapors.

An additional problem associated with the loading operation is the generation of static electricity. This is especially hazardous if flammable cargoes are involved. To a degree this can be controlled by the use of in-line static charge neutralizers which should be installed on downstream filters, pumps, and other equipment which may be contributing to the generation of static charges.

The loading/unloading of railroad tank cars involves the risk of cargo spillage also. Fortunately, the loading of railroad tank cars may be engineered into a fully automated procedure. Previously a single rackman (loader) may have had to attend to the loading of several cars at the same time. Occasionally the loader's attention was diverted whereby spills may have occurred. Today, the entire loading procedure may be pre-programmed and tanks can be filled to a desired level with automatic pump shutdown following the filling process. As with tank-truck loading static electricity generation can be greatly reduced with the use of the aforementioned in-line static charge neutralizers.

Tank car and truck loading/offloading racks

The hazard related to these areas is spillage (generally overfill) followed by fire and explosion when flammable materials are handled. Considering the vast amounts of hazardous materials handled daily, the incidents are relatively small in number; however, a single casualty can be catastrophic. In view of the exposures, loading racks should be constructed entirely of noncombustible materials. Treated wooden racks, stairways, ramps, and frame enclosures (once state-of-the-art) should be avoided. The drainage area from loading/offloading racks should be fully paved and curbed so that any spill will quickly flow to trapped drains without any backup of liquids at the drain.

Within this area of the facility the distance between the racks and other structures which may develop potential ignition sources is important. The Industrial Risk Insurers Company (IRI), Hartford, Connecticut, recommends the spacing between racks and other structures to be in accordance with the recommendations in Table 3. By providing adequate separation distances a degree of damage control is provided in the event of an emergency. The IRI recommends further that racks handling low-flash materials be wired to conform to National Electrical Code requirements. Proper electrical grounding of all equipment in the rack area will reduce the probability of electrostatic spark formation. Figure 2 depicts the American Petroleum Institute recommendations for grounding both types of transportation vehicles. Furthermore, each section of railroad track in the loading area should be grounded properly.

Hazardous material bulk storage

Tank overflow is one of the major causes of spills. Overfills result from human failure to properly calculate a tank's content or inattention to the work assignment during the tank-topping procedure. This spill cause can be reduced significantly by the installation and use of high and high/high liquid-level alarms. It is preferable that the alarms be equipped with an audible-high-sounding signal, high-intensity strobe lights (Fig. 3), and have a built-in pump shutoff control. Until the implementation of Federal regulations and en-

TABLE 3

Recommended spacing between loading racks and other structures (Industrial Risk Insurers illustration)

	Product tanks	LPG tanks	Loading rack	Pump houses	Service buildings	Docks	Fire pumps	Fire hydrants	Compressors	Process units
Minimum distance in feet	250	100	50	200	200	200	150	100	200	200
	76.2 m	30.5 m	15.2 m	61 m	61 m	61 m	45.7 m	30.5 m	61 m	61 m

