Publication No 1/92 A Study of Tank Farm Fires in Kuwait

FIRE RESEARCH & DEVELOPMENT GROUP

Home Office Fire and Emergency Planning Department

Fire Research and Development Group

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A Study of Tank Farm Fires in Kuwait

R A Bladon & S Miller

(Motherwell Bridge Projects Limited)

&

Divisional Officer - M W Freeman

"It should be noted that the unusual circumstances in which the tank farm fires in Kuwait were ignited, and the long periods that some were left to burn unattended, mean that great care is necessary in applying the Kuwait experience to United Kingdom facilities."

Home Office
Fire and Emergency Planning Department
Fire Research and Development Group
Horseferry House
Dean Ryle Street
LONDON SW1P 2AW

ABSTRACT

This report introduces the reader to the principles of current storage tank and bund design and then goes on to describe the effect of large uncontrolled fires and other related damage on the various facilities in which crude oil, oil products and water are stored in Kuwait. It describes the various types of storage tanks, tank bunds, and fire protection systems and their effectiveness in design and operation.

MANAGEMENT SUMMARY

The situation in Kuwait after the Iraqi withdrawal, provided an unprecedented opportunity to assess the effect of major fire damage on petroleum storage facilities. Two people, Robert Bladon, a Construction Engineer for Motherwell Bridge Projects Limited and Mike Freeman, the Divisional Officer seconded to the Home Office Fire Experimental Unit, visited Kuwait for a 12 day period in July 1991.

Petrochemical storage facilities are designed to meet a variety of different requirements, depending on the properties of the products to be stored. There are a wide range of Codes and Specifications covering the design of the tanks, the bund size and construction and the spacing of the tanks within it, as well as the fire protection systems. The report summarises these and highlights the differences between them.

The team visited sites at the North Pier Loading Area, the North Tank Farm in Ahmadi, the South Tank Farm in Ahmadi and the Doha Power Station, the refineries at Mina Ahmadi, Mina Shuaibah and Mina Abdulla, and the three Gathering Centres.

They were able to see a wide variety of tanks which had been on fire, some where the fire had been fought, and others which had been allowed to burn out. Some of these were individual bunds, and others shared bunds with other tanks. In many cases, witnesses were able to describe the course of events from ignition right through to extinction. This may have been when the fire burnt out, rather than when it was put out.

During the visit several firefighting techniques were discussed with Kuwaiti firefighters. These included using Hydraulic Platforms, dealing with large spill fires, long burning rim seal fire, and the effects of cooling the tank on fire.

In general, the study has shown that the problems encountered in Kuwait provide pointers to what might happen in incidents in tank farms elsewhere in the world. Even though the method of ignition is rarely met in peacetime, the sequence of events from then on, and the lessons to be learnt, provide very valuable information.

- In general tanks in separate bunds proved safer than tanks sharing bunds. In several cases one tank fire in a bund led to other tanks in that bund being ignited.

- Compacted earth bund walls proved more reliable than concrete bund walls. In all cases any pipework passing through the bund wall must be properly sealed.

- In one case, the bund was ineffective because when the pipe from the tank ruptured, the oil jetted out over the bund. This possibility should be taken into consideration when designing the bund walls.

- Some fixed protection systems proved effective. However, in some cases, the layout of the fixed fire protection systems meant that either they were destroyed early in the fire, or they were so exposed that the operator would have been placed at risk. Some of the older systems were not capable of doing the job for which they were designed.

- The report concludes that there is a need for closer co-operation between firefighters, design and construction engineers, the customer, and plant operators.

- Due to the limited numbers of tank disasters it would be tempting to say that no problem exists with such fires, and therefore research in this field is not necessary. Such incidents, however, identify areas worthy of research such as the performance of various types of rim seal before and during a fire. The use of heat sensitive paints should be considered to help the firefighting officer decide which tanks to cool.

The main message is that the reader should take a new look at the plant or installation they know and ask some pointed questions. Are the bund walls adequate? Is there access? Could improvements be made to cut down the resources required for firefighting by means of upgraded fixed protection systems and fire mains? Are they happy with plant modifications? Do they know about them? Many more examples can be given. The report is not based on theoretical studies. It is a catalogue of the results of real tank fires, their resultant spread and system failures.

CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

1.0 INTRODUCTION AND SCOPE OF REPORT

This report examines various fire scenarios and consequences observed in Kuwait at a number of oil storage depots, refineries and power stations, with particular regard to oil tanks. The observations included the full range of typical oil tank fires and disaster scenarios such as :

- Rim Seal Fires
- Bund Fires
- Full Roof Fires
- Internal Over pressurisation
- Jet Fire
- Boil-over
- Bund overflow
- Fragmentation impact on tanks

From the observations and later study, both the active and passive systems installed within the various depots could be examined for effectiveness in performing their designed duty.

The report tries to acquaint the reader with the various types of tanks likely to be encountered within a facility and examines the major codes with regard to fire protection systems, safety distances, bunding and their effectiveness in Kuwait.

The report shows that further investigations are required and asks if a more uniform philosophy of fire prevention and fire-fighting should be introduced.

2.0 CURRENT STORAGE AND BUND DESIGN

2.1 CURRENT CODES, STANDARDS, STORAGE ANDE BUND DESIGN

Various National and International Codes and Standards are followed for design of storage tanks and fire protection systems.

The major Codes and Standards are :-

a) **Tank Design**

API 650	Welded steel tanks for crude oil
BS 2654	Vertical steel welded storage tanks
DIN 4119	Oberirdische zylindrische tankbauwerre ause stahl

b) **Fire Protection Systems**

NFPA 30	Flammable and combustible liquids code
NFPA 11	Low expansion foam and combined agent systems
NFPA 15	Water spray fixed systems for fire protection
BS 5306	Fire extinguishers installations and equipment on premises.

European Model Code of safe practice in the storage and handling of petroleum products Part II design, layout and construction.

In addition to the above, the major International Oil Companies have established their own requirements with regard to layout, fire systems and tank design. These can exceed the codes or vary from the codes according to the company's experience, and in some cases may go against the ideas of the Fire Services.

2.2 STORAGE CLASSIFICATION

2.2.1 TYPES OF STORAGE

The term "tank" is used to cover the full range of storage containment systems. However, the word "tank" can cover a wide variety of storage conditions, and so "tanks" are classified according to the product and storage conditions. The classifications that are generally used are as follows :-

a) ABOVE GROUND

- **ATMOSPHERIC**

Atmospheric pressure tanks are designed and equipped for the storage of contents at atmospheric pressure. This category usually employs tanks of vertical cylindrical configuration that range in size from small shop welded to large field erected tanks. Bolted tanks, and occasionally rectangular welded tanks, are also used for atmospheric storage service.

- **LOW PRESSURE (0 to 2.5 psig*)**

Low pressure tanks are normally used in applications for storage of intermediates and products that require an internal gas pressure from close to atmospheric up to a gas pressure of 2.5 psig. The shape is generally cylindrical with flat or dished bottoms and sloped or domed roofs. Low pressure storage tanks are usually of welded design. However, bolted tanks are often used for operating pressures near atmospheric. Many refrigerated storage tanks operate at approximately 0.5 psig.

- **MEDIUM PRESSURE (2.5 to 15 psig)**

Medium pressure tanks are normally used for the storage of higher volatility intermediates and products that cannot be stored in low pressure tanks. The shape may be cylindrical with flat or dished bottoms and sloped or domed roofs. Medium pressure tanks are usually of welded design. Welded spheres may also be used, particularly for pressure at or near 15 psig.

*** Pounds per square inch gauge pressure**

- **HIGH PRESSURE (Above 15 psig)**

High pressure tanks are generally used for storage of refined products or fractionate components at pressures above 15 psig. Tanks are of welded design and may be of cylindrical or spherical configuration.

b) UNDERGROUND

Gas processing industry liquids may be stored in underground, conventionally mined or solution mined caverns. No known standard procedures are available for this type of storage; however, there are many publications and books covering this subject in detail.

c) MOUNDED

Mounded vessels are primarily High Pressure above ground tanks used for propane, butane or ammonia and are covered with earth.

Vertical cylindrical tanks have been constructed to 109m diameter with shell heights up to 22mm. Horizontal cylindrical tanks can be up to 8m diameter and 80m long. Spherical tanks can be up to 25m diameter.

Various types of tanks are constructed to suit the classification system. Selection of the appropriate type of tank is dictated by the product and its stored condition. Table III, Chapter 5 of Part 6B of the Manual of Firemanship gives recommendations for uses of the various types.

2.2.2 ATMOSPHERIC STORAGE TANKS

Atmospheric storage tanks can be divided into two main categories :-

- Refrigerated
- Non-refrigerated

a) <u>REFRIGERATED TANKS</u> -

These are used to store liquefied gases at or near their boiling point. They can be sub-divided into three main types. Within each type there may be variations in concepts, design and materials.

The three main types of refrigerated tanks are :

- Single Containment
- Double Containment
- Full Containment

- **SINGLE CONTAINMENT**

Single or double wall tanks designed and constructed so that only the containing element in contact with the refrigerated product is required to meet the low temperature requirements. The outer wall (if any) of a single containment storage system is primarily for the retention and protection of insulation and is not designed to contain liquid in the event of product leakage from the inner container.

A single containment tank will be surrounded by a traditional low bund wall to contain any leakage. (See Figure 2A.)

- **DOUBLE CONTAINMENT**

A double wall tank designed and constructed so that both inner and outer walls shall be capable of containing the product. The inner tank shall store the product under normal operating conditions. The outer tank shall be able to contain any product leakage from the inner tank.

The outer tank will not be designed to contain vapour released due to product leakage from the inner tank.
(See Figure 2B.)

- **FULL CONTAINMENT**

A double wall tank designed and constructed so that both inner and outer tanks shall be capable of containing the product. The inner tank shall store the product under normal operation conditions. The outer roof is supported by the outer wall.

The outer tank shall be capable of containing the product and vapour resulting from product leakage from the inner tank. (See Figure 2C.)

b) <u>**NON-REFRIGERATED TANKS**</u> -

These tanks can be used to store a large variety of refinery products, the two main categories for this type are :

- Open top floating roof tanks
- Fixed roof tanks

A third hybrid type exists that is basically a fixed roof tank with an internal floating deck.

- **OPEN TOP FLOATING ROOF TANKS**

These may be furnished with floating roofs whereby the tank roof floats upon the stored contents. This type of tank is primarily used for storage at near atmospheric pressure. Floating roofs are designed to move vertically within the tank shell in order to provide a constant minimum void between the surface of the stored product and the roof. Floating roofs incorporate a sealing system between its periphery and the tank shell. Floating roofs can be fabricated as open top (that is exposed to the weather) or constructed under a fixed roof. The latter are termed internal floating roof tanks and are used in areas of heavy snowfalls since accumulations of snow or water on the floating roof affect the operating buoyancy. These can be installed in existing tanks as well as new tanks.

Both floating roofs and internal floating roofs are utilised to reduce vapour losses and aid in conservation of stored fluids.

The main types of floating roof used are :

- Pontoon
- Double Deck
- Pan

- **Pontoon (Fig 2D)**

These are generally used on tanks up to 65m diameter, and consist of a sectionalised pontoon annular ring with a centre deck made from single thickness plates. The roof is designed to float on the product and remain floating even with two pontoon sections and the centre deck punctured. They are provided with water drainage facilities, venting facilities and support legs for use when the tank is taken out of service.

- **Double Deck (Fig 2E)**

These can be used on tanks up to 122m diameter. This type of roof provides better insulation to the product, thus providing lower vapour generation. It is less likely to leak and will not allow product onto the deck. The floating roof will remain afloat with two compartments punctured. They are provided with accessories similar to those on pontoon roofs.

- **Pan Roof (Fig 2F)**

These are generally only used as internal floating roofs. They are of a much lighter construction and are usually provided with a simple foam seal, support legs and various other accessories required by the operator.

- **FIXED ROOF TANKS**

Fixed roof tanks are utilised for the storage of high solid products or for low volatility products. Fixed roofs can be supplied in various types, designed as non-pressure or pressure type. The commonest type of fixed roof tank is the cone, with or without framing.

Typical types of fixed roof detail are shown in Fig 2G.

Generally frameless roofs are used on tanks up to 20m diameter. Larger diameters require domed, trussed cone, or framed cone roofs. For special applications, variations on any of the above types can be supplied.

Fixed roof tanks are generally provided with free or safety vents, and/or a frangible roof to shell joint. The purpose of this is that if there is a sudden internal pressure increase that could cause the tank to rupture, the vent or the roof rupturing will relieve the excess pressure, whilst maintaining the liquid integrity of the shell and bottom. An example of this design feature is shown in Section 3.5.4 where the roof to curb angle weld did rupture.

2.2.3 PRESSURE TANKS

Pressure tanks fall into two categories :

- Spheres
- Horizontal Cylindrical

- Spheres

These are very common for a wide variety of products at varying pressures. They have been constructed up to 25m diameter, but are now considered to pose a very high risk in a plant.

- Horizontal Cylindrical Tanks

These are generally used for LPG or natural gas. They have been constructed up to 8m diameter and 80m long, but as with spheres they are considered a very high risk in a plant.

A development in pressure tanks is the introduction of Mounded Tanks. These are basically horizontal cylindrical tanks either buried or covered with earth. These are of similar size to above ground horizontal tanks, but are considered to provide a lower risk for pressurised tanks.

2.3 LAYOUT AND CONTAINMENT

2.3.1 DEFINITION OF TERMS

The requirements for spacing and bunding is generally covered in the applicable National Codes. However, the spacing and arrangement of tanks should be carried out from the view point of good operating and engineering practice, with the aim of minimising or eliminating fire and explosion hazards.

The most widely used codes for petroleum liquids (NFPA and European Model Code) define the product stored as both flammable and combustible and give the following definitions :-

- **Flammable Liquids**

A liquid having a flash point below 37.8°C and a vapour pressure not exceeding 2.76 Bar Absolute.

- **Combustible Liquids**

A liquid having a flash point at or above 37.8°C.

Flammable liquids shall be subdivided as follows :-

CLASS IA shall include those having a flash point below 22.2°C and a boiling point below 37.8°C.

CLASS IB shall include those having a flash point below 22.8°C and a boiling point at or above 37.8°C.

CLASS IC shall include those having a flash point at or above 22.8°C and below 37.8°C.

Combustible liquids shall be subdivided as follows :-

CLASS II liquids shall include those having a flash point at or above 37.8°C and below 60°C.

CLASS IIIA liquids shall include those having a flash point at or above 60°C and below 93°C.

CLASS IIIB liquids shall include those having a flash point at or above 93°C.

In Europe the following categories are used :-

CLASS O	Liquified petroleum gas (LPG)
CLASS I	Liquids which have a flash point below 21°C
CLASS II	Liquids which have a flash point from 21°C to 55°C inclusive
CLASS III	Liquids which have a flash point above 55°C and up to and including 100°C

Unclassified liquids which have a flash point above 100°C.

Class II and Class III petroleum may be sub-divided in accordance with the circumstances under which they are handled. Class II (1) or III (1) petroleum products refers to Petroleum Products handled at a temperature below its flash point.

If petroleum products are stored or handled at temperature at or above their flash point they fall into Class II (2) or Class III (3) and they should be treated as though they were in Class I.

2.3.2 SPACING OF TANKS

Distances between tanks storing the various classes of products are covered by the various National Codes which may be subject to modification, by the rules and regulations locally in force, in any country. This makes it difficult to perform meaningful comparisons between various country's codes.

The requirements for layout also varies between types of tanks and the categories of tanks.

Generally distances between liquified gas tanks (refrigerated and pressure) should be based on exposure radiation levels at various target locations, taking into account other emergency credible scenarios.

For fixed roof and floating roof petroleum product tanks, distances are generally more clearly defined, although various conditions and sub-clauses may be applicable to any given location, which may allow reduced distances or require greater distances.

The spacing between tanks in a bunded area is covered by the following requirements :-

(a) **U.S. REQUIREMENTS - MINIMUM TANK SPACING (SHELL TO SHELL)**

- **FLOATING ROOF TANKS**

- All tanks not over 45m diameter - 1/6 sum of adjacent tank diameters but not less than 1m.

- Tanks larger than 45m diameter with remote impounding - 1/6 sum of adjacent tank diameters.

- Tanks larger than 45m diameter where impounding is around tanks - 1/4 sum adjacent tank diameters.

- **FIXED OR HORIZONTAL TANKS**

Class I or II Liquids :

- All tanks not over 45m diameter - 1/6 sum of adjacent tank diameters but not less than 1m.

- Tanks larger than 45m diameter with remote impounding - 1/4 sum of adjacent tank diameters.

- Tanks larger than 45m diameter where impounding is around tanks - 1/3 sum of adjacent tank diameters.

Class IIIA Liquids :

- All tanks not over 45m diameter - 1/6 sum of adjacent tank diameters but not less than 1m.

- Tanks larger than 45m diameter with remote impounding - 1/6 sum of adjacent tank diameters.

- Tanks larger than 45m diameter where impounding is around tank - 1/4 sum of adjacent tank diameters.

(b) EUROPEAN REQUIREMENTS

Tanks for Class I, II (2) or III (3) Products.

These tanks should, for safety reasons, be arranged at the following minimum distances from one another. The distances being measured horizontally between the tank shells and being calculated on the basis of the diameter of the largest tank present. The distances between any two should be :

Fixed Roof Tanks	0.5 Diameter
Floating Roof Tanks	0.3 Diameter
Fixed Roof and Floating Roof Tanks	0.5 Diameter of the fixed roof tank or 0.3 diameter of the floating roof tank - whichever is larger.

