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CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, CA

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

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**CARGO FIRE HAZARDS AND HAZARD CONTROL FOR THE
SUPPLEMENTAL FUEL SUPPLY ASSEMBLY (SFSA)**

August 1980

An Investigation Conducted by
ENERGY ANALYSTS, INC.
2001 Priestley Avenue
P. O. Box 1508
Norman, OK

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SECTION ONE

INTRODUCTION

The U. S. Navy is evaluating a Supplemental Fuel Supply Assembly (SFSa) as a temporary means for transferring fuel from supply ships to shore during the early phases of a conventional amphibious assault operation. The system addressed in this study consists of Dracone bladders and a float mounted pump moored offshore of the assault beach. Fuels would be transferred from the Dracone bladders through a buoyant fuel transfer hose line to beach storage facilities. An additional function of the SFSa is to support troops which relocate for one or two day intervals.

The use of the SFSa in these applications will eliminate the requirement for LST's to serve as fuel shuttles between deep-draft tankers and the offshore terminus of a fuel transfer line, or for LST's to moor at the terminus to offload fuel stocks carried to the area in their own tanks.

Whenever liquid fuels are being transferred, there is the potential for a spill. Spills of hydrocarbon fuels onto water can produce a serious fire hazard. If the SFSa is involved in a fire, the fire can do major damage to the Dracone bladders, the fuel transfer pump and the transfer hoses. Given the mission of the SFSa, the potential consequences of fuel spills and resulting fires are of major concern.

This study addresses the potential for fuel spills and fires resulting from the operation of the Supplemental Fuel Supply Assembly (SFSa). Estimates of the volume, location, and frequency of these fuel spills are given.

The capabilities of available equipment to limit the size of spills and to control fuel fires are discussed. Systems and procedures to detect and control fuel spills and fires have been identified.

Specific recommendations include:

1. Methods of spill detection.
2. Potential fuel spill fire hazards and the equipment and procedures needed to control these fires.
3. Methods for confining and/or dispersing fuel spills to minimize pollution hazards.
4. Required personnel training for operating spill control and fire fighting equipment.



SECTION TWO

DESCRIPTION OF SYSTEM CONFIGURATION AND PERFORMANCE REQUIREMENTS

This study is predicated on specific mission performance criteria, SFSA systems configuration, and applicable codes. The following presents a summary of these design constraints.

2.1 Mission Performance Criteria

Pursuant to the contract statement of work "Investigation of Fire Protection Requirements in the Amphibious Objective Area" Number 79-0021 and dated May 25, 1979, the Supplemental Fuel Supply Assembly should be designed for the following operating conditions:

1. Sea swell wave height of 6 feet with 18 second period.
2. Installation in sea state 3.
3. Operation in sea state 3, with winds to 15 knots, water currents to 4 knots.
4. Survivability against sea state 6, with winds to 48 knots and water currents to 4 knots, by retrieval when given 24 hours notice.
5. Storage in air temperature from -28° to 65°C.
6. Operational in all varied environmental conditions, from polar to tropical extremes.
7. Maximum fuel receiving rate = 2,000 gallons per minute per bladder, at 125 psi.
8. Maximum beach fuel delivery rate = generally 800 gallons per minute.
9. Connecting hose size = 6 inches.
10. Tanker to SFSA delivery hose size = 10 inches manifold to 6 inches.
11. Frequent make and break connections at the tanker and floating pump suction hose interfaces.
12. Service life expectancy = one year maximum.



2.2 SFSA System Configuration

The Supplemental Fuel Supply Assembly is being developed to provide a temporary means of supplying fuel to an amphibious assault operation for a period of about two weeks and to support troops that relocate for short intervals of one or two days. The basic components of this system consist of the following:

1. Three Type L Dracone bladders, each having 135,000 gallon capacity.
2. Three amphibious craft (e.g. LCVP, LCM6, LCM8, warping tug, powered causeway section, or a combination of these or similar craft).
3. One 6-inch diameter buoyant fuel transfer hose line 2,500 feet long in 50 foot sections, with separate floats, tension cable and anchors.
4. One two-point Dracone mooring, installed at the seaward terminus of the buoyant hose line.
5. Two single-point Dracone moorings for idle Dracones, located near the seaward terminus of the buoyant hose line; however, no mooring shall be closer than 1,000 feet from another Dracone mooring, and a clear 500 foot swing circle from any potential obstacle shall be provided.
6. One float-mounted electrically-powered pump, located at and attached to the seaward terminus of the buoyant hose line (30-40 hp, design flow rate of 700 gpm at 2,500 feet of 6-inch hose line, remotely powered and operated from a beach station including a generator and necessary power transmission cable).
7. Thirty to fifty feet of 6-inch fuel suction hose attached to the suction part of the float-mounted pump, to connect the floating pump and Dracone.

Figures 2.1 and 2.2 illustrate some of these components and show the conceptual layout of the system. In this arrangement, one Dracone is connected to the beach by a single 6-inch hose line. Given the system capacities, approximately 3 1/2 hours are required to transfer the contents of a full Dracone to the fuel storage facilities on the beach.

Since three fuels are to be handled by the system and since three Dracones are provided, we assume that each Dracone is to be dedicated to handling one type of fuel. Further, we assume for operational considerations, that once a Dracone is connected to the fuel transfer pump, it will remain in place until it is emptied.