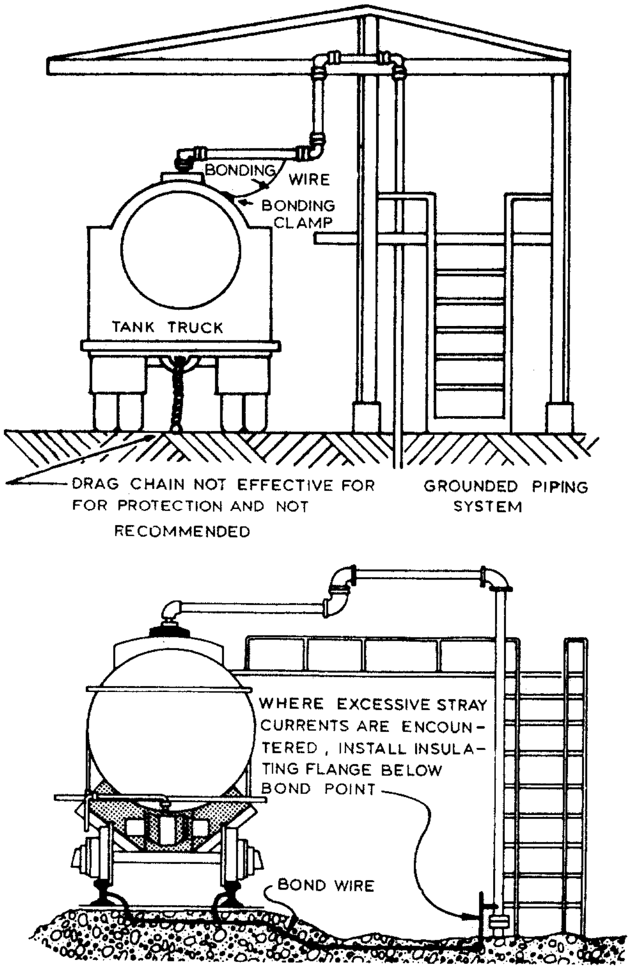


Fig. 2. API recommendations for grounding tank trucks and tank cars.

forcement actions, industry refrained from using high liquid-level alarms. It was claimed that the devices "worked for a few months then failed", required too much maintenance", or "the tank gauger places too much reliance on the alarms". There exists a line of alarms and pump controls that have increased reliability and remarkable accuracy. No storage tank should lack an audible/visual alarm system, many of which are designed for service with the most corrosive chemicals.

Tank thickness testing is becoming a regular maintenance practice. Inexpensive, nondestructive, metal-thickness testers are now available. Many are equipped with direct digital readout displays, and contractual services are available from companies who have developed thickness-testing units. Al-