Fixed roof tanks with floating covers or inert gas blankets must be considered as fixed roof tanks, but where there is a rigid internal floating roof and a properly ventilated vapour space then they may be considered as floating roof tanks.

2.3.3 ARRANGEMENT OF TANKS

Tanks for the storage of Class I, II and III products should be arranged and disposed so that, irrespective of whether they are erected within one or several compounds, any fires in nearby tanks in the same or adjacent compounds or in nearby equipment of buildings will have a minimal effect. As a further safety factor, consideration can be given to ensuring that they may be further protected against fire by mobile or stationary fire fighting equipment (in the event of such an emergency). Furthermore, tanks should be arranged, so that, if a fire does break out, then fire fighting may be carried out effectively with mobile and stationary fire fighting equipment. Access and operating availability for such equipment is therefore of prime importance.

Tanks for the storage of Class I, II (2) and III (3) should be arranged so that each tank is adjacent to a (fire) road or place accessible to mobile fire fighting equipment.

Tanks for the storage of Class II (1) and III (1) products may be arranged in up to three rows adjacent to a (fire) road or open place.

Suggested tank layouts are shown in Fig 2H.

2.3.4 SIZE OF BUNDED AREA

Bunds shall be sized according to the volume of product stored within the bund, and when surrounding only one tank, should be capable of retaining the maximum stored capacity. When surrounding a group of tanks, the bund should be capable of retaining the greatest amount of liquid that can be released from the largest tank, or at least 10 percent of the total stored contents. When groups of tanks are bunded, reduction in bund volume may be made to take account of the volume of all tanks below bund height except for the largest tank.

The minimum distance between the tank and the interior wall of the bund shall be 1.5m (U.S.) or 0.15 times the tank shell height (European).

If the shell height was 10m, the distance would be 1.5m.

2.3.5 BUND DIMENSIONS

Bund dimensions should take into account various requirements, and the guidance given in the various codes is quite dissimilar. NFPA 30 recommends an average interior height of 1.8m above ground level, while EMC Part II states there is no limit to the height of bund walls.

(NFPA qualifies any bund height above 1.8m by requiring that provision be made for access and egress to the bund valve operation area without going below the level of the top of the bund. EMC Part II makes no such requirements, and, in fact, states that the outside height should be sufficient to afford protection for personnel involved in fire fighting.)

2.3.6 BUND CONSTRUCTION

Bunds may be constructed from earth, steel, masonry or concrete and must be permanent and capable of withstanding the static liquid pressure.

Bunds constructed of concrete should be fire resistant for a minimum of 4 hours. All bunds should be liquid tight and any joint sealed. Piping passing through bunds shall be designed to prevent excessive stresses. Bund walls must not break down under fire or firefighting conditions.

Recommendations include that where bunded areas contain two or more tanks, drainage channels or intermediate dykes should be provided. This is to prevent spills endangering adjacent tanks. NFPA 30 requires a minimum height of 450mm, whilst EMC Part II states a height up to 0.5 times the main bund, but normally not more than 500mm.

Where water can be drained from bunded areas, control of the drainage shall be possible. Control sluice valves should be located outside the bund.

2.4 SEALS

2.4.1 TYPES OF SEAL

All floating roofs are designed such that the gap between the roof and the tank shell is sealed to reduce vapour losses. The seal must also take account of any variations in shell distortion. Seal design has changed very little over the years, the only major development being the widespread introduction of secondary seals.

The main types of primary seals are :

- Mechanical shoe seals
- Liquid filled seals
- Foam filled seals

With any of the above primary seals, the following type of secondary seals can be utilised :

- Wiper seal
- Compression plate seal

2.4.2 PRIMARY SEALS

(a) **MECHANICAL SHOE SEAL (See Fig 2J) -**

This consists of a galvanised or stainless steel sealing ring (shoe) and a continuous vapour tight membrane between the shoe and the rim and pantograph hangers that exerts a uniform radial pressure between the roof and the shell. This type is very widely used, providing a good vapour seal with long life and low maintenance.

(b) **LIQUID-FILLED SEALS (See Fig 2K) -**

These are considered to provide the best vapour seal, since the seal envelope easily moulds to any shell distortion. It is normally filled with kerosene. This automatically compensates for a degree of roof tipping, thereby maintaining the seal continuity within the rim space.

(c) **FOAM FILLED SEALS (See Figs 2L & 2M) -**

These are very similar to the liquid-filled seals except that its main advantage is that any small tear or abrasion in the seal envelope will not cause a sudden failure of the seal. However, should product enter through the envelope, the resiliant polyurethane foam core may become saturated with the product.

2.4.3 SECONDARY SEALS

Secondary seals are installed to reduce the vapour losses from primary seals. They have a number of advantages in performing this task.

- Conserve product
- Reduce environmental pollution
- Increase safety against rim seal fires
- Reduce product contamination from rain
- Increase centering capability of roof

The two main styles of secondary seal are -

- Compression plate
- Wiper seal

(a) **COMPRESSION PLATE SEALS (See Fig 2N & 2P)**

Various styles are available, but all rely on a spring steel compression plate attached to the roof rim above the primary seal. The top of the compression plate is sealed with a rubber tip or strip. This type can be installed with any primary seal. It also has the advantage of being able to be fitted without taking the tank out of service.

(b) **WIPER SEALS (See Fig 2R) -**

These are basically an add-on to the mechanical shoe seal. They are not designed to be used with other types of primary seals.

2.5 FIXED FIRE PROTECTION SYSTEMS

2.5.1 CODES OF PRACTICE

The installation of fixed fire protection systems is primarily dictated by the owner's requirements since National Codes, products, tank size/type, location, on site facilities, authority requirements, all can dictate what is required. No clear rules/guidelines are available to cover the full range of tanks. Much information is available in terms of actual tank fire reports, simulated tests, reports and general literature. Once it has been established that a particular fixed system is required, then that system can be designed to a particular code, although no codes specifically cover large diameter floating roof tanks, refrigerated storage tanks or mounded tanks, each of these presenting problems not specifically addressed in the codes.

If we consider a group of four oil storage tanks within a bund, the following fixed protection systems would be considered as acceptable.

2.5.2 FOAM SYSTEMS

Fixed roof tanks containing non - water soluble products, should be protected with subsurface (Base Injection) foam system designed in accordance with NFPA 11 (1988) para 3.4.6.

Fixed roof tanks containing water soluble products should be protected with a foam pourer (surface) system designed in accordance with NFPA 11 (1988) para 3.2.5.

Floating roof tanks should each be protected with a rimseal foam pourer system designed in accordance with NFPA 11 (1988) Para A - 3.2.11.1.

Portable foam making equipment should be provided in addition to the fixed systems above as supplementary protection for small spill fires. Each hose should have a minimum flow rate of 189 l/min. The minimum quantity and operating time of this equipment should be in accordance with NFPA 11 (1988) para 3.4.8.2.

As an option, foam/water monitors could be provided as additional protection. The quantity and size of these monitors must be decided on an individual basis in conjunction with the client as there are no hard and fast rules specified by NFPA.

2.5.3 WATER SUPPLY

As the water requirements for a water spray system specified by NFPA are sometimes considered excessive although we would not wish here to comment which is right or wrong (10.2l/min/m2 of tank wall area), an alternative is the Institute of Petroleum Refining Safety Code. This specifies a water application rate of 16.7 l/min/m of tank circumference, applied using one ring of nozzles around the top of the tank shell.

A hydrant ringmain should run around the tank bund area. The water flow velocities along the hydrant main should not normally exceed 3m/sec. Fire hydrants should be spaced at approximately 70 metres apart, each hydrant having 2 x 63.5mm (2.5") valved outlets and 1 x 100mm (4") hard suction connection for fire appliance use.

Hydrant equipment cabinets containing 2 x 30m lengths of hose and 1 x water branchpipe should be positioned adjacent to each of the hydrants.

Note : If the hydrant main pressure exceeds 7 bar g (gauge) the hydrant valves should be pressure regulating type to avoid hose lines being used at excessive pressures.

The maximum water requirements should be based on the following systems/equipment operating simultaneously :-

a) 1 x foam system (tank on fire)
b) 2 x waterspray systems (adjacent tanks)*
c) Supplementary hose streams
d) 1 x water branchpipe (700 to 1000 lt/min)

2.5.4 DETECTION SYSTEMS

Detection systems for floating roofs are based on a variety of possibilities, some of which are :-

- Heat
- Smoke
- Ultraviolet Radiation
- Infra Red Radiation

Of these, it is generally acknowledged that detection by heat provides the best all round method of detection.

Generally a fire cannot exist between a primary and secondary seal or below a primary seal. The most critical area for a fire is just above the primary seal or a secondary seal when fitted. Any detection system should be mounted in this area.

Line type detection systems are usually preferred over point type because of there faster reaction times.

The two types of line detection are :

- electric line
- pneumatic line

Selection of either of these is really the owner's choice with advocates for each method. Detection systems can provide activation of any fixed fire system as well as signalling a fire condition.

* This assumes that the tank diagonally opposite the one on fire does not require waterspray protection.

2.5.5 HALON SYSTEMS

Although Halon is very widely used for rim seal fires, the Montreal Convention has resulted in the demise of the Halon system by most industrialised countries and major oil companies.

At the time of writing, no long term replacement is available. However, the principle of operation is valid for whatever type of extinguishing gas used.

The system basically consists of a high pressure gas cylinder linked to distribution piping containing nozzles, located within the rim space area. These systems are usually linked to a detection system that activates the release of the gas within the particular area of detection. Normally a single gas cylinder can cover up to 40m of distribution piping.

2.6 COMMENTS ON THE MANUAL OF FIREMANSHIP WITH REGARD TO STORAGE TANKS

The Fire Manual Part 6, chapter 5 Section III covers storage tanks in a satisfactory way, giving the non-technical reader a basic idea of storage tanks and the appurtenances. However, it is felt that this section should be updated to include the newer type seals, mounded pressure tanks, an expansion of the types of refrigerated tanks and a new section on tank fixed fire systems. Additionally, a more detailed description of tank roofs and their design features/limitations would possibly be beneficial.

The section on extinguishing petroleum fires should be reviewed with reference to the observations made in Kuwait.

3.0 CASE HISTORIES OF KUWAIT FACILITIES

3.1 NORTH PIER LOADING AREA

The area contained a large distribution manifold, loading pumps, pipework and two oil storage tanks. This area was attacked by RPG rockets and the two tanks set on fire. As the area was occupied by hostile forces at the time, only limited fire fighting took place.

Tank 77/101 was a 17.98m diameter, 10.97m high floating roof tank, built in 1985 to API 650, an International Code for the design and construction of vertical storage tanks. This tank had fixed fire protection consisting of a deluge water system around the shell to cool the tank and foam pourers around the top of the shell to allow foam to be poured on to the roof. The supply pipework to the water spray system was damaged by the fire and was rendered inoperable. If this pipe had been buried in the bund and protected on its exit at the tank, it could have been used to cool the tank.

Ground monitors had been set up inside the bund to fight the full surface fire and cool the tank.

The fire was eventually extinguished, but only after partial collapse of the tank. The position of the fire monitors directed at the area of collapse would indicate that the cooling effect of the water led to the premature collapse of the tank shell where the water impinged. This could affect the extinguishment times due to the shell protecting some parts of the oil surface, not allowing foam to complete the seal.

The oil level in the tank at this time was low and so avoided the oil spilling over into the bund (See Plate 1).

The bund surrounding tank 77/101 was constructed of compacted sand and gatch (a local soft rock easily compacted with water) covered by tarmac to stop wind and water erosion of the bund (See Plate 2).

The second tank (204) at this site had a fixed roof and was 30.48m diameter and 10.97m high. This was built in 1959 again to API 650, but an earlier edition. The tank had no fixed fire protection. This tank had completely collapsed and spilt a considerable quantity of oil into the bund, to a level within 2m of the top.

We were advised that no firefighting had taken place due to the presence of hostile forces. At the time of our visit, five months after the collapse of the tank, the bund was still full of oil and its integrity was holding. The fire apparently self-extinguished but, as no analysis of the remaining product was possible, it is difficult to conclude why.

The bund surrounding tank 204 was of similar construction to that of Tank 77/101, but instead of being covered with tarmac, it was covered by oiled sand. This would seem to be equally effective in preventing wind erosion, but might be prone to water erosion, and this bund had certainly prevented a large spill fire. This was particularly significant in that this facility was adjacent to a main road (See Plate 3).

3.2 KUWAIT OIL COMPANY, NORTH TANK FARM

3.2.1 INTRODUCTION

This tank farm is situated in Ahmadi, South of Kuwait City and is the smaller of KOC's two tank farms.

This facility had sustained considerable damage especially to those tanks situated at the north west end of the plot (See Layout Plan - Fig 3A).

A fire was first reported as smoke being seen over the North Tank Farm, from the main office complex some miles away. Due to the occupation forces no attendance could be made at this time and it was some 3-4 days later before firefighters arrived at the site. Fortunately firefighters present during the occupation were available during our visit to give eye witness accounts to the sequence of events concerning these fires :-

3.2.2 TANKS 51, 52, 53, 54 AND 55, 36, 37, 38 AND 39

The fire that developed into a full surface fire, had started in tank 54, a floating roof tank 78.9m diameter and 18.44m high. There was approximately 7.7m of crude oil in the tank, ($37,500m^3$) at the time of the fire. (See Plate 4)

Tank 54 is contained in a bund together with four other tanks of the same design, size and capacity. Due to the water storage tanks in the South Tank Farm being blown up, fire fighting was severely curtailed by the lack of water. Tank 54 was involved in a boilover which was witnessed by several firefighters. They described the event as being very violent and receiving short notice of the boilover about to occur. This was described as a change in the noise from the fire and the lightening of smoke. They had to retire so quickly that they were unable to save a foam tanker. (See Plate 5)

Also seen on the adjacent roadway was a large patch where oil had 'splashed'. The fire-fighters saw the oil from the boilover landing in the bunded area which formed a 'wave' of oil that swept over the bund and down the other side.

The bund construction around these tanks is of compacted sand and gatch covered with oiled sand. Even though the 'wave' burning oil slopped over the bund, its integrity was maintained.

This burning oil had two main effects. First, it ran down and started a fire in the pump house, situated below the level of the bund. This caused the electrically powered fire pumps to fail. Second, it spread burning oil to tanks 51 and 52 which caught fire.

There was no standby system for these fire pumps. As a back up it should be recommended to have either a small generator or diesel driven pumps.

The fire then spread to tank 53 with the firefighters having little hope of preventing this due to the lack of water.

Tank 52 was involved in a slopover. This was shown by the position of the floating roof. (See Plate 6). Tank 55 sustained only a rim seal fire even though it was closer to the first tank on fire (54) than 52. The line of damage to these tanks would imply that the wind direction helped to propagate the spread of the fire. Tanks 54 and 52 were completely destroyed whilst those around suffered comparatively less damage.

The rim seal fire in tank 55 was still burning at the time of our investigation (6 months later). The firefighters stated that they were encountering problems in getting the foam to penetrate under the weather shields on to the area of the fire and also with the lack of good foam distribution from the pourers.

Tanks 51-55 are contained within a single bund with only low level dividing earthworks. This was not sufficient to contain burning oil from any one tank and the fire spread uncontrolled within the area, igniting the other tanks.

The spread of fire in this area was assisted by a flume (channel or pathway leading to a discharge or collection point) running NNE between the tanks. The idea of the flume is to allow any spillage from the tanks to run outside the tank farm area to a large lagoon where it could be safely burnt off or collected.

Firefighters fought a spill fire in one bund with the limited water supplies carried on their fire appliances and 75KG Dry Powder extinguishers. They reported a very successful extinguishment by means of using Dry Powder to extinguish and a water spray following behind to cool the liquid.

Damage was also sustained by tanks 36, 37 and 38 as a result of the fire spread from tanks 51, 52 and 54. As there was no fixed water spray systems on the tanks firefighters had to cover these tanks with portable monitors. They did this by the two stage method of firstly putting a monitor into position to allow firefighters to be protected by the spray.

They then positioned another monitor using this protection to place a water curtain between the tanks. To be effective these had to be placed on the road between tanks 51, 52 and 53 and tanks 36, 37 and 39. This was a perilous and time consuming act, but resulted in a water curtain being achieved and limited the damage to these tanks.

Tank 37 had its upper portion of the tangential stairway destroyed (See Plate 7). As with tanks 51 - 55, the foam pipework was supported by this stairway, so it was rendered inoperative.

There were several other small fires in this facility during the occupation. These were extinguished by the water carried on fire appliances and foam tenders and in some cases with hand held extinguishers. These later were used to put out a rim fire on tank 41 and also to extinguish four small fires on the roof of tank 57. Rain water from the roof was also used on these four fires, the water being carried in the firefighters helmets!

There was no water spray system installed on tanks 51 - 55. A fixed foam system was installed, limited to one discharge outlet situated at the gauges platform. One result of this type of installation is that firefighters have to traverse the windgirder to fight any rim fire.

3.2.3 TANKS 56, 57, 58 AND 59

Tanks 56 - 59 were the latest additions to the tank farm and are 79.25m diameter, 18.29m high floating roof tanks. These were built in 1985 to API 650, 1980 edition.

Each tank is located in a separate earth bund, with comprehensive fixed fire protection installations and considerable distance separation.