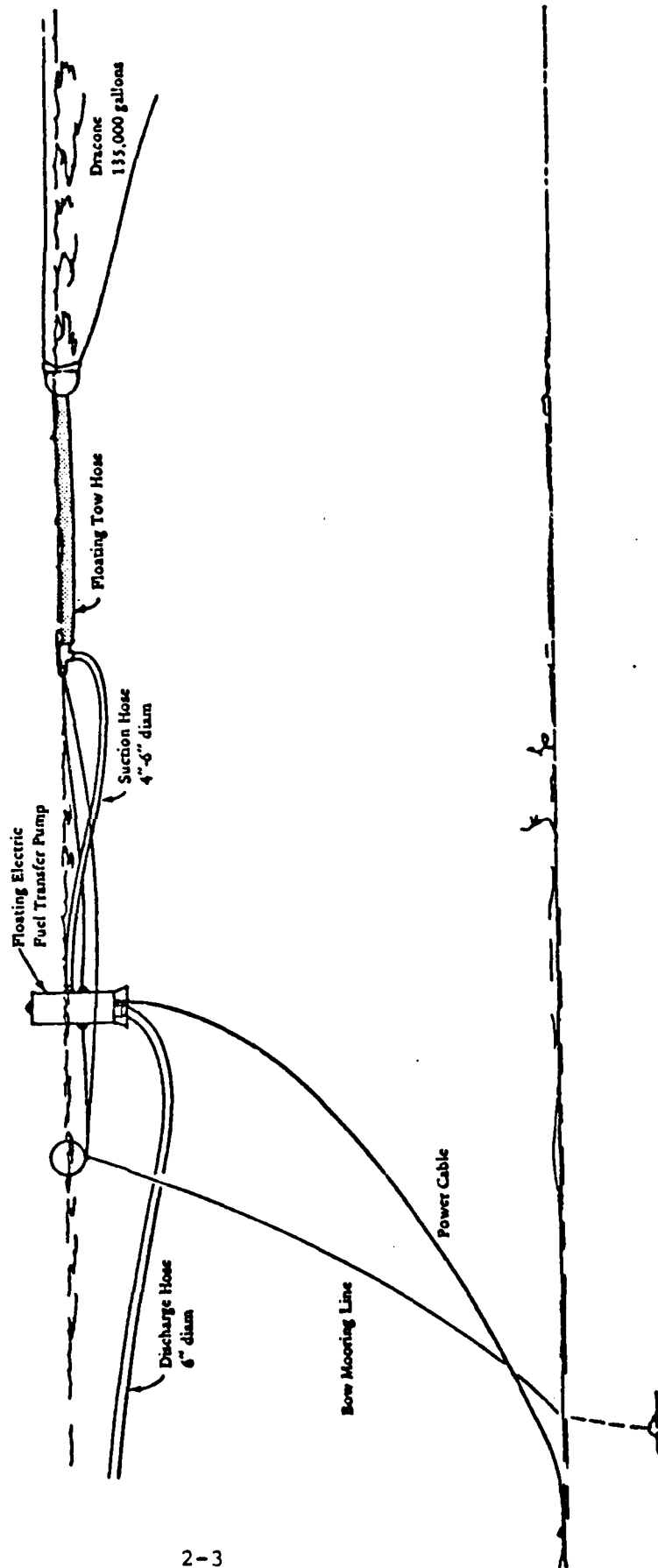


Figure 2.1. SFSA Components

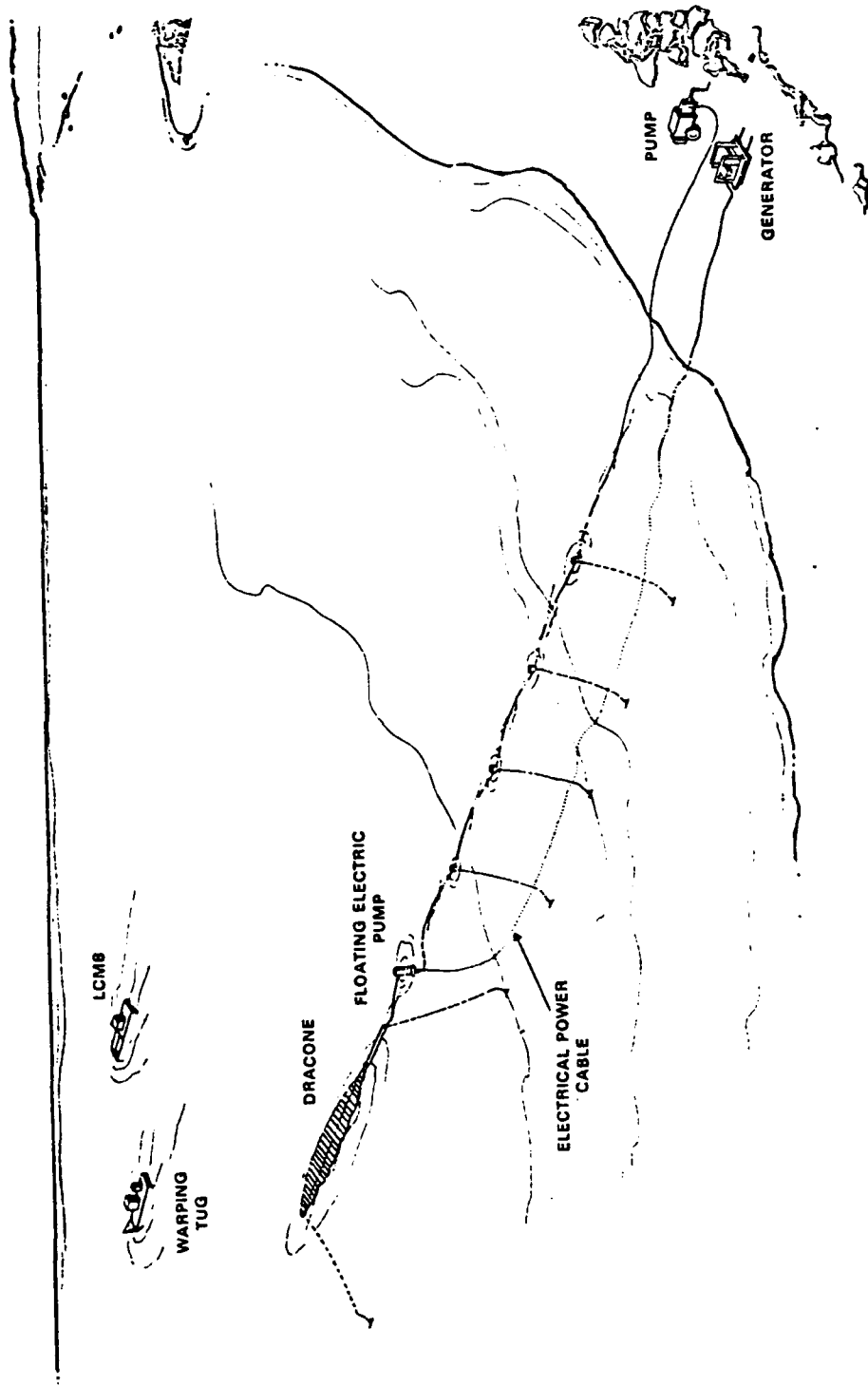


Figure 2.2. SFSA System Configuration

2.3 Special Considerations for Hoses

Hoses make up a substantial part of the SFSA and, in general, the hose assemblies are the weak links in the system. While the failure modes analysis does not predict high probabilities of failures involving hoses because of the short operating cycle, a hose testing and inspection program is highly recommended.

The Oil Companies International Marine Forum "Buoy Mooring Forum Hose Guide" [1] describes transfer hose inspection testing and inspection frequency. This body recommends that hoses be removed from service and subjected to extensive tests every six months and if the hoses are subjected to heavy weather, it is recommended that inspections be conducted every 3 months.

The following is reproduced from this document:

4.3 Hose Testing and Inspection

4.3.1 Pressure testing of the hose strings should be performed every three to six months depending upon environmental conditions at the buoy site. Testing after a very severe period of bad weather should be considered. Present or future governmental regulations may also require periodic testing. This test should consist of raising the internal pressure in the hose to its rated pressure or maximum operating pressure plus 50%, whichever is lower, preferably with water, and holding this pressure for a period of three hours. A visual inspection of all hose should be commenced after the pressure has stabilized. The visual inspection shall be as outlined in Section 4.0.

4.3.2 Testing as outlined below will be dependent upon the results of in situ and visual testing and inspection. However, as a minimum, it is suggested that all hoses be taken out of service and tested and inspected in accordance with the following criteria. (The frequency of testing will be dependent on time or throughput whichever occurs first and environmental conditions at the site).

TIME CRITERIA

Type of Hose Recommended	Period of Time
Floating	1/2 years
Submarine	1/2 years
Underbuoy	midway between buoy drydocking period- maximum of 3 years
Tanker Rail	6 months-1 year
First Off the Buoy	6 months-1 year



THROUGHPUT CRITERIA