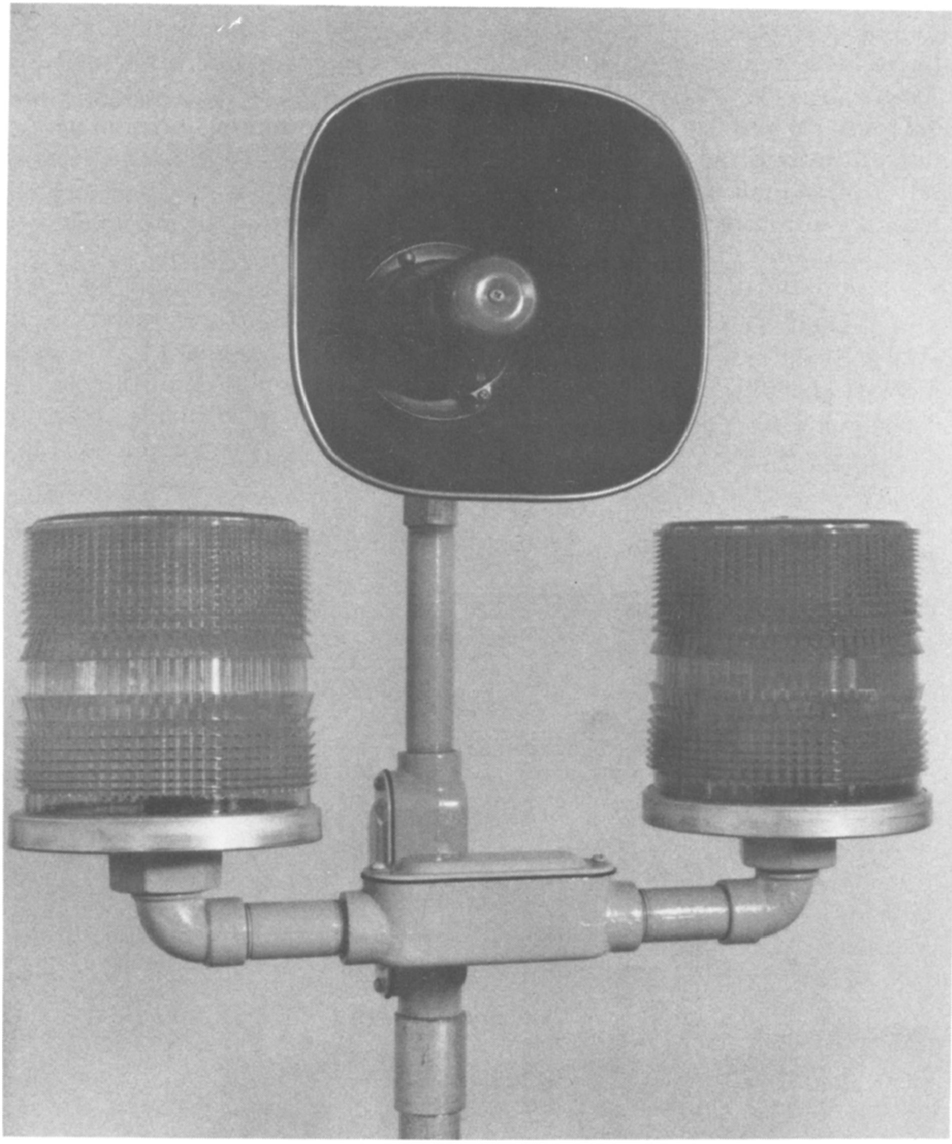


Fig. 3. Visual/audible high liquid level alarm (BDS Systems, Inc., New Britain, PA).

though somewhat limited to the total area which may be tested during a given amount of time, most of the tank may be spot-checked for problem areas. Unfortunately, the lowermost head of a tank cannot be gauged in this manner until the container is empty and vapor free. The lower head is, however, prone to corrosive attack from direct contact with the condensate water that accumulates in the lower reaches of a tank which contains floatable products. One remedy for this problem is to line the internal tank surface with an inert synthetic epoxy coating. Once applied to clean metal surfaces it fills rust pits, reduces corrosion and greatly extends the operating life of the tank.

The presence and use of water draw/drain valves to remove bottom-accumulated-water provides an additional risk of spillage. The drainage of condensate from a tank can be a lengthy process and valves have been opened for drainage and forgotten. A solution is to drain the material into a waste treatment lagoon or an oil and water separator, if floatable chemicals are involved. For materials such as gasoline, benzene, toluene, xylene, ethylbenzene, styrene, polychlorinated biphenyls (PCBs), and 1,1,1-trichloroethane, an imbiber valve may be the answer. This lightweight valve is attached to the water draw valve; it permits the passage of water but blocks the flow of the previously listed chemicals. One-time use, disposable valves are available, as are valves that are reusable once a replacement cartridge has been installed (Fig.4).

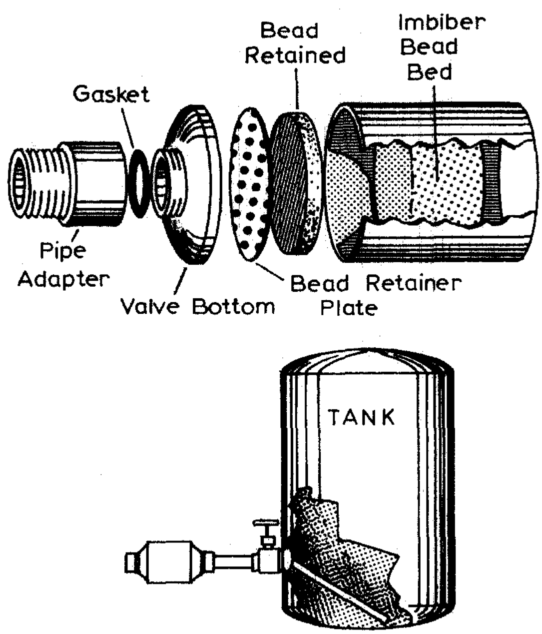


Fig. 4. Imbiber valve and method of installation (illustration, Dow Chemical Co.).

Diked areas

Secondary-containment systems have been improved considerably. Hitherto, earthen dikes were constructed with little regard given to the permeability of the resulting barrier or the earth contained within the barrier. Designs of this type resulted in numerous cases of ground water contaminations when overfill spills percolated down into an aquifer. New designs incorporate impervious foundations and cores within the earth dikes. Dikes are protected