A change in newer tanks (56 - 59) was that there were a number of foam pourers around the circumference of the top of the tanks. These points were connected by a ring main of pipework. This meant that firefighters did not have to go on to burning tanks to fight fires as foam could be directed down to the rim.

These tanks had a number of fixed fire protection systems installed.

(a) Water Spray System
(b) Foam System
(c) Detection System

(a) WATER SPRAY SYSTEM -

There was a water spray system consisting of two rings of pipework around the complete circumference of the tank shell. One ring was halfway up the shell and the other just under the windgirder. This could be considered very effective in cooling the tank shell below the windgirder, but left the area above the windgirder unprotected.

The system was fed from two inlet points locations diametrically opposite each other outside the tank bund. This means that should access to one point be restricted, the system could still be used, the complete system being fed from the other inlet point. The riser pipework was supported on brackets welded to the tank shell.

(b) FOAM SYSTEM -

The tanks also had a foam system designed to deliver foam onto the tank roof in the area of the seal. The foam pourers were located around the circumference of the top curb angle so that complete cover of the seal could be achieved.

The risers for this were also supported by brackets welded to the tank shell again allowing them to be cooled by water from the deluge system.

The philosophy of having two inlet points as with the water spray system was also applied to the foam system. The foam inlets were situated alongside the water inlet points.

Firefighters had experienced some difficulty with the foam pourers located around the circumference of the curb angle. During high winds the foam was blown away from the pourers as they discharged and before the foam started to run down the shell. (See Plate 8)

Weather shields were also fitted to these tanks, and it had been found by firefighters that it was difficult to get foam under these plates into the area above the primary seal.

(c) DETECTION SYSTEM -

The third fixed fire protection installed on the tanks was an infra red flame detection system. This system required two detectors to operate before an alarm would sound. This was found necessary to avoid false alarms. The alarm was connected to the central control room to indicate a fire situation and summon help. It was not interlocked to start up any of the fire protection systems.

Whilst these tanks did not come under attack it is felt that they would have performed better than older tanks due to the better bunding arrangements and fixed fire protection.

3.3 KUWAIT OIL COMPANY, SOUTH TANK FARM

3.3.1 INTRODUCTION

This facility is also located in Ahmadi, and is due south of the other main depot. (See Plate 9 and Fig 3B)

The Tank Farm had been systematically sabotaged by the occupying forces; it was also damaged by "friendly fire". While there are lessons to be learnt from this experience it would not normally be expected to design tanks etc. for a war scenario, but the lessons are nonetheless valid.

The Tank Farm Operations staff over a period of months contrived to empty the tanks or keep minimum stock levels. This resulted in the damage to the installation being considerably reduced.

Water storage tanks seemed to have been a priority target for sabotage and two 1.5 million gallon tanks had been completely destroyed. These tanks also fed the North Tank Farm mentioned previously. This had been achieved by blowing off the shell manhole creating a sudden outflow of water causing a vacuum resulting in a "rip/zip" effect splitting the shell from top to bottom. (See Plate 10)

Some sabotage attempts had been less successful than others, only blowing off small nozzles and puncturing plates. Tanks with this type of damage had already been repaired by KOC Maintenance Department.

3.3.2 TANKS 3 AND 4

Tanks 3 and 4 are 43.90m diameter and 13.4m high floating roof tanks built in 1949, located in a shared bund. Access to both tanks is by a shared tangential stairway. The only fixed fire protection on these tanks was a single foam outlet on the gauges platform. The pipework for this was supported from the stairway.

Both tanks had been sabotaged by having demolition charges attached to the shell nozzles and pipelines. As previously stated the level of product had been reduced by operations staff so the resultant oil spillage and spill fire was small, although this fire was enough to cause the shell plates in the vicinity to be distorted. The firefighters were not allowed to fight this fire by the occupying forces, however, because of the small amount of oil present, the fire burnt itself out.

3.3.3 TANKS 9, 10, 11 AND 16

Tank 9, a 43.90m diameter, 16.15m high floating roof tank is located in a single bund. It was built in 1947 to the relevant Codes and Standards of the day. The only fixed fire protection was again a single foam outlet located on the gauges platform. The pipework was supported off the tangential stairway.

Demolition charges were attached to the inlet and outlet nozzles and the resultant explosion ruptured the tank shell spilling oil into the bund area. The level of oil in this tank was not as low as other tanks and a considerable amount of oil was set on fire.

Due to the occupation this fire was not fought and was allowed to burn itself out causing the tank shell in the area of the nozzles to collapse together with the top section of the stairway. As the foam pipework was supported from this stairway this also collapsed.

Had the firefighters been allowed to fight the fire they would have been severely hampered and could not have got foam onto the tank roof to extinguish any resulting rim seal fire by using the fixed protection system.

This tank also suffered from "friendly fire" with 3 bombs falling within the bund. There is considerable shrapnel damage, with the tank shell being penetrated at the level of the second tier.

Tanks 10, 11 and 16 are of similar size, design and age to tank 9. These three tanks were also sabotaged by the same method used on tank 9, but they had only a small quantity of oil in them at the time. There was only a small spill fire, which caused limited damage to the shell plates. This resulted in buckling of some plates in the area of the blown out nozzles.

3.3.4 TANKS 60, 61, 62 AND 63

The most significant losses in this tank farm were tanks 60, 61, 62 and 63. These four tanks were all 79.25m diameter and 18.29m high floating roof tanks with a capacity of 84,260m^3 each. They were built in 1985 to the latest edition of API 650. Each tank is located in a separate bund constructed of compacted sand and gatch covered with oiled sand to stop wind erosion.

Although all four tanks had been completely destroyed, the way the tanks burnt and collapsed was not the same in all cases.

The oil in tanks 60 and 61 had burnt down inside the tank shells. The upper courses of the shells became plastic and collapsed inwards. In this way the tanks maintained their integrity for some time, but eventually burning oil spilt out into the bund covering approximately 50 percent of the area.

Although other tanks in the area were destroyed there is no evidence that fire from one tank spread to adjacent tanks. It is believed that all four tanks were set alight simultaneously by the occupying force.

The fire in tank 62 had a slightly different effect on the tank shell. The majority of the tank shell had collapsed in the same way as it had in tanks 60 and 61. However, a portion of the shell had remained upright. This was in the area of the external stair and the internal rolling ladder. Whilst these two structures would give some additional support to the shell it would not be sufficient to stop a collapse. Obviously other factors were contributing to the integrity of this section of the shell. A factor may have been the prevailing wind blowing on this area of the shell which had a cooling effect. Additionally, behind this tank was a severe fire and the smoke from this fire may have insulated this area of the tank shell from some of the radiated heat. (See Plate 11)

Tank 63 was also completely destroyed by fire. It was interesting to note the pattern left by the distorted and collapsed shell plates. There was obviously a slow build up of heat, most probably from a large spill fire. The plates had become plastic and had "flowed" to form varied shapes and folds. The floating roof had also moved outside the curtilage of the shell on the outflow of the oil.

Under normal operating conditions it is reasonable to assume that, had there been a major fire in any one of these tanks, it could have been contained and the adjacent tanks remain undamaged.

This can be compared with what happened to tanks 51-55 in the North Tank Farm where all 5 tanks were in one single bund and all were lost from fire spread rather than sabotage acts.

3.3.5 TANKS 34 AND 35

Tanks 34 and 35, both 43.90m diameter, 16.16m high floating roof tanks built in 1952 were completely destroyed. Both tanks were contained in the same bund area. Demolition charges had been attached to the inlet and outlet nozzles and exposed. This caused spill fires as with other tanks attacked in this way.

No firefighting took place due to the presence of the occupying forces. However, the compacted sand and gatch bunds performed extremely well and contained all the spilt oil, thus limiting the damage that could have been caused to other tanks had the bunds been breached.

3.3.6 SUMMARY

In no case in this facility had any bund been breached. They had performed well and satisfied the function for which they were designed. All the bunds were of similar design and constructed of the same materials, local sand and gatch compacted in layers until the desired height was reached.

This type of bund construction has the added advantage of being easy to open up when major maintenance work is to be done on the tanks when out of service. A disadvantage is that they do occupy quite a lot of space, which may well be a problem in facilities where the area is limited. (See Plate 12)

3.4 DOHA POWER STATION TANK FARM

3.4.1 INTRODUCTION

This is the main power station for Kuwait City, located to the North of the City. (See Plate 13 and Fig 3C)

The products stored in this facility were heavy fuel oil, crude oil and gas oil, all used as fuel for the power station.

With the exception of two heavy fuel oil tanks, all other tanks in the tank farm had been destroyed. This destruction was a combination of enemy action and the subsequent spread of uncontrolled fires throughout the tank farm.

3.4.2 TANKS A, B AND C

A fire started in Tank B after it was hit accidentally by an Iraqi missile in February 1991. This tank was 60m diameter and 16m high with a fixed roof and a capacity of 45,000m^3 although at the time of the incident there was only 35,000m^3 of heavy fuel oil in the tank.

It was located in a single bund. The bund wall was constructed of reinforced concrete. The tank had been built in 1981 to API 650 and had incorporated in its design fixed fire protection system. These consisted of a water spray system and a foam inlet system into the top of the tank as well as foam pourers into the bund area. However, it is not known for certain whether these systems were operated at this time, but strong doubts exist due to Kuwaiti personnel being removed by the occupation forces.

The tank was completely destroyed, collapsing into itself as the upper tier plates became heated and could no longer support their own weight. (See Plate 14)

The foam system pipework, both for the tank injection points and the bund was supported just above ground level outside the bund. This pipework had been rendered inoperative by a spill fire from adjacent tanks. Whilst this is not relevant in the sense of timing for the fire in Tank B, which occurred well before the spill fire, it is nevertheless a lesson that fixed fire protection systems should themselves be protected. Fixed foam pourers to cover bund fires as seen at Doha Power Station, if used, would have required a considerable amount of foam to cover the area concerned. The number of pourers and their location could cast doubt on the ability of the foam to flow throughout the bund and in particular the corners. Therefore, the possibly of supplying take off points for hand held foam branches would be advantageous to deal with any incomplete coverage. (See Plate 15)

Tanks A and C on either side of Tank B, sustained little or no damage at the time of fire in tank B. It would seem that the protection afforded to them by their own fixed water spray systems worked well and no doubt prevented the fire spreading to these tanks. The water supply to these tanks was automatic and actuated when the explosions occurred. Water only ceased when supplies were not maintained to the system due to occupational forces' actions. (See Plate 16)

3.4.3 TANK 'X'

Tank X, with a capacity of 16,000m^3 was 80 percent full of Gas Oil when detonation charges were exploded at the inlet/outlet nozzle. This resulted in a "jet" fire with burning oil directed onto the adjacent concrete bund wall. The severity of the fire was sufficient to melt the concrete allowing a large quantity of burning oil to form a spill fire outside the bund. This spread along the adjoining roadway. (See Plate 17)

From the coking and fire investigation it can be seen that the level of oil was approximately 0.6m deep just outside the damaged bund area (See Plate 18). This large quantity of oil spilt on such an extended area knocked out the fixed fire protection systems on the other tanks and all the product lines in this area.

The fracture of product lines caused by the spill fire contributed to the severity of the incident. (See Plate 19)

As previously mentioned, the concrete bund wall was badly affected by fire from both inside and outside. The expansion joints had been burnt out with the result that gaps had opened up in the bund which had allowed oil to flow out. While it is recognised that these openings were not large enough to allow large quantities of oil to escape, it could contribute to a spill fire if only by concentrating burning oil on the product pipework running around the outside of the bund at ground level. (See Plate 20)

From this example it is fair to say that consideration should be given when designing bunds, not only to the amount of product they can contain, but also to the height of the walls. The height of the bund should be such that any tank nozzle is well below the top of the bund. This was not the case in this instance.

3.4.4 TANKS Y AND Z

Tanks Y and Z, both floating roof tanks with a capacity of 25,000m^3 each, were used for the storage of crude oil.

Both tanks were contained in a single earth bund lined with concrete tiles. There was a smaller earthwork mound between the two tanks. (See Plate 21)

This bund had been opened up prior to the fires, most probably to allow maintenance work to be carried out. The breach of the bund was carried out intelligently in that only part was removed. This still allowed access, but ensured the bund would still perform its duties.

The tanks had been set on fire by demolition charges and burning oil had covered the whole of the bund area to a height of several inches. Oil did not escape through the excavated portion of the bund as this level was above that of the oil spillage.

These earthwork bunds appeared to perform better than the concrete one as the only damage sustained was the uplifting of some of the lining slabs due to expansion. This was superficial and the bund maintained its integrity.

It was noted that product piping passed through the bund walls. In some cases the sleeving had allowed oil to pass through, the spillage resulting in pool fires outside the bunded area, affecting the adjacent roadway.

On two identical installations where pipes passed through the bund, one sealed by means of concrete which did not breach, whilst a second was not and this one did. This sleeving through bunds is potentially hazardous as fire appliances, etc would be located on the roadway in the event of a tank fire or oil spill. (See Plates 22 and 23)

The position of a foam inductor and its controls on the exposed top of the earth bund gave cause for concern. Any personnel operating the system would be exposed to the full force of a fire. In fact this equipment showed signs of fire damage. (See Plate 24)

This could be prevented by positioning this equipment outside the bund and giving it suitable protection, such as a concrete shelter.

3.5 REFINERIES

3.5.1 INTRODUCTION

There are three refineries in Kuwait operated by Kuwait National Petroleum Company (KNPC). They are Mina Ahmadi, Mina Shuaiban and Mina Abdulla. All three refineries sustained damage at some of their facilities.

3.5.2 MINA AHMADI REFINERY

The main damage to this refinery was caused by demolition charges being exploded in the CD 3 control room and at the South Loading Jetty.

The ability of firefighters at this site to tackle fires depended upon the occupation forces agreeing. There were incidents they were allowed to deal with, whilst others they were stopped from doing so. Damage to storage tanks was limited to bullet and shrapnel holes in a small number of tanks.

Tank No. 533, a floating roof tank, had contained Aviation fuel when it was hit by cannon fire. Product spilt from a hole in the shell and caught fire in the bund. This tank was fitted with both a foam system and water spray system as fixed fire protection. These systems were operated and proved their effectiveness, the fire causing little damage to the tank.

The water spray systems on the adjacent tanks were activated at the time of the fire on tank 533 and again proved to be very effective, the only damage to these tanks being to the paintwork.

Tanks 912, 751 and 754 also had their shells punctured by bullets. Although there was some spillage there were no major fires. The holes in the shell were plugged with wooden bungs hammered hard into place. This proved to be an efficient short term solution to the problem and the tanks were able to be operated.

3.5.3 MINA SHUAIBAH REFINERY

Of the three refineries, the storage tanks at Mina Shuaibah sustained the most damage. Several were completely destroyed.

Numerous tanks sustained punctures in their shells and roofs due to bullets and shrapnel. Although they were in service at the time, they did not catch fire. The holes were plugged with wooden bungs to stop the leak of product into the bund and remained in service.

(a) TANKS 412 AND 414 -

The first fire took place in Tank No. 412 a fixed roof tank 59m diameter, 14.6m high. This tank had 40,000m^3 of kerosene stored in it at the time of the fire. There were no fixed fire protection systems installed on the tank. It is not known how the fire started, but it resulted in the tank roof being ruptured and the top 300mm of the top tier plates around the complete circumference being destroyed. (See Plate 25)

The fire was contained inside the tank and there was no spillage. Firefighters working from a Hydraulic Platform directed AFFF foam through a hole in the tank roof and extinguished the fire in about thirty minutes.

Tank No. 414 was on fire at the same time. This tank is the same size and design as Tank 412. Again it is not known how the fire started, but it had the same effect on the roof as the fire in Tank 412. However, the access to the bund did not permit the Hydraulic Platform to be deployed. The firefighters had to direct foam monitors from ground level through a hole in the tank roof to extinguish the fire. This was also effective, although the use of the Hydraulic Platform was said by the fire-fighters to make the first tank easier to extinguish. This fire took two hours to put out.

(b) TANKS 401, 403, 405, 407

The second sequence of fires occurred in tanks 405, 403, 401 and 407. These tanks were located in two separate earthwork bunds.

A fire started in tank 405 and this spread to tank 403. Due to the restrictions of the occupying forces the firefighters were not permitted to fight these fires. The tanks were left to burn and collapse spilling oil into the bund. Oil leaked through the pipe sleeves in the bund wall into the adjoining bund of tanks 401 and 407 and was ignited there, eventually setting these tanks on fire. (See Plate 26)

Again the firefighters were not allowed to fight the fire although they operated the water spray systems on adjacent tanks which proved effective and sustained minimal damage to the paintwork only.

(c) TANK 415

The third major fire was on tank 415, a fixed roof tank 61m diameter, 19.5m high with a capacity of 55650m^3. The cause of the fire is unknown. Firefighters were not allowed to fight the fire.

However, the water spray systems on adjacent tanks was operated and despite the wind changing directions several times the fire did not spread to other tanks. No oil spilt into the bund as the tank collapsed in on itself. The upper courses did not support their own weight as they became heated. The lower tiers being thicker did not distort as badly and retained the oil.

3.5.4 MINA ABDULLA REFINERY

This refinery had suffered quite badly and a number of different facilities had been put out of action. The Central Control Centre had been rendered inoperable by an explosion. The Centre was designed to withstand external explosions but the fabric of the building showed little sign of the massive internal explosion. While all central control was lost, most of the process units could be operated locally.