Hose Nominal Inside Diameter	Throughput (Millions)		inches (mm)
	Barrels	Cubic Meters	
	30	(750)	225 36
24 (600)	150		24
20 (500)	100		16
16 (400)	75		12
12 (300)	50		8

4.3.3 Hydrostatic Test

4.3.3.1 Each hose shall be tested with water to pressure rating of the hose being tested. The procedure shall be as follows:

- (a) Lay out the hose as straight as possible on supports that permit the hose to elongate freely.
- (b) Fill with water, venting to remove all air and apply a pressure of 0.7 Bar (10 psi).
- (c) Measure the overall length of the hose assembly.
- (d) Increase the pressure over a period of 5 minutes, from 0.7 Bar (10 psi) to one half of the rated pressure; hold this pressure 10 minutes, then reduce the pressure over a period of 5 minutes to zero.
- (e) Raise the pressure over a period of 5 minutes to rated pressure and hold for 10 minutes.
- (f) Before releasing the full test pressure, measure the overall length of the hose assembly to ascertain the temporary elongation and record the increase as percentage of the original length measured at 0.7 Bar (10 psi).
- (g) Reduce the pressure over a period of 5 minutes to zero.
- (h) After an interval of at least 15 minutes raise the pressure again to 0.7 Bar (10 psi).
- (i) Measure the overall length of the hose assembly to ascertain the permanent elongation; record the increase as a percentage of the original length measured at 0.7 Bar (10 psi).

Test records should be kept of each hose so that the temporary elongation under pressure can be compared to the original test and subsequent routine tests. Discussions on suitable forms are noted in Paragraph 5.0.



When the field test temporary or permanent elongation of a hose exceeds the factory test temporary or permanent elongation respectively by 2% of the overall length, the hose should be retired from service.

4.3.4 Electrical Continuity Test

This test should be carried out on all hose removed from service for hydrostatic pressure tests.

For electrically bonded hose, continuity should exist during and after the hydraulic test. (See SPM Forum Hose Standards, Part A.6.1.3). For electrically discontinuous hose, the resistance between the end nipples of each length of hose shall not be less than 100,000 ohms.