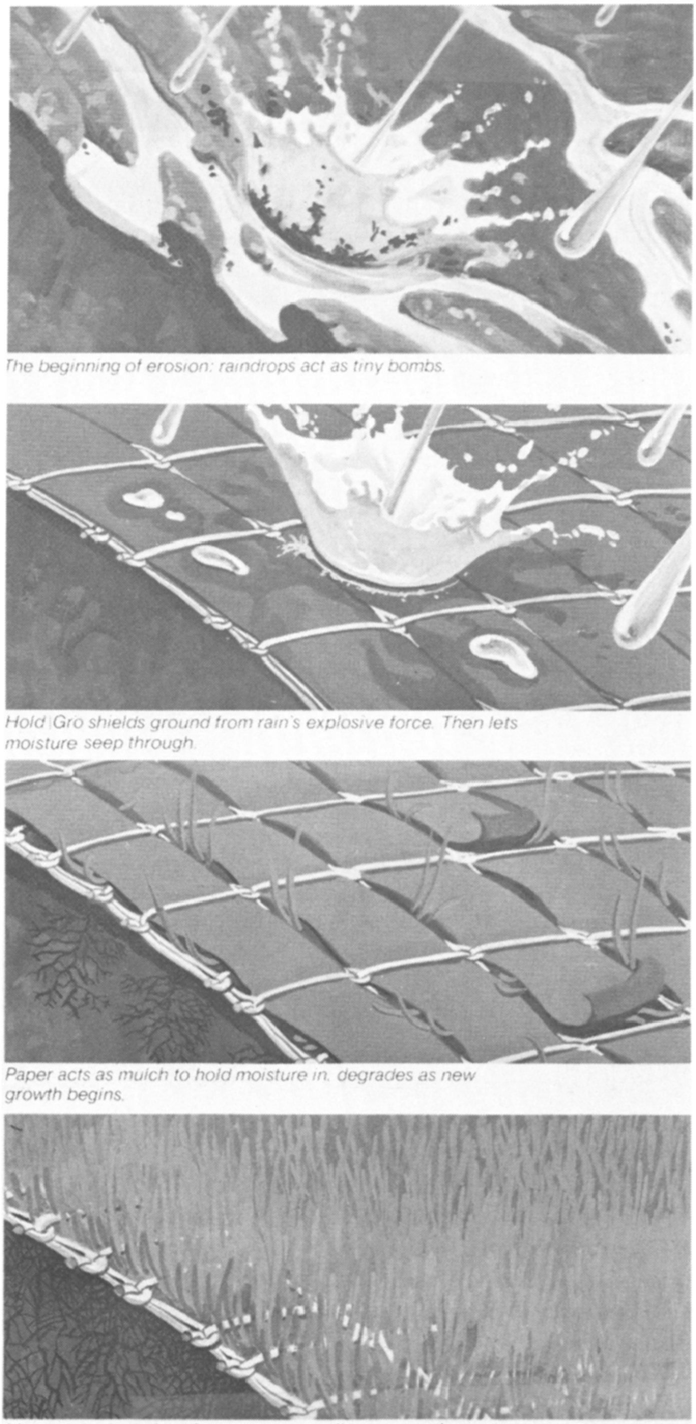


Fig. 5. Use of mulching blanket for dike erosion control (illustration, Gulf States Paper Corporation).

from erosion by a layer of concrete encasing reinforcing steel, or by planting and growing mulching blankets (Fig. 5). The floor of the diked areas can be covered with an impermeable material, such as a synthetic liner, impermeable clay, or a layer of steel-reinforced pumped concrete. This will reduce the probability of contaminating nearby aquifers.

To reduce accidents caused by human failure, some organizations have eliminated drain valves from diked areas. This is done with the assumption that accumulated rain water can evaporate; otherwise, it can be tested for chemical contamination prior to ultimate disposal. Clean rain water which accumulates in the diked area can be pumped into the surface drainage water system, whereas contaminated water would be pumped into a disposal truck or pumped directly into a wastewater treatment facility. Older facilities may have limited space so that the use of dikes is precluded. In such cases, engineered drainage into a specially constructed holding pond has become an accepted practice.

Barrier walls may be used for secondary containment; however, concrete block construction should not be used for this purpose. The blocks may settle, and it is difficult to maintain liquid-tight integrity with mortared joints. Poured concrete walls provide a better means of spill containment.