The inter-transfer pump station and the transfer pump stations, containing a total of 20 pumps, were completely destroyed by fire. Adjacent tanks had been effectively protected by their water spray systems and had sustained only minor damage to the paintwork.

Several other tanks had been hit by bullets and shells, but these did not catch fire.

(a) TANK 52-169

Tank 52-169, a cone roof tank, 36.57m diameter and 12.19m high with a capacity of 12,180m^3 was set on fire. At the time of the fire the tank was full of fuel oil. The burning product caused the internal pressure to exceed the design pressure of the tank and the roof blew off, landing 25-30m away. Tank design is such that the welded joint between the roof plating and the curb angle is a 'weak' joint. In the event of the tank becoming pressurised this weld would fail first leaving the shell undamaged. (See Plate 27)

The full surface fire was extinguished in 4-5 hours using a Simon Snorkel to deliver FP70 foam on to the burning oil.

The water spray systems on the adjacent tanks operated and the tanks sustained no damage.

3.6 GATHERING CENTRES

Visits were made to three Gathering Centres, GC22, GC20 and GC14. There were varying degrees of damage, from bullet and shrapnel holes in small tanks, to the complete destruction of the whole Gathering Centre.

The main point of interest, common to all the Centres visited was the consistently high performance of the earthwork tank bunds. Where tanks had collapsed and spilt oil into the bund, in no case had the bund been breached.

The full surface fire was extinguished in 4-5 hours using a Simon Snorkel to deliver FP70 foam onto the burning oil.

The water spray systems on the adjacent tanks operated and the tanks sustained no damage.

4.0 COMMENTS REGARDING EWBANK PREECE REPORT

4.1 INTRODUCTION

As a result of the investigations carried out in Kuwait it would be useful to see how the relevant sections of the Ewbank Preece Report scenarios compare with the Case Histories described in Section 3.0.

4.2 POSITION OF MONITORS
(Ewbank Preece Report Part 2 Section 3.2.8 p36)

Ewbank Preece state that :-

"Deployment of monitors should ideally be on, or, better still, outside the bund wall."

One comment to make is that the bund itself can be subjected to considerable heat. For example, controls to fixed fire protection for a tank was located on top of a bund wall (Section 3.4.4). This had been affected by the tank fire inside the bund, damaging armoured electric and control cables, and it would be hazardous and difficult for firefighters or plant personnel to operate this equipment.

4.3 RIM SEAL FIRES
(Ewbank Preece Report Part 2 Section 3.2.8 p39)

A point brought out in Part 2 - Tactics and equipment of the Ewbank Preece Report states that :-

"The progress of a fire from the rim seal stage can be quite rapid. If floating pontoon sections are not fully air tight these may contain an explosive mixture of gas and air. An explosion in a pontoon section could rapidly sink or tilt the roof exposing the crude oil surface to spread of flame. Once the tank becomes fully involved, the full scale emergency plan should be brought into action. Decisions on the correct action need to be taken as events unfold, and flexibility of response together with close monitoring of developments is essential."

Whilst the above is a possible scenario it fails to acknowledge that a rim seal fire does not always lead to a full scale roof fire (Section 3.2.2). In fact, experiences from Kuwait would indicate that a rim seal fire could burn for some months without adverse effects to the roof.

The design of a pontoon floating roof takes into account two adjacent pontoon sections and the centre deck punctured. Thus even with this degree of damage it will still remain floating.

Prevention of fully involved roof fires, as a result of a rim seal fire, should be the prime aim with appropriate back up measures to take account of a major roof fire.

4.4 COOLING THE INVOLVED TANK
(Ewbank Preece Report Part 2.3.2 8a p40)

Ewbank Preece state :-

"It is only worthwhile cooling the freeboard area above the contents".

Cooling jets would be best directed just above the level of the floating roof. This would reduce the temperature of the shell allowing a better foam seal. However, this cooling must be done around the complete circumference of the tank simultaneously to avoid hot spots on the tank allowing the foam to burn back. This would be a very difficult thing to do practically.

One disadvantage of localised monitor cooling is that it can cause collapse of the tank shell where the monitor is directed. This can result in parts of the tank touching the oil surface and creating difficulties for foam to spread over the entire surface. (Plate 1 and Section 3.1)

There is a better solution to this problem, seen to good effect in Kuwait, that of water spray systems as permanent fire protection. This ensures even cooling of the tank provided the water supplies are protected.

4.5 **COOLING AN EXPOSED TANK**

Logistically it would be easier to cool an exposed tank by means of a fixed system. This would save on the Ewbank Preece figures for a 45m diameter, 15m high crude oil storage tank, 7 water monitors, 4 hydrants, 52 lengths of hose and the necessary pumping appliances for each tank at risk, and more importantly the manpower to bring these monitors into action.

The decision on whether to cool or not cool a tank, thereby conserving water and resources would be aided by some means of identifying radiated heat. This could be either by a heat radiation meter or heat sensitive paint applied in vertical strips to the sides at risk as mentioned in the Ewbank Preece Report.

4.6 **LARGE TANK FIRES**
(Ewbank Preece Report Part 3 p18)

The Ewbank Preece report accepts (Part 3 Fig 1 p18) in its "Idealised arrangement" the one tank one bund principle with access completely around the tanks.

This layout was seen in Kuwait and was shown to limit destruction in a Tank Farm. This statement is made against a background of examples where multiple tank losses only occurred in joint bunded areas. Some of these were due to occupation forces destroying many tanks in one operation, but others were due to fire spread.

However, Kuwaiti experience of protecting their tanks by means of fixed fire protection (water spray) is not taken into account by Ewbank Preece's "Idealised Arrangement". It is difficult to prove conclusively that tanks would have been lost if water sprays were not used on adjacent tanks, but the number of tanks seen where water sprays were used and no damage occurred would tend to support their use. This is even more important when considering the lack or non-existence of personnel and equipment to deploy water cooling of 'at risk tanks'. The message must be that a system connected to the fire ring main should be supplied by sufficient water and thus is the preferred option.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL

5.1.1 Consideration should be given to carrying out modification to tanks to incorporate new ideas. This could be done during routine maintenance work.

5.1.2 Firefighters, Plant Operators, Contractors and Customers must be involved in planning, design, installation and the acceptance phase of Tank Farm construction. This would allow for past firefighting experiences to be taken into account.

5.2 FOAM

5.2.1 Design of floating roof foam dams should take into consideration the increasing use of secondary tank seals. If the foam dam is not high enough to come above the secondary seal the effectiveness of this system is limited.

5.2.2 Consideration should be given to the design of the back plates of the foam pourers. In many cases these were not large enough to prevent foam being blown away from the tank by wind.

5.2.3 The layout of foam pourers should be such as to give an overlap of foam when it is being released onto the roof to ensure complete coverage with sufficient foam as soon as possible. (Section 3.2.2)

5.2.4 Secondary sealing systems are now available with burn out ports in them to allow for the injection of foam directly into the rim gap area, above the primary seal, so alleviating problems of foam penetration. (Section 3.2.2)

5.2.5 Having fixed foam pourers located on bund walls to allow foam to be applied to the bund in the event of a spill fire is advantageous. However, the amount of foam needed to fill the bund and therefore be effective would be considerable. A fixed installation with remotely controlled fire pumps and foam concentrate supplies is considered preferable. There is doubt whether the foam would flow into the corners of the bund if sufficient pourers are not provided. Additionally, take off points for a hand controlled foam branch to tackle any fire remaining in the corners would be advantageous. (Plate 15 also Section 3.4.2)

5.2.6 Foam inductors and their control systems should not be placed on the tops of bunds. This exposes them and any operators to the full force of the fire. Positioning the equipment outside the bund surrounded by protective shelters should be standard practice. (Section 3.4.4)

5.3 BUNDS

5.3.1 Common to all the facilities was the consistent high performance of the earthwork tank bunds. Where tanks had collapsed and spilt oil into this type of bund no major breach had occurred.

5.3.2 Expansion joints between sections of concrete bund walls did not perform well. The joint material was destroyed allowing daylight to be seen through the resulting gap. Whilst these openings on their own were not sufficient to allow large quantities of product to escape, they would add to firefighters' difficulties, also putting at risk fixed protection systems to other tanks.

5.3.3 The height of bund walls should take into account not only the capacity to be contained, but also the relationship of the tank outlet valve height, to the bund wall. (Section 3.4.3).

5.3.4 The sleeving of product pipes through both earth and concrete bunds should be such that no product can leak out. Failures of sleeving were observed during the investigation and in many cases leakage from one bund to another, or outside, resulted in pool fires outside the original bund.

5.3.5 Tanks should be in separate bunds. Experience of visits to the sites shows that all tanks within a bunded area are at risk. Access to all sides of the tank should be provided. This would assess the firefighters and also give opportunity to use aerial appliances in an early stage of firefighting.

5.4 FIRE FIGHTING

5.4.1 A second means of exit/access from the wind girder should be considered. This would be particularly advantageous when dealing with large diameter tanks and different wind directions.

5.4.2 The use of a dry powder (75Kgs) extinguisher to fight a spill fire when backed up with water sprays, to cool, proved successful. Fire-fighters felt this technique had merit. (Section 3.2.2)

5.4.3 Firefighters successfully used a two-stage method of deploying a water monitor between tanks. This would not be required if fixed water spray systems, suitably protected, were installed. (Section 3.2.2)

5.4.4 Standby systems for fixed fire pumps should be considered.

5.4.5 A unique situation occurred where two identical tanks, both containing the same product and quantity, caught fire, also sustaining damage resulting in similar openings in their roofs.

These were tackled by firefighters and one extinguished in 30 minutes by use of a hydraulic platform to deliver the foam. The other tank was positioned so that access was not available for the hydraulic platform and it had to be extinguished by fire monitors, taking 2 hours. This would support arguments regarding elevating the monitor (see Ewbank Preece Report Part 2 Section 6.3) and allowance for aerial appliances should be taken account of in bund architecture.

5.4.6 The deployment of aerial appliances will have to be assessed by the Officer in Charge with regards to the stage of fire development, and product in the tanks concerned. The possibility of a boilover affecting escape should be considered.

5.4.7 Water application rates, how much and where? This question needs resolving across various Codes.

5.5 DRAINAGE

5.5.1 The design and layout of drains within bunds should be considered. Where seen, all drains had been filled with oil and undoubtedly contributed to the spread of spill fires.

5.6 RESEARCH REQUIREMENT

5.6.1 The method of extinguishing a rim seal fire requires further investigation because of the multiplicity of design of tank seals and fire protection systems. They are also a frequent source of fire when compared to major tank incidents.

5.6.2 The possible cooling effect of both wind and smoke should be investigated. (Section 3.3.4)

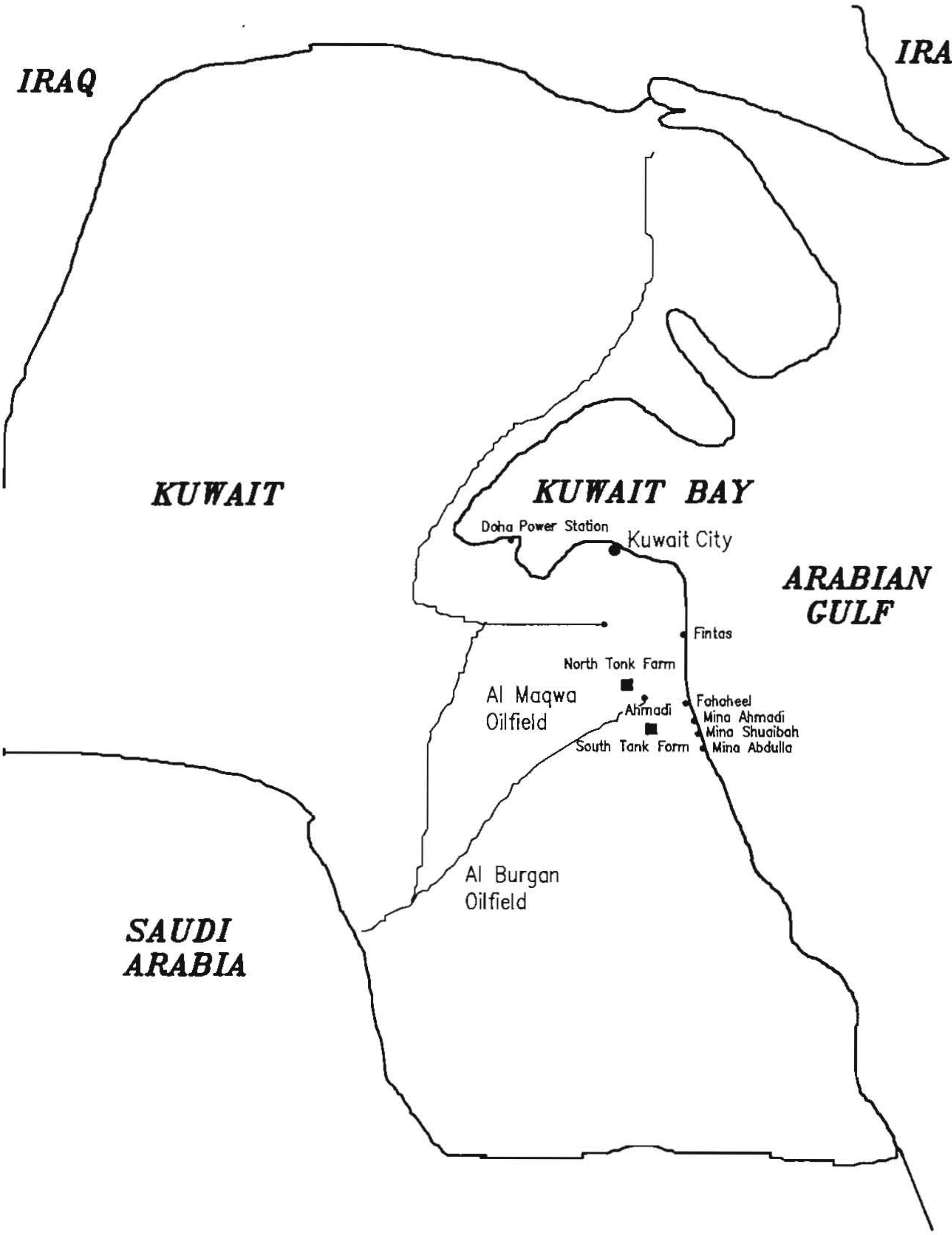
5.6.3 The development and/or identification of a radiation heat detector suitable to monitor the temperature of tanks at risk, should be considered.

5.6.4 The effectiveness of temperature indication paints in assisting the Officer in Charge in deciding which tanks to cool, should be investigated.

5.6.5 Carry out research into efficiency of the various types of foam pourer systems and the best solutions regarding their location.

6.0 ACKNOWLEDGEMENTS

We wish to acknowledge the considerable help given to us by the Kuwaiti Government. The personnel of Kuwait Oil Company, Kuwait National Petroleum Company, Motherwell Bridge's agent in Kuwait, the Foreign and Commonwealth Office and its Embassy in Kuwait, for their assistance with this project.