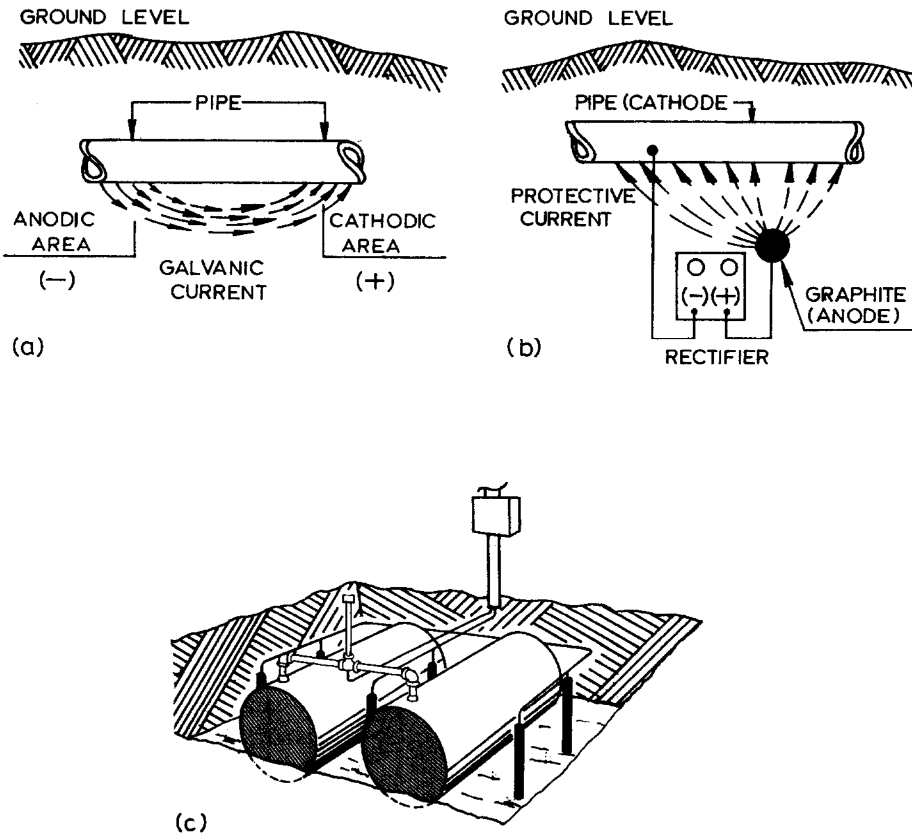
Buried pipelines and tanks (inplant)

Referring, again, to Table 2, we observe that "pipe rupture or leak" remains a significant cause of oil spills. More importantly, pipeline incidents account for a significant amount of oil which is spilled. One can hypothesize many reasons for this seemingly inordinate number of incidents, and owners and operators should be aware of this history.

Fire codes and regulations require that certain materials be stored in buried containers. Because of increased maintenance and repair costs, however, buried lines and tanks should be avoided. Unless the buried structure is uncovered at regular intervals, visual inspection is impossible and reliance is placed upon remote examination, such as hydrostatic testing.

Failing visual examination or hydrostatic testing, the conditions of the buried metal is an uncertain factor. Following are some ways to retard the deterioration process:

- The tank or pipe should be abrasive-blast cleaned and painted with a protective coating such as asphalt, coal tar, somastic, polyethylene tape, or any proven synthetic coating developed for underground protection. The coating selected should be the one to provide the best protection for the soil conditions at the burial location.
- Existing Federal regulations which are applicable to long-distance pipelines mandate that a buried or submerged pipeline be outfitted with a cathodic protection system (Fig. 6). Owners and/or operators of pipeline systems which do not have cathodic protection systems installed may avoid pipeline failure if cathodic protection was employed. As a matter of interest, the energy required for cathodic protection in remote areas may be furnished by solar (voltaic) cells.



Fig; 6. Galvanic protection for buried pipelines and tanks: (a) corroding pipe; (b) protected pipe; (c) tanks. (illustrations, Harco Corporation, Medina, Ohio).

Facility security

Further review of spill causes, Table 2, reveals that 177 incidents were the result of an "unknown cause". We are unable to determine additional detailed information regarding spills resulting from unknown causes. However, we are certain that some of these are the result of sabotage, vandalism, or malicious mischief. Our perception is supported by the periodic reporting of vandalism acts. Some incidents of vandalism are reported elsewhere [2]. Recent headlines, "Vandals Allegedly Responsible for Maryland Tank Spill [3], and "Vandals Allegedly Spill Crude Oil at West Virginia Oil Field [4], support our feelings that all spills are not the result of industrial operations. Nevertheless, the owner/operator of the facility bears the responsibility for responding and cleaning up the spilled material.