KUWAIT

(NOT TO SCALE)

PLATE 1

MONITOR POSITION AND RESULTS TO THE TANK SHELL
FROM ITS COOLING JET

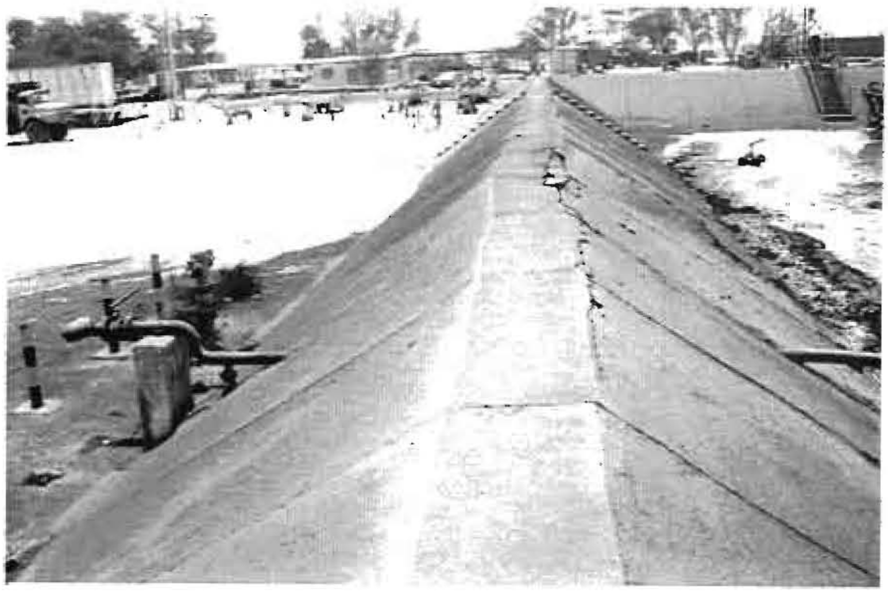


PLATE 2

BUND CONSTRUCTION - TANK 77/101 NORTH PIER LOADING AREA

PLATE 3

BUND SURROUNDING TANK 204 SHOWING OIL CONTAINMENT

PLATE 4

TANK 52 KOC NORTH TANK FARM

PLATE 5

FOAM TENDER CAUGHT BY BOILOVER

PLATE 6

FLOATING ROOF DISPLACED TO OUTSIDE OF TANK SHELL

PLATE 7

VULNERABILITY OF PLACING FOAM/WATER PIPES UP STAIRWAY

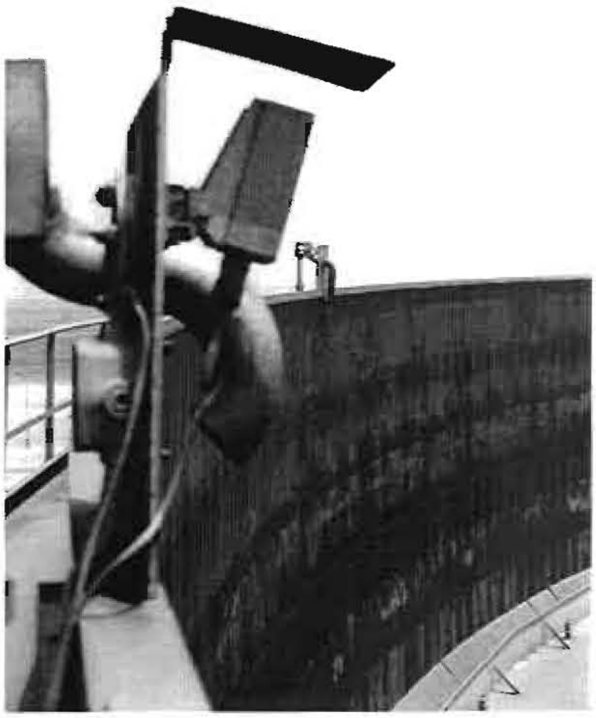


PLATE 8

FOAM POURERS WITH MODIFIED POURER IN BACKGROUND

PLATE 9

GENERAL VIEW OVER K.O.C. SOUTH TANK FARM

PLATE 10

RIP/ZIP WATER TANK

PLATE 11

TANK 62 - SOUTH TANK FARM

PLATE 12

CROSS SECTION OF SAND BUND (FIREFIGHTER SHOWS SCALE)

PLATE 13

DOHA POWER STATION TANK FARM

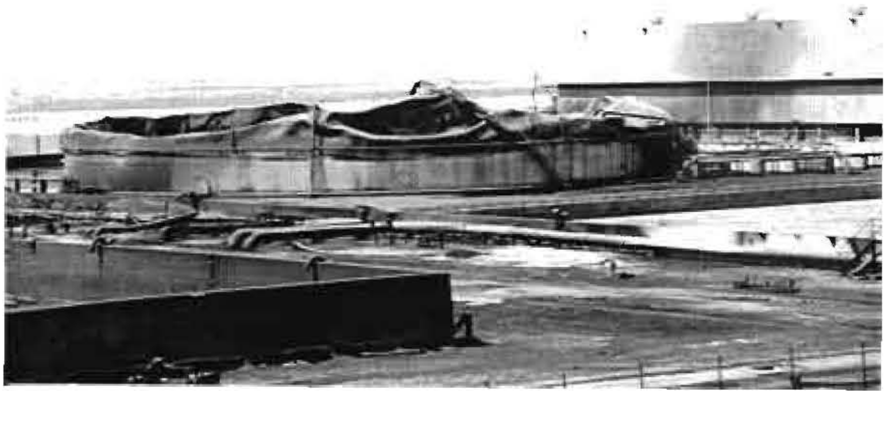


PLATE 14

TANK B DOHA POWER STATION

PLATE 15

FOAM POURER AND PIPEWORK DESTROYED BY FIRE

PLATE 16

GENERAL VIEW TANK B DESTROYED BY FIRE

PLATE 17

EFFECT OF FIRE ON CONCRETE BUND WALL

PLATE 18

SHOWING DEPTH TO WHICH OIL POOLED OUTSIDE BUND

PLATE 19

EFFECT OF FIRE ON PRODUCT LINE

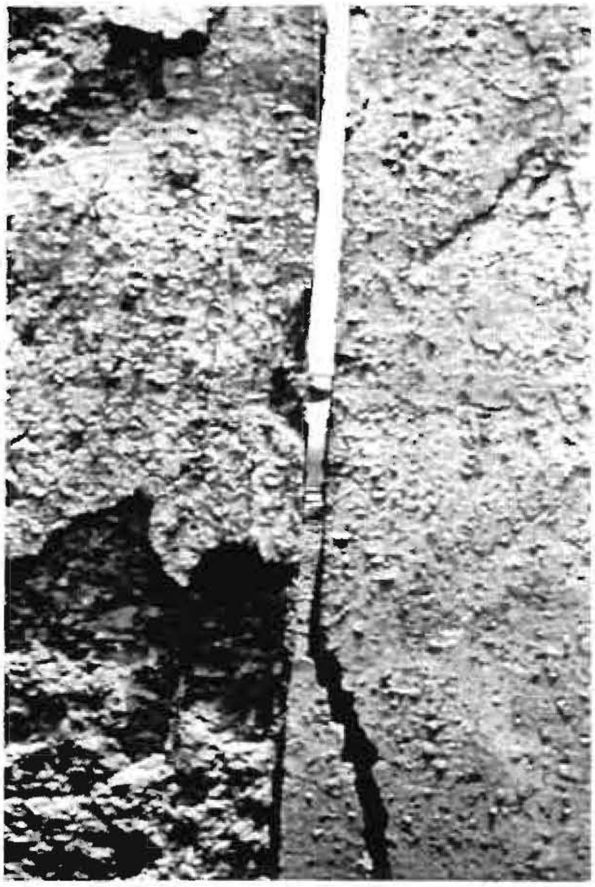


PLATE 20

JOINT IN CONCRETE BUND WALL BURNT OUT BY SPILL FIRE

PLATE 21

TANKS Y AND Z GENERAL VIEW OF BUND ARRANGEMENT

PLATE 22

ARRANGEMENT FOR PIPE THROUGH BUND

PLATE 23

ALTERNATIVE PIPE SLEAVING THROUGH BUND

PLATE 24

FOAM INDUCTOR AND CONTROLS POSITIONED ON TOP OF BUND

PLATE 25

EFFECT OF FULL SURFACE FIRE INSIDE FIXED ROOF TANK

PLATE 26

FIRE SPREAD THROUGH SLEAVING BETWEEN BUNDS

PLATE 27

FRANGIBLE ROOF BLOWN CLEAR OF TANK (IN BACKGROUND)

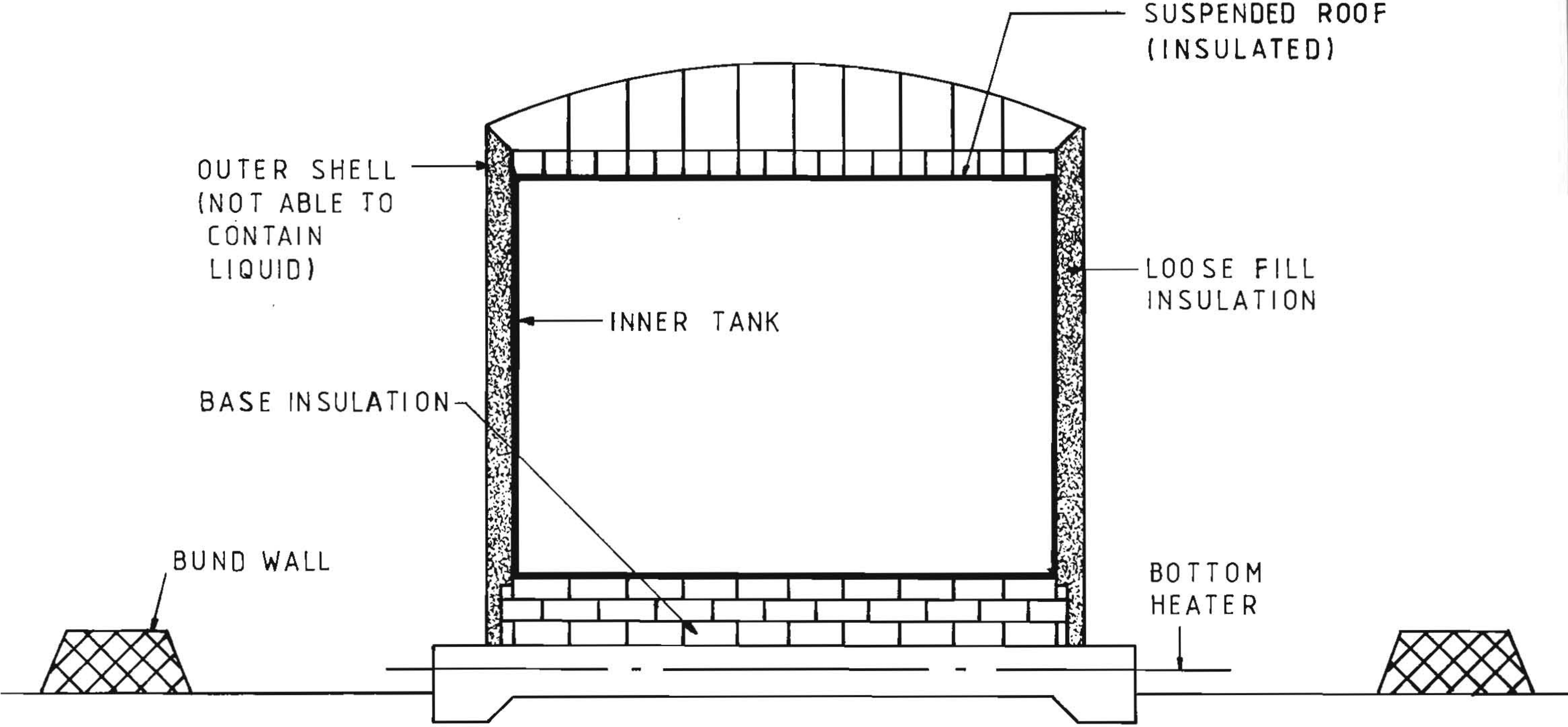
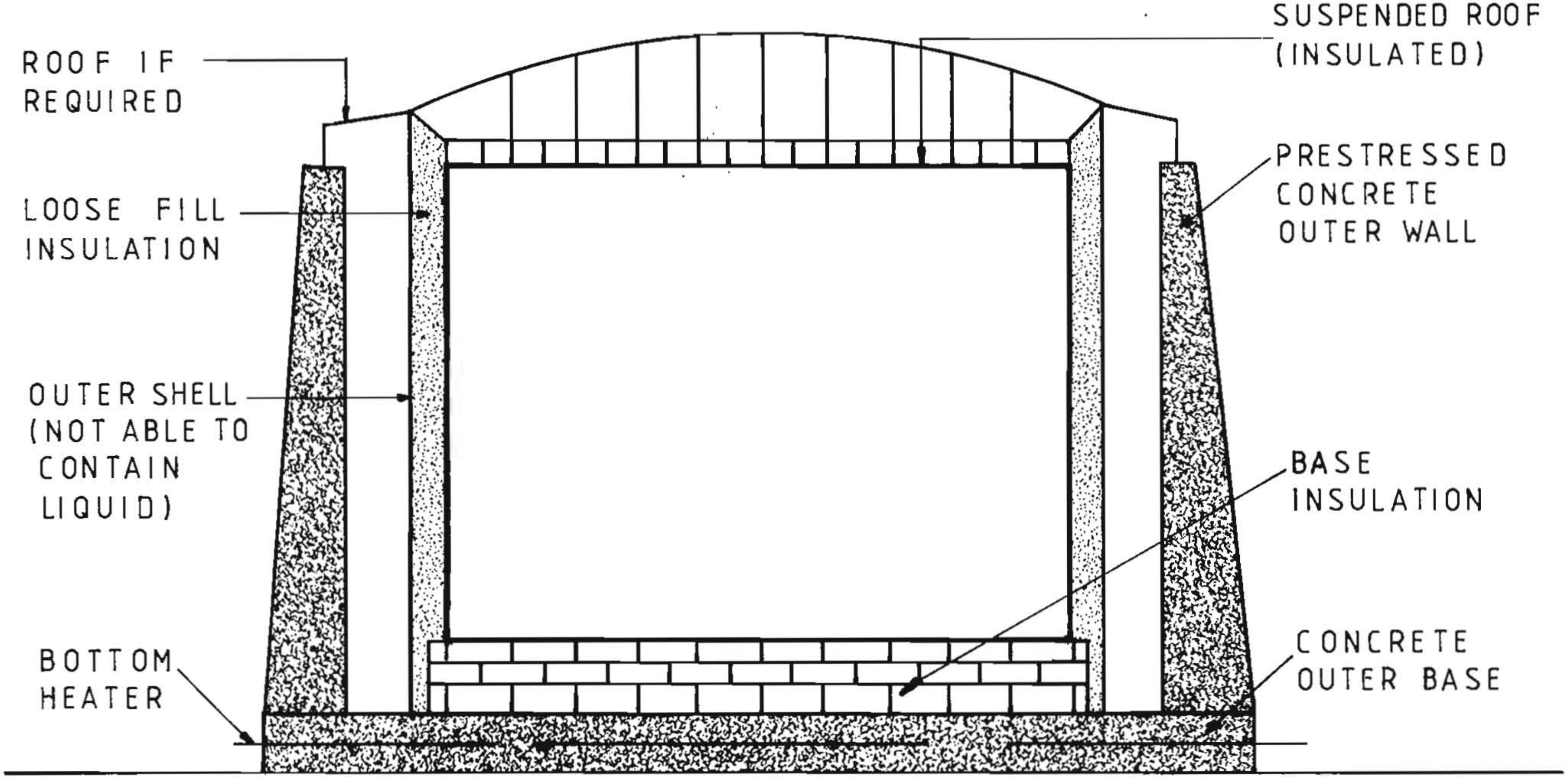

SUSPENDED ROOF
(INSULATED)
OUTER SHELL
(NOT ABLE TO
CONTAIN
LIQUID)
LOOSE FILL
INSULATION
INNER TANK
BASE INSULATION
BUND WALL
BOTTOM
HEATER

FIG 2A



ROOF IF REQUIRED
SUSPENDED ROOF (INSULATED)
LOOSE FILL INSULATION
PRESTRESSED CONCRETE OUTER WALL
OUTER SHELL (NOT ABLE TO CONTAIN LIQUID)
BASE INSULATION
BOTTOM HEATER
CONCRETE OUTER BASE

FIG 2B

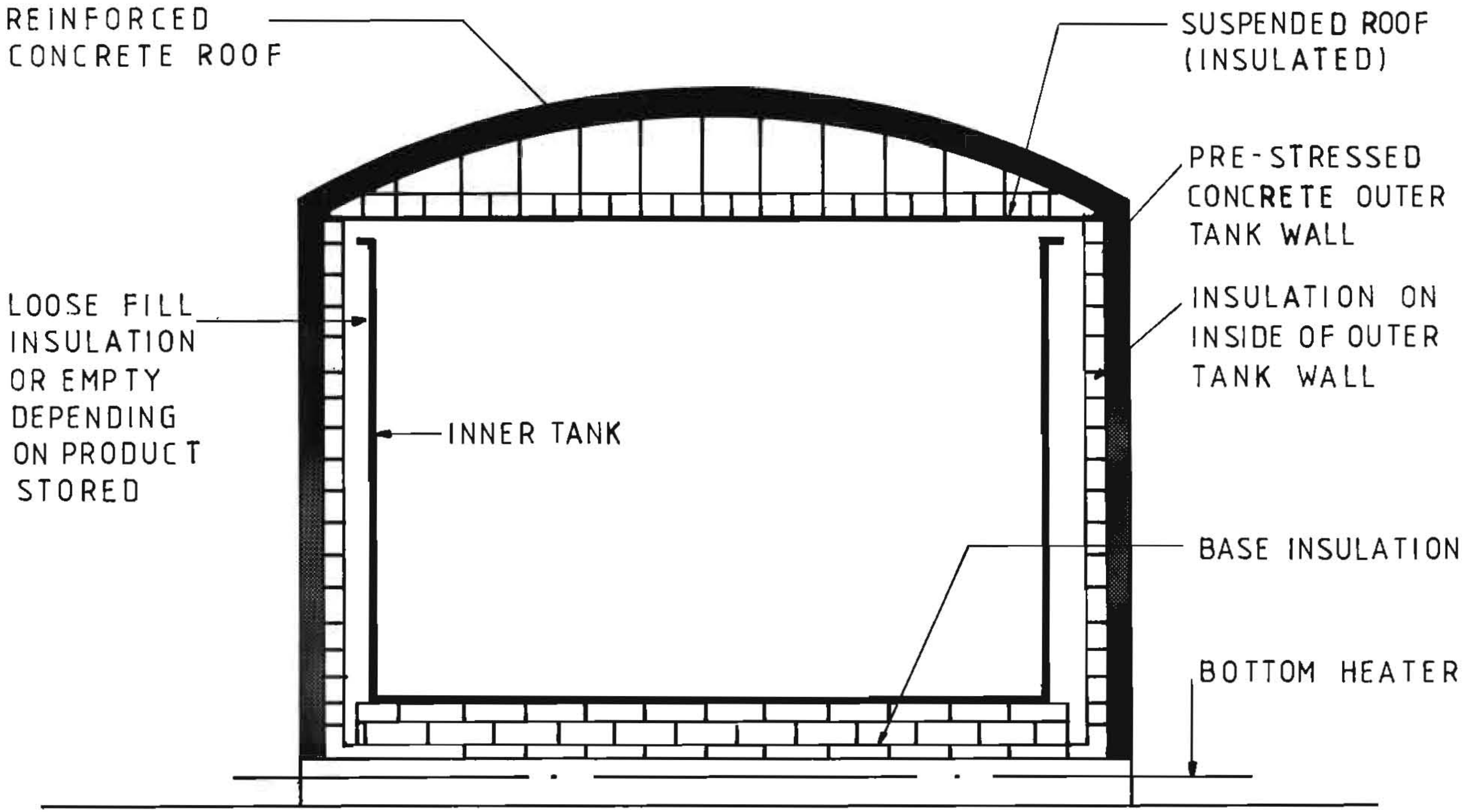

REINFORCED
CONCRETE ROOF
SUSPENDED ROOF
(INSULATED)
PRE-STRESSED
CONCRETE OUTER
TANK WALL
LOOSE FILL
INSULATION
OR EMPTY
DEPENDING
ON PRODUCT
STORED
INSULATION ON
INSIDE OF OUTER
TANK WALL
INNER TANK
BASE INSULATION
BOTTOM HEATER