In some cases, it can be said that facilities invite intrusion by individuals intending to create mischief. Most waterfront facilities are fenced on only three sides; the shoreline side of the plant and the loading/unloading piers are open to unauthorized access. Master flow control valves and drainage valves from diked areas are more often than not unlocked, presenting an easy target to the saboteur. In a similar manner, bulk tank water draw valves, normally designed to be padlocked, either lack the necessary padlock or the padlock is left on the ground near the valve.

Nationwide surveys of plant properties indicate that many facilities could improve security measures. There are no known Federal regulations, voluntary codes, or industrial guidelines applicable to the security of petroleum industry facilities; however, the U.S. DOE has funded extensive security research for facilities handling nuclear materials. Although other organizations have set standards related to plant security, there is no consolidation of information. The Institute of Electrical and Electronic Engineers (IEEE) is a professional organization that deals with the advancement of electrical design, methods, standards, and codes for equipment, some of which is related to security systems. The American Society for Testing and Materials (ASTM) establishes industrial standards and has a testing program for security equipment. The Institute of Nuclear Materials Management (INMM) is developing security standards for the American National Standard Institute (ANSI). This particular organization deals with standards for nuclear materials security which could be somewhat excessive for facilities handling petroleum products.

Common security improvements include fencing, lighting, closed circuit television surveillance, and/or guards.

Fencing should not be construed as maximum security. It restricts or makes unauthorized plant entry more difficult, but under most circumstances, would preclude only the entry of children or persons intent on malicious mischief. We are the opinion that facilities which store highly flammable or explosive materials warrant additional protection.

To gain added security, it has been a practice to install up to three strands of barbed wire above the fixed fence structure. Unfortunately, the three-strand protection can be easily surmounted by an individual having specific "intent" to enter.

Government reports by the U.S. Army [5] and the U.S. Department of Energy [6] show that conventional chain-link fence topped with barbed wire of German barbed tape concertina (BTC) can be easily crossed in seconds without the use of breaching aids.

A 1970 fence topping improvement known as "general purpose barbed tape obstacle" (GPBTO) is a nickel—chrome stainless steel barbed material. It is manufactured by the Man Barrier Corporation, Seymour, Connecticut, and is illustrated in Fig. 7.

Until a decade ago, exits, entrances, storage areas, and so forth, had to be watched by individual guards. There was no practical way to extend man's vision to a site at which he was not physically present. Today we may use a closed circuit television (CCTV) system, whereby different security locations

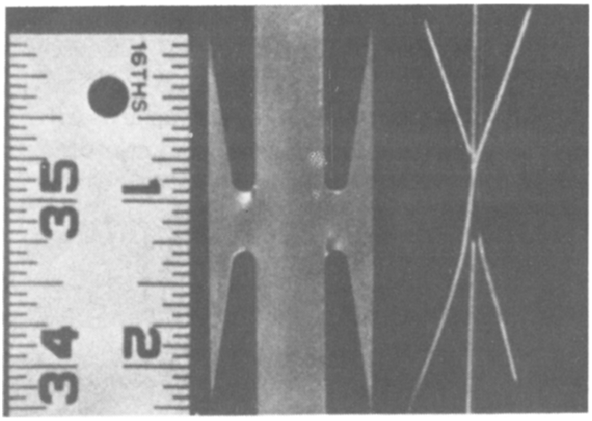


Fig. 7. Fence topping-barb configuration (GPBTO Type II) (Photograph courtesy of Man Barrier Corporation).

can be seen on a single monitor. Typically, a security guard may wish to observe several different entrances and exits, plus certain critical loading areas, and so forth. Using a "video switch", each of the cameras' views are seen in a designated sequence for a selected time period from one second to a minute or more. In some installations, it may be desirable to route the signal from a single CCTV camera to several monitors so that people spatially separated are able to observe the same TV picture. With CCTV systems, it is not only possible to see things beyond the reach of human eyesight, but also to record these events for later analysis. This capacity has proved invaluable, since it is often necessary to document evidence of wrongdoing.