FIG 2C

PONTOON FLOATING ROOF

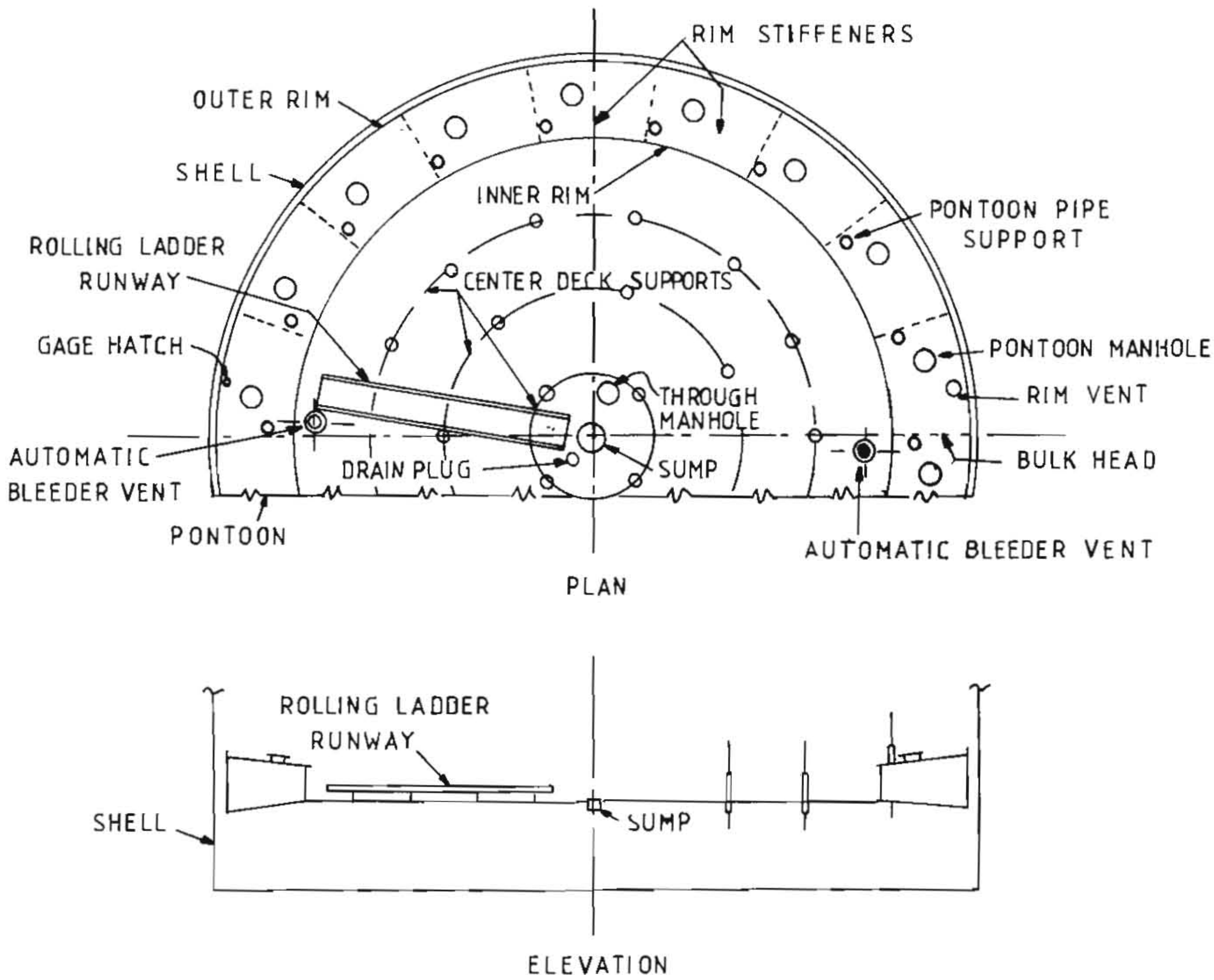


FIG 2D

DOUBLE DECK
FLOATING ROOF

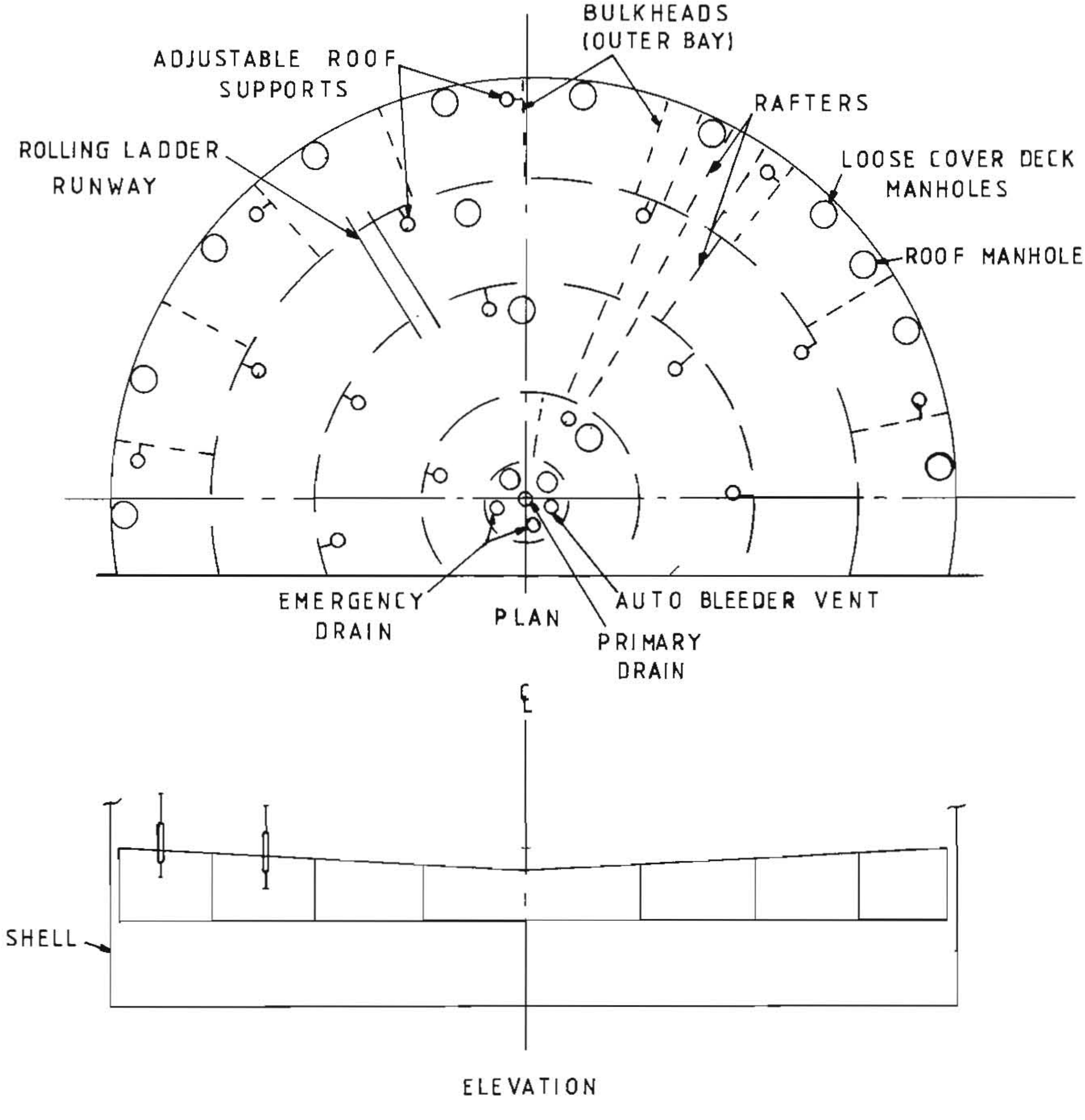


FIG 2E

CONE ROOF TANK

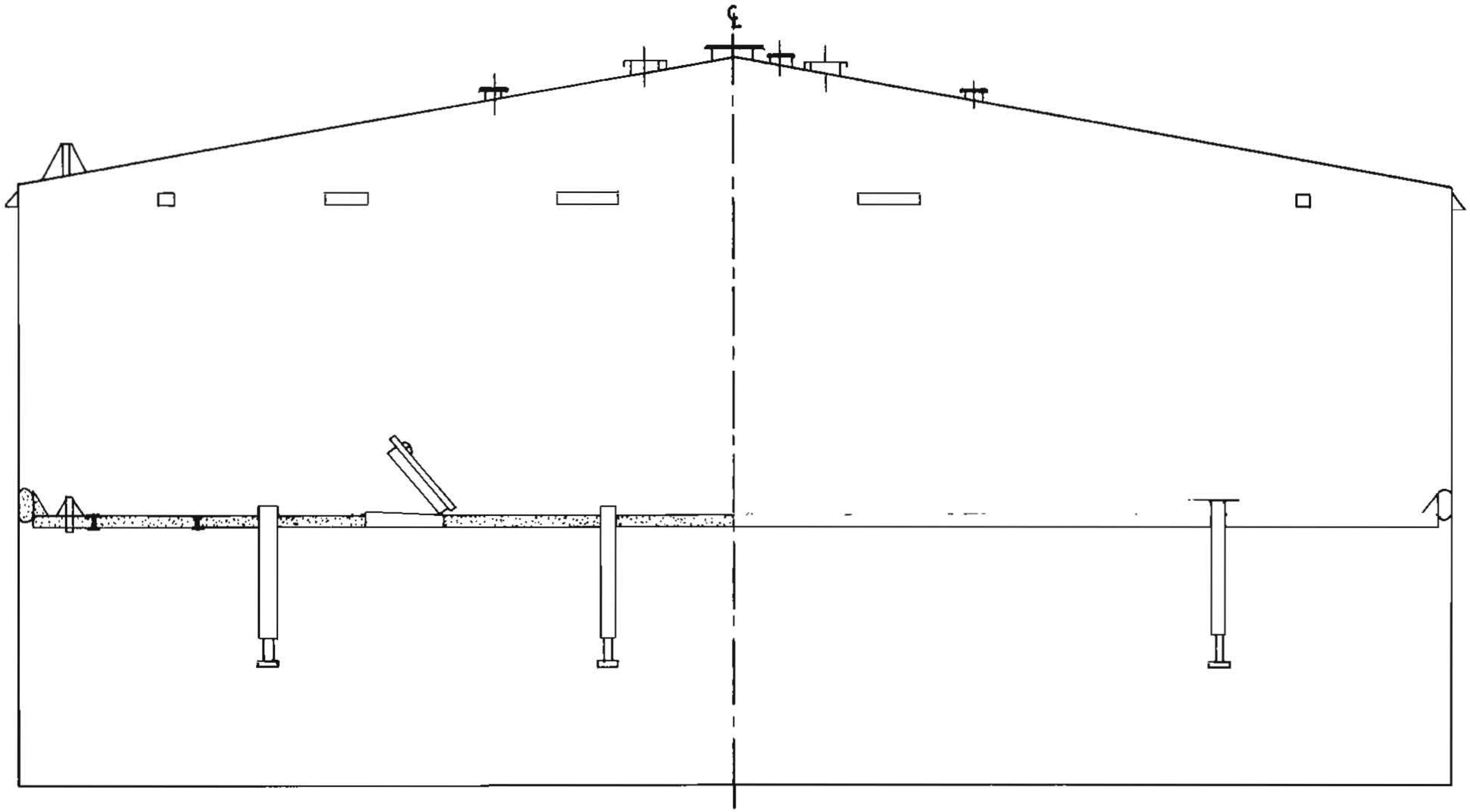
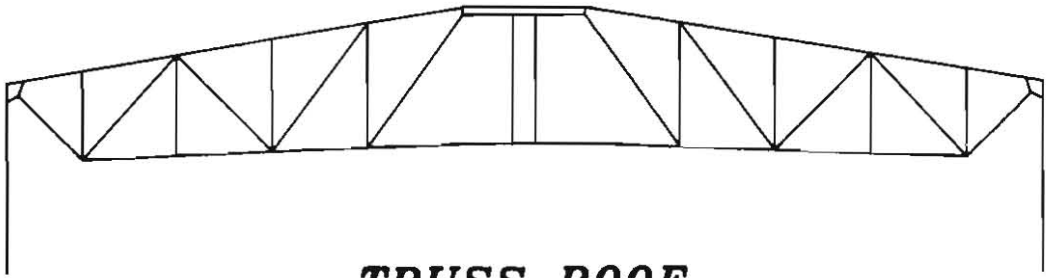
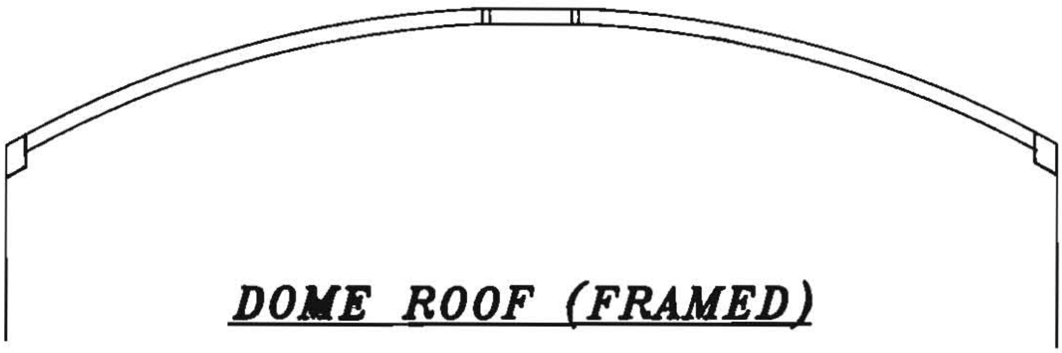


FIG 2F

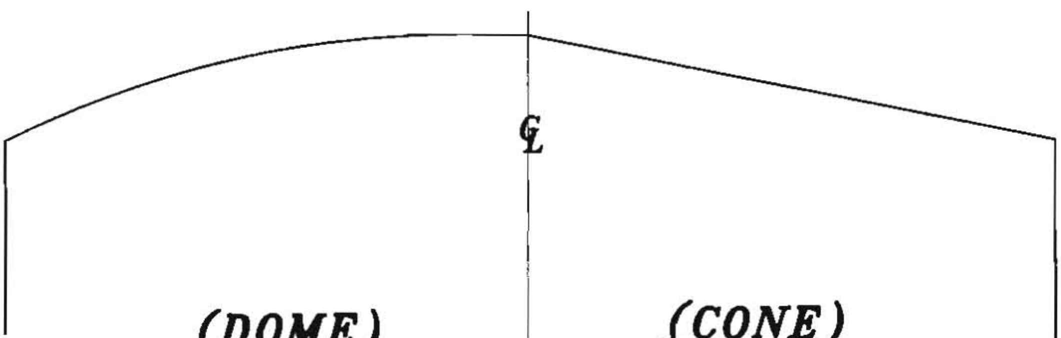


TRUSS ROOF

RAFTER ROOF



DOME ROOF (FRAMED)



(DOME) ***(CONE)***

SELF SUPPORTING ROOF

FIG NO.2G

LAYOUT OF TANKS

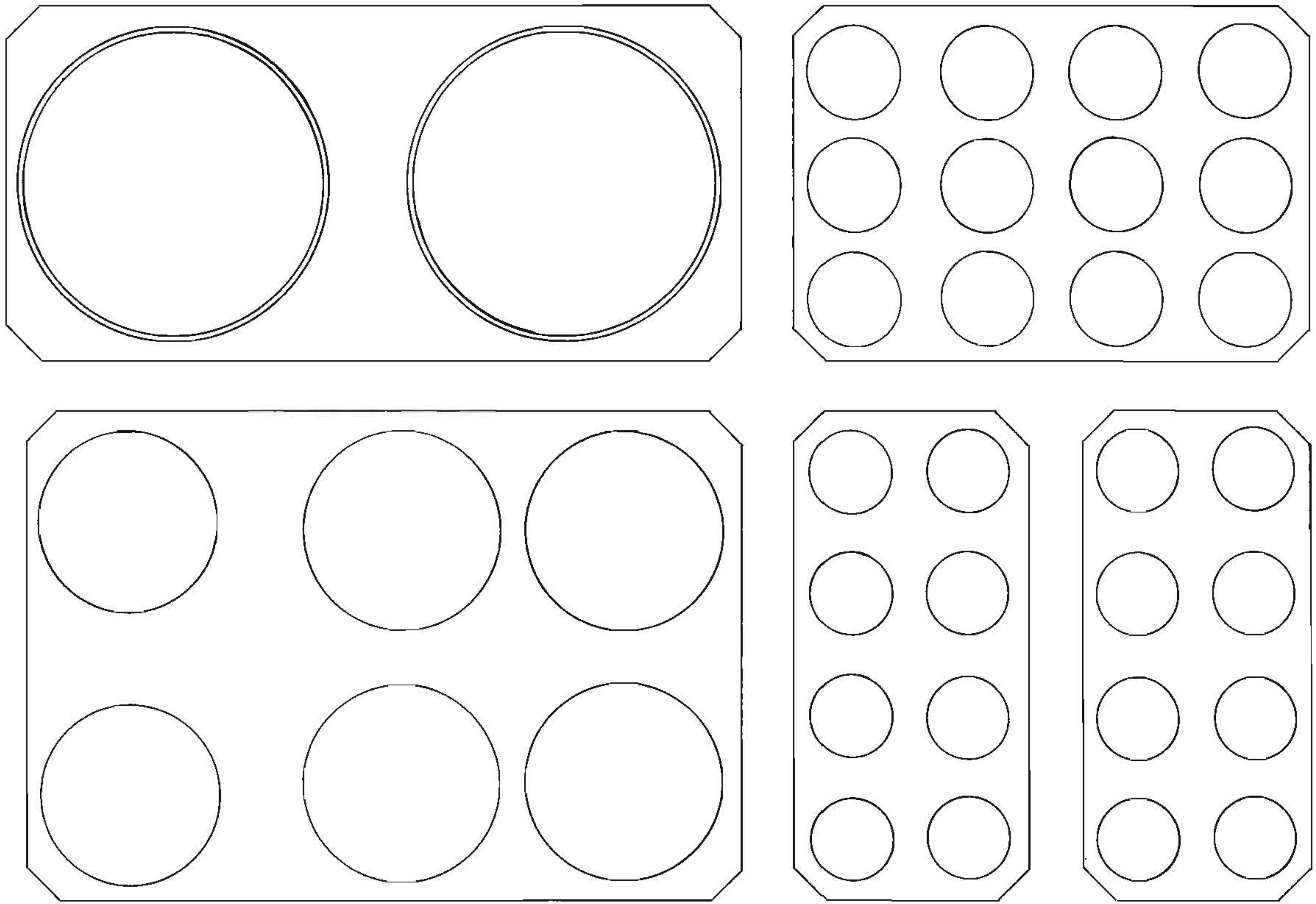


FIG 2H

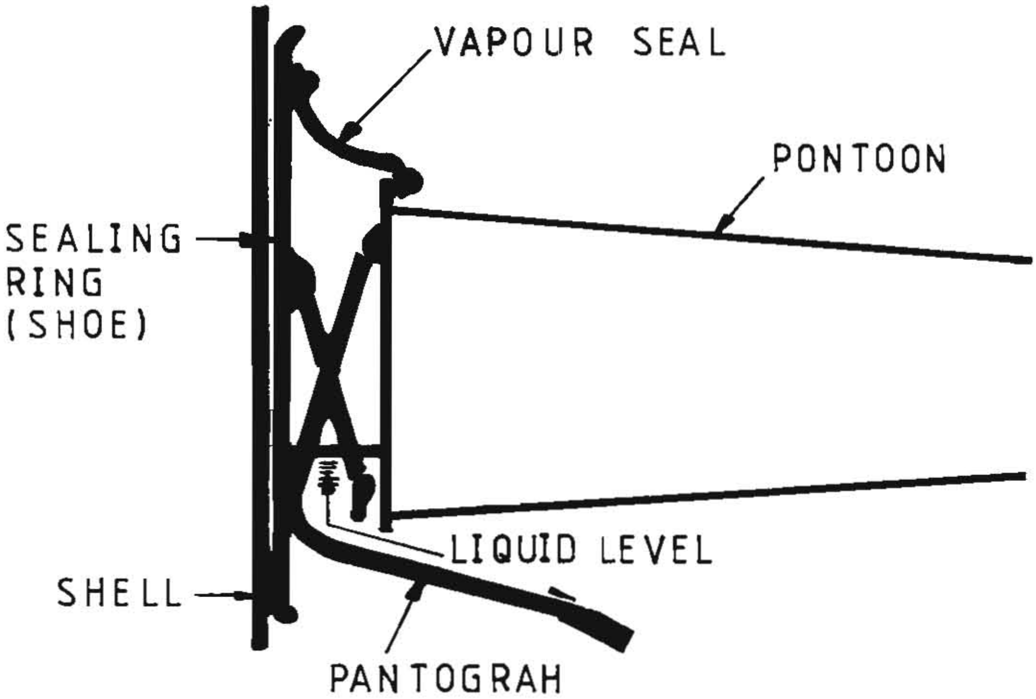

VAPOUR SEAL
PONTOON
SEALING RING (SHOE)
LIQUID LEVEL
SHELL
PANTOGRAH

FIG 2J

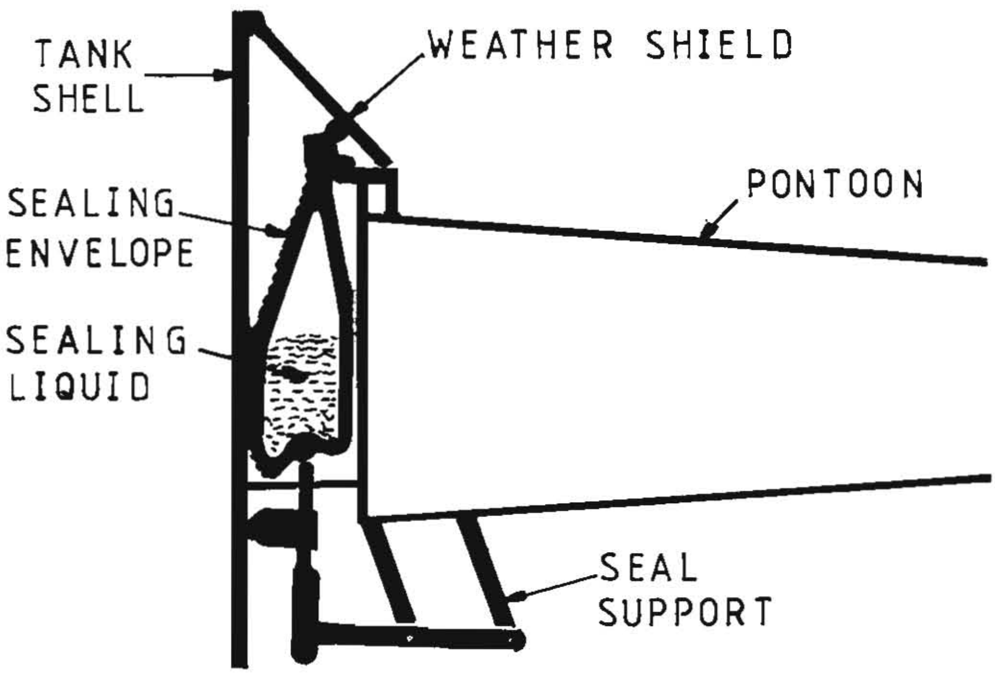

TANK SHELL
WEATHER SHIELD
PONTOON
SEALING ENVELOPE
SEALING LIQUID
SEAL SUPPORT

FIG 2K

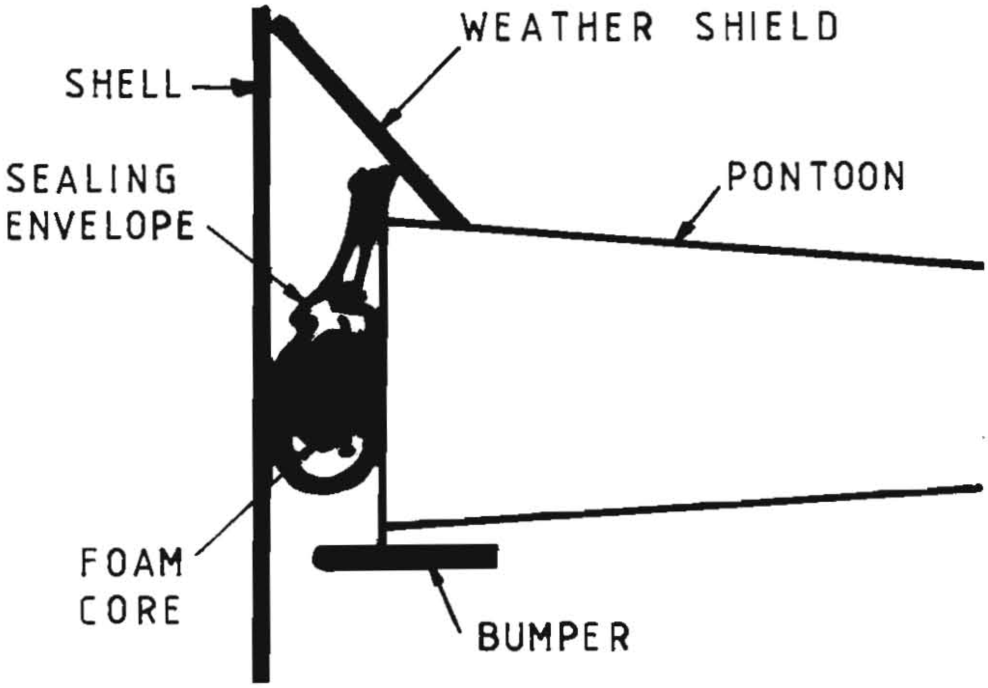

WEATHER SHIELD
SHELL
SEALING
ENVELOPE
PONTOON
FOAM
CORE
BUMPER

FIG 2L

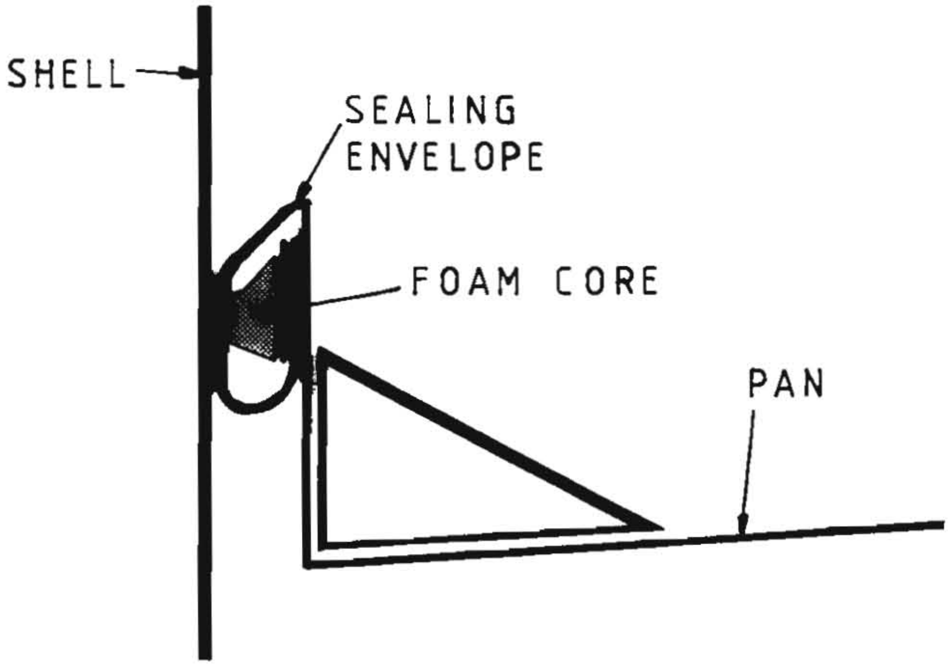

SHELL
SEALING
ENVELOPE
FOAM CORE
PAN

FIG 2M

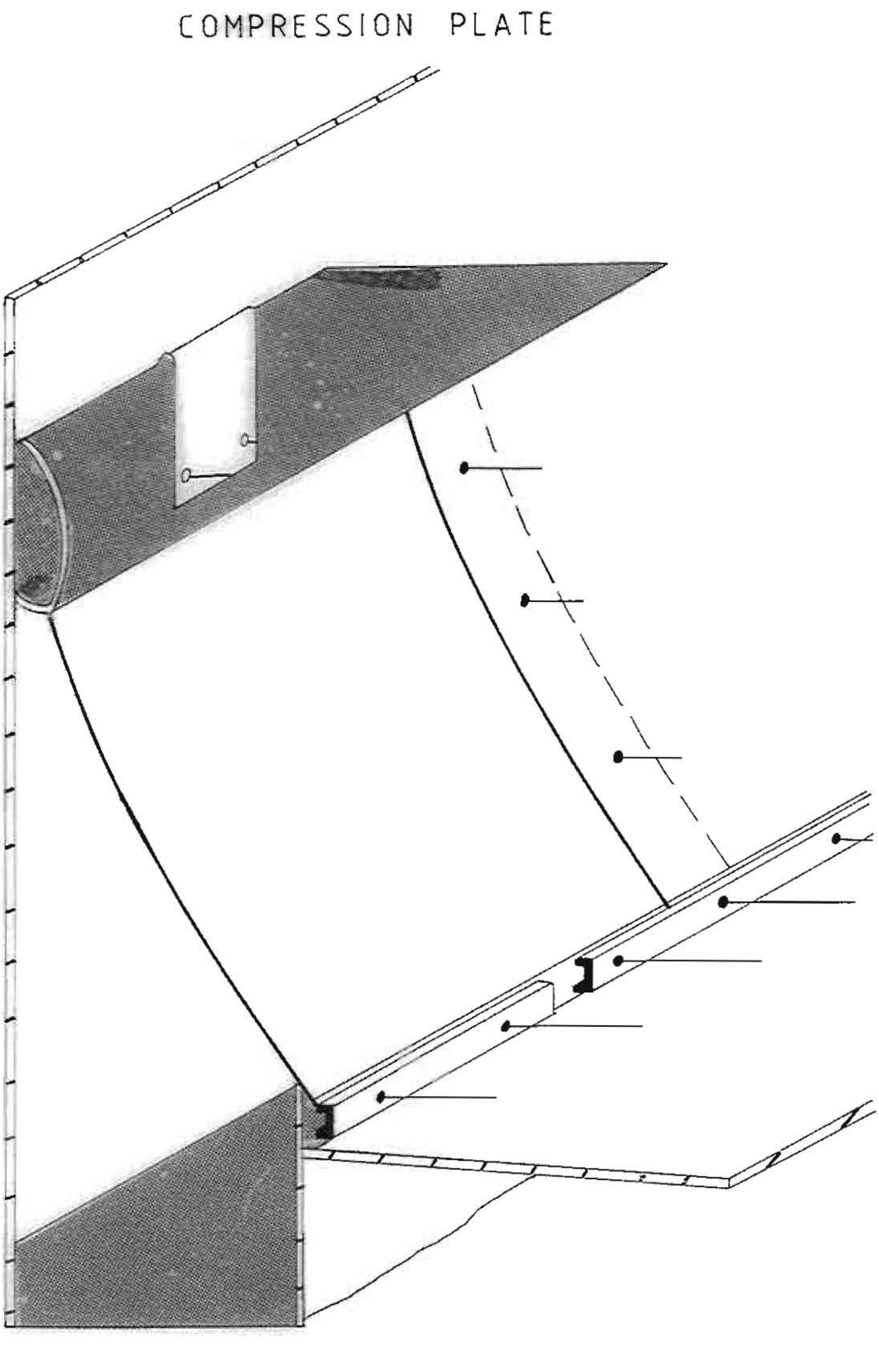


FIG 2N