Utilization of a properly designed lighting system may discourage intrusion by vandals. Lighting system designs may be analyzed completely so that installation and operating costs are minimized. One lighting company, Hi/Tek Corporation, markets their Hi/Tek ECON program, which is designed to provide a relative economic comparison and financial analysis of up to four different lighting systems, including an existing system if desired. A complete comparison of initial costs, operating costs, and total owning costs is made to determine the relative cost relationships between systems. All systems are then compared to the lowest initial cost system to determine payback periods, return on investment, and benefit/cost ratios.

The security of plant facilities, equipment, fuels, and stored raw and finished materials can be maintained by plant employees, a plant-employed guard force, or a contractual guard service.

An essential feature of plant protection during non-operating hours is adequate guard patrols. Plant management should carefully select the proper guard personnel and equipment, as well as the layout and schedule of routes to be patrolled. If a contract guard service is employed, most of the administrative details may be developed under the contract, but this should not relieve management's responsibility to ensure that the contract service meets standards equal to a company-operated service.

The initial and continuing training of a plant guard staff should be a formal, well-documented program covering all applicable protection procedures. Personnel should be acquainted with the general nature of the facility's operations and have a specific knowledge of the inherent or special hazards of the stored products. They should be familiar with all fire protection equipment, both manual and automatic, know the location and operation of fire alarms, and the proper method of informing the fire department and/or designated company officers of the location of and directions to the fire or spill area within the plant. Security personnel should be familiar with the contents of the plant's spill prevention control and countermeasure plan (SPCC Plan) required of certain onshore and offshore oil storage handling facilities (40 CFR 112). Since the guard may (should) be the first to arrive at the scene of an incident, it is to the benefit of the owner/operator that the person be properly prepared to respond to emergencies.

Conclusions

Unfortunately, space limitations will not permit further discussion of the various spill types and suggested methods to prevent them. Persons interested in this subject are referred to Ref. [2], a recent U.S. Department of Energy report, which reviews spill-prevention engineering in more detail. Although directed to the prevention of oil spills, the content of the publication can be applied to operations and/or procedures whose goal is the reduction of hazardous materials spills.

Nationwide surveys show that industrial actions directed to spill containment have brought us to the "high water mark". The spill situation can only get better. Already the average chemical plant has spent $1.7 million on spill prevention and the remedial actions continue unabated [7]. A few plants, mainly older installations, have made little or no effort to introduce even basic spill-prevention measures. This is to the extent that some facilities, along with some Federal establishments, are unaware of 40 CFR 112, Oil Pollution Prevention regulations. It appears only a matter of time before an enforcement action or a Federal inplant survey will catch up with them. From an economic standpoint, the potential fines and law suits for bodily injury or property damage should goad the "mavericks" into action. This is especially true in light of U.S. EPA information which estimates the cost of a hazardous material spill cleanup can range from $10 to $175 per gallon spilled [8].

Appendix

*Basic content of operations manual**

(1) The equipment and procedures used to meet operating rules.

* See 33 CFR 154.

(2) An outline of the duties and responsibilities of personnel involved in oil-transfer operations.
(3) A map and description of the facility's geographical location and a physical description, including a plan that shows mooring areas, transfer locations, control stations, and storage locations of safety equipment.
(4) Operational hours, sizes, types, and number of vessels that can transfer oil simultaneously.
(5) A list of other products that may be handled at the facility that may be incompatible with oil.
(6) The minimum number of persons on duty during transfer operations and a description of their duties.
(7) Names and telephone numbers of Federal and industrial personnel who will be called by the facility in the event of an emergency.
(8) The duties of watchmen required by law to guard or protect unmanned vessels in the facility.
(9) A description of each communication system at the facility.
(10) The location and description of personnel shelters on the property.
(11) A description of drip and discharge collection and vessel slop reception facilities, if any.
(12) A description of emergency shutdown systems and their location.
(13) Quantity and type, location, and use techniques of spill response containment equipment.
(14) Maximum relief valve setting or, if relief valves are not provided, the maximum system pressure of each oil-transfer system.
(15) Procedures for:

- loading arm operation and limitations of same
- oil transfer
- completion of pumping
- emergencies
- contingency plan for reporting and containing oil discharges

(16) A brief summary of Federal, state, and local oil pollution laws and regulations.
(17) A description of training and qualifying persons in charge of oil-transfer operations.

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