COMPRESSION PLATE
WITH VAPOUR BARRIER

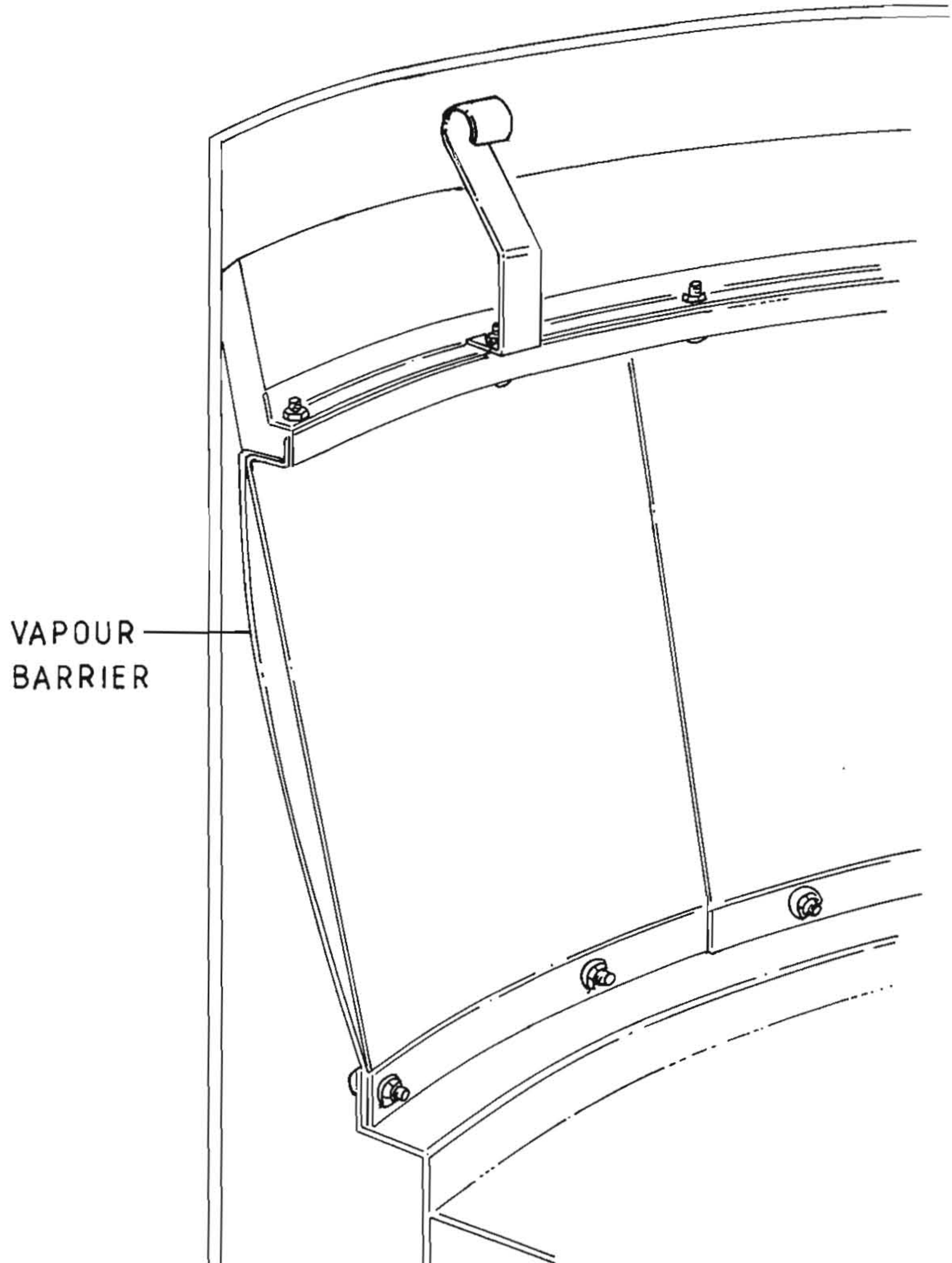


FIG 2P

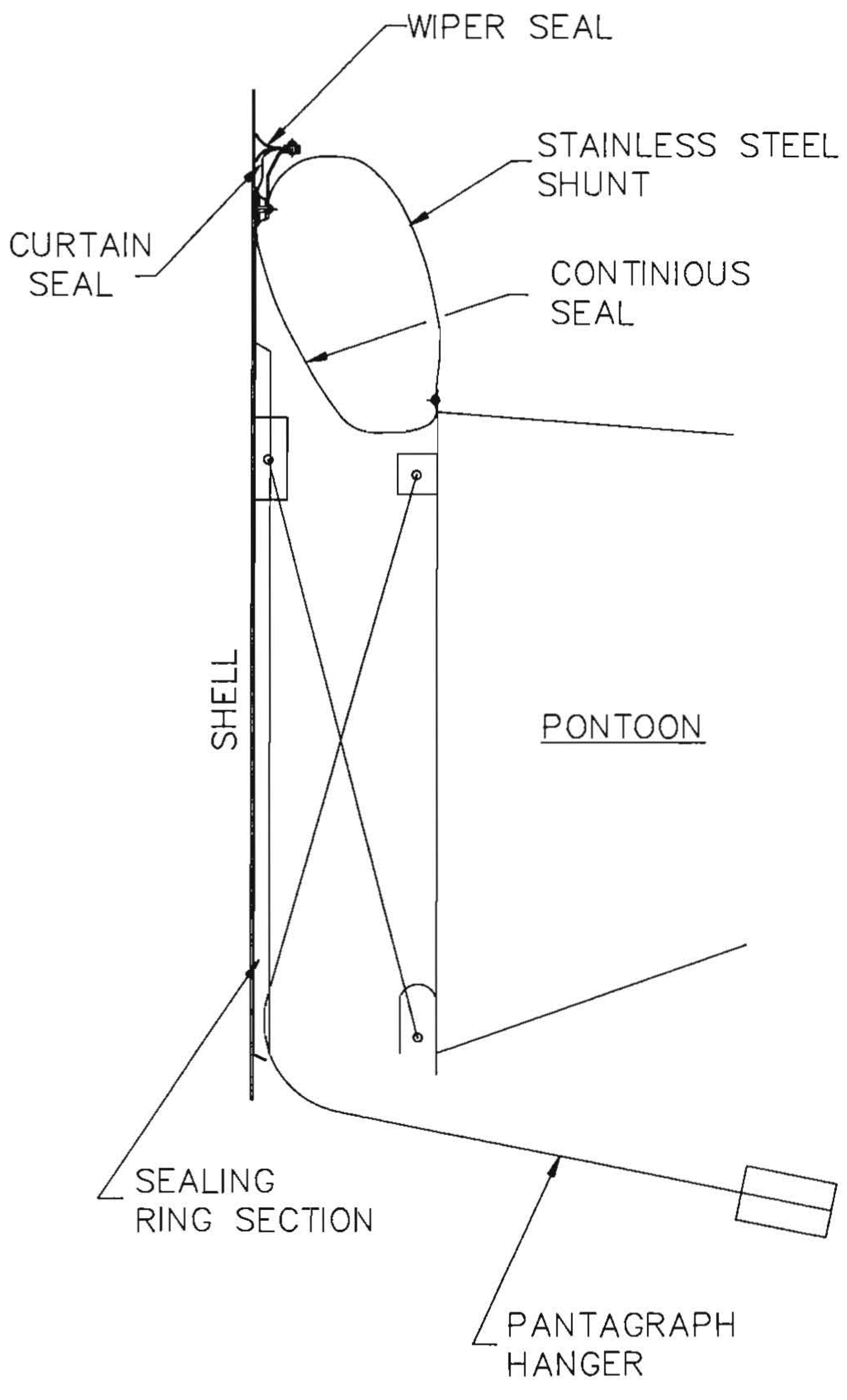

WIPER SEAL
STAINLESS STEEL
SHUNT
CURTAIN
SEAL
CONTINIOUS
SEAL
SHELL
PONTOON
SEALING
RING SECTION
PANTAGRAPH
HANGER

FIG NO.2 R

NORTH TANK FARM

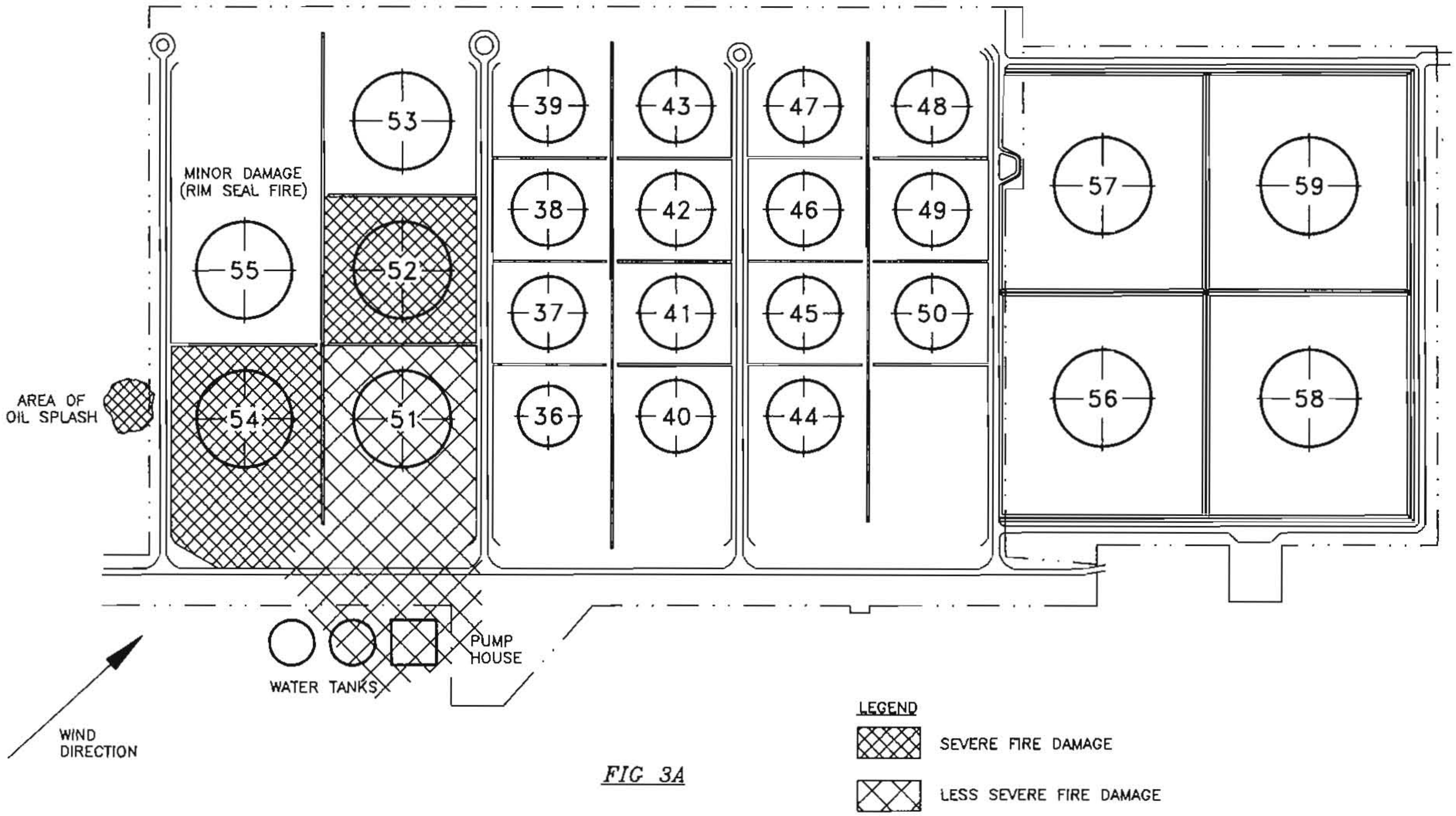


FIG 3A

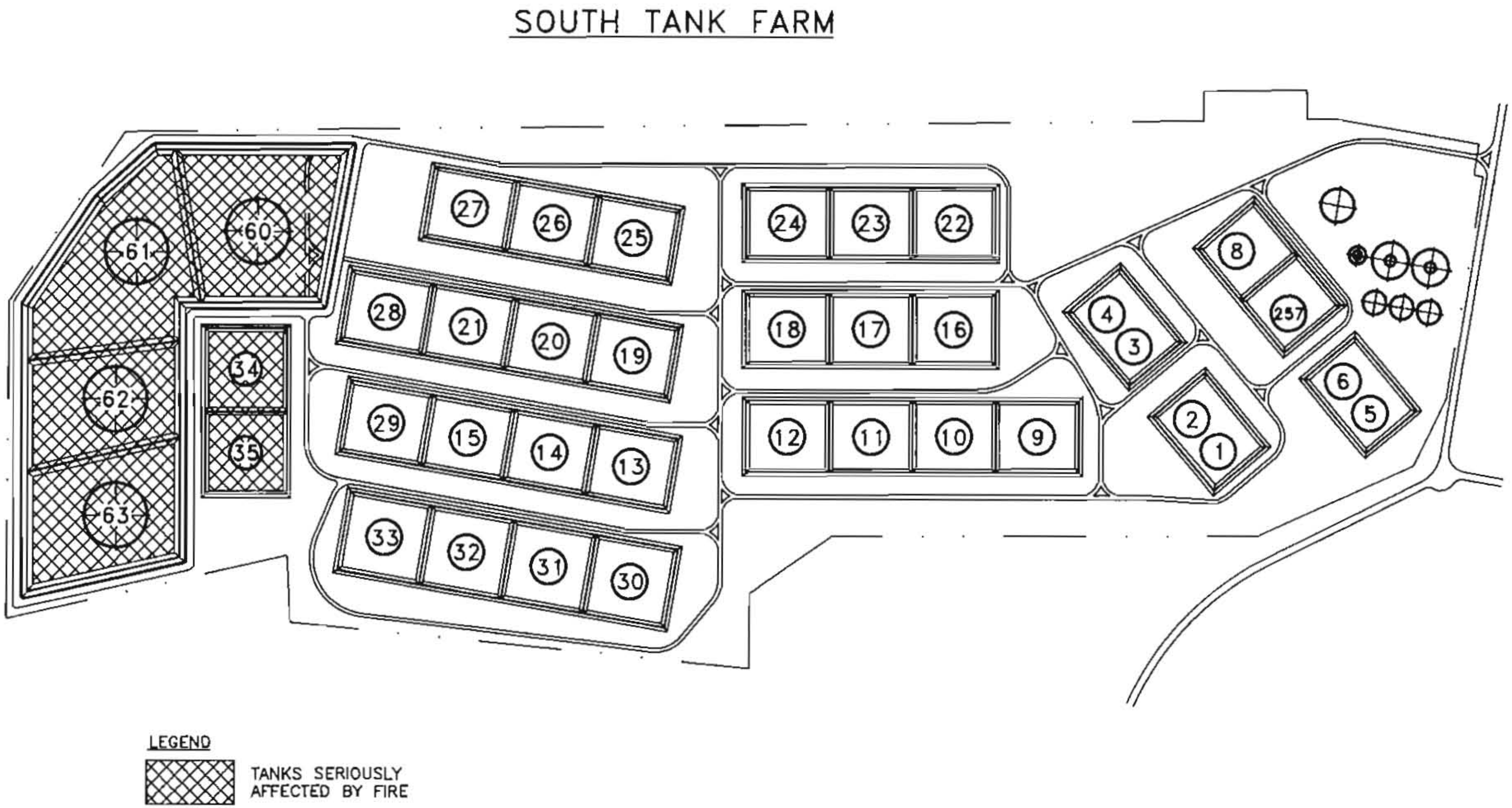

SOUTH TANK FARM
27
26
25
24
23
22
61
60
28
21
20
19
18
17
16
8
4
3
257
62
34
35
29
15
14
13
12
11
10
9
2
1
6
5
63
33
32
31
30
LEGEND
TANKS SERIOUSLY AFFECTED BY FIRE

FIG 3B

DOHA POWER STATION TANK FARM (NOT TO SCALE)

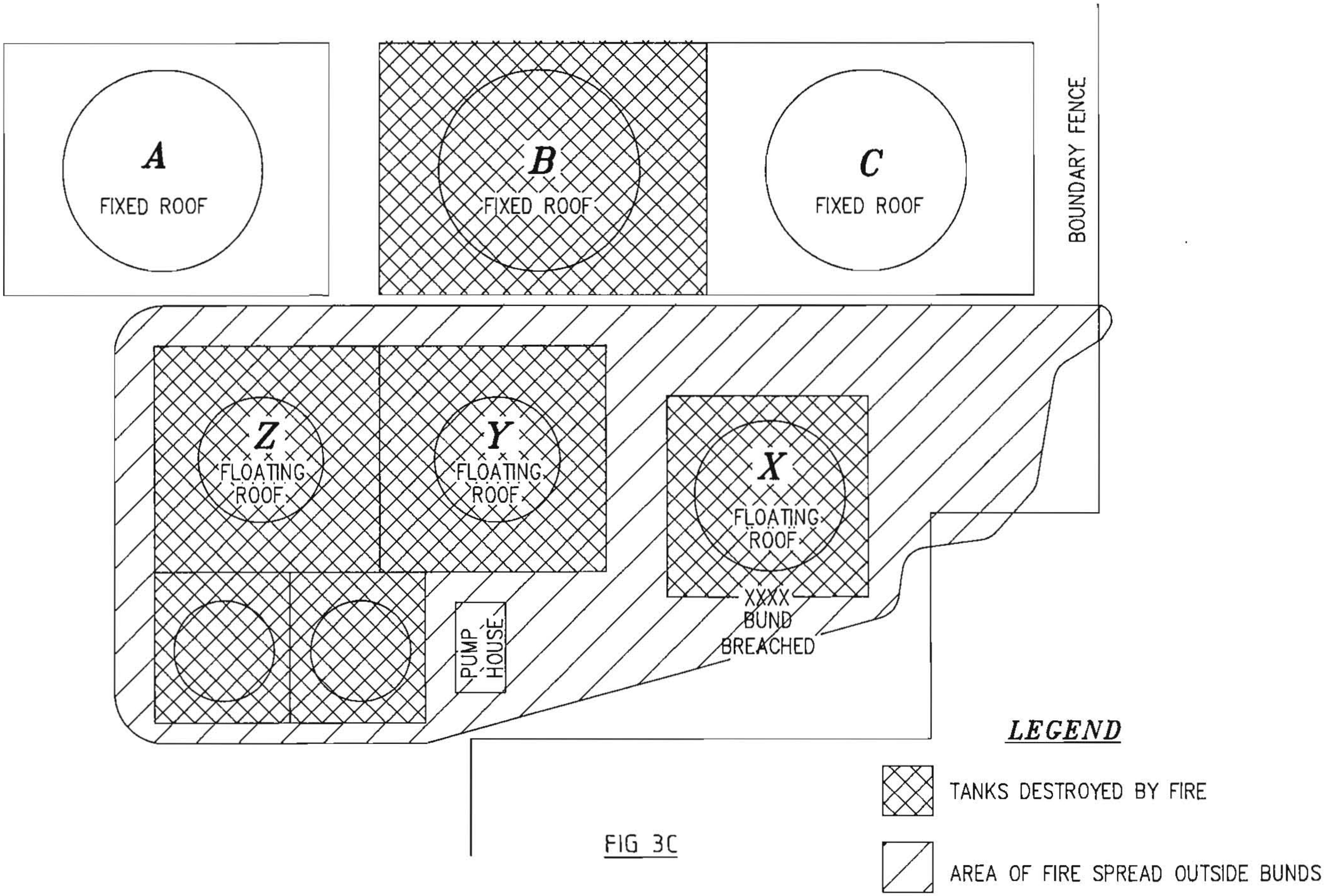


FIG 3C