4.3.5 Vacuum Test

This test should be carried out on hose removed from service for hydrostatic pressure tests.

Seal off both ends with transparent plexiglass plates of sufficient strength, using putty as a sealant or bolt up using a soft rubber gasket. One plate shall be fixed for connection to a vacuum source. Lay a flashlight in this end with its beam directed toward the opposite end. An inspection mirror using sunlight may also be manipulated from outside the plates to provide a proper light source.

Apply a vacuum of at least--510 millibar gauge (15 inches of mercury) and preferably--680 millibar gauge (20 inches of mercury) for a period of 10 minutes.

Inspect the interior of the hose for blisters or bulges. Blisters, bulges or separation of tube from carcass is reason to retire hose from service. Any tear, cut or gouge through the tube is reason to retire hose from service.

4.3.6 External Inspection

4.3.6.1 Covers

The rubber cover on the hose serves the primary function of protecting the reinforcement or the flotation material of the hose from damage. The cover should be cleaned and carefully examined to detect areas wherein reinforcement or flotation damage may have



occurred. Inspect hose cover for cuts, gouges, tears and abraded spots.

Any cuts, gouges or tears down to or through the cover breaker, but not into the outer reinforcement, should be repaired before hose is returned to service. Hose repair kits and repair instructions are available from hose manufacturers and should be provided with all new installations.

If reinforcement or flotation material is exposed, determine extent of damage by visual inspection at rest and under pressure. If damage is minor, repair and return to service. If damage is extensive, retire from service.

Covers may show surface cracking or crazing due to prolonged exposure to sunlight or to ozone. Such deterioration, which does not expose reinforcing or flotation material, is not cause for retirement. Localized areas of oil-softened rubber are cause for retirement.

4.3.6.2 Carcass

Look for crushed or kinked spots or broken reinforcement as evidence by any permanent distortion, longitudinal ridges or bulges. Hoses showing such defects shall be removed from service. Bulged areas shall be marked and examined again under pressure. If they become hard, indicating leaking tube or ruptured reinforcement, the hose shall be retired from service.

4.3.6.3 Fittings

Exposed surfaces of couplings, flanges and nipples shall be examined for cracks or excessive corrosion. Either condition shall cause the hose to be retired from service.

4.3.7 Internal Inspection

Wipe the inside of the couplings and nipples clean with a rag and examine with flashlight for cracks or excessive corrosion. Cracks or excessive corrosion shall cause the hose to be retired from service. Inspection shall be made of the interior for blisters, bulges or separation of tube from carcass. Any of the foregoing defects plus any tear, cut or gouge in the tube shall be cause for removal of the hose from service. For hose of sufficiently large bore, it is recommended that a man physically examine the full-length interior of the hose for soft spots. Any evidence of soft spots should result in the retirement of the hose from service. Appropriate safety precautions should be taken while conducting this inspection.



SECTION THREE

HAZARD IDENTIFICATION

The primary hazards associated with the operation of the SFSA are fuel spills and fuel fires that result if the spills are ignited. An analysis of the likely sources of fuel spills was conducted by considering component failure modes. Estimates of spill times were made by consideration of spill detection methods and the time required for spill isolation. This information was then combined to produce the estimated spill volumes.

3.1 Failure Mode Analysis

The primary hazards associated with operation of the SFSA are fires and pollution that result from fuel spills. In order to better understand the magnitude of these hazards, a failure mode analysis was conducted to identify the likely causes of fuel spills.

The principal causes of fuel spills associated with operation of the SFSA are:

1. hose leaks
2. gasket and seal failures, and
3. Dracone leaks.

These events can be caused by a variety of sources such as operational error, material failure, environmentally induced stress, and hostile action.

The component failure modes and associated leak rates are given in Table 3-1.

3.2 Estimation of Spill Volumes

The estimated spill volumes depend upon the type of component failure, the location of the failure, and the spill detection and isolation time. Estimated spill times for each spill situation can be combined with the spill rates to obtain estimates of the spill volumes that may be encountered during operation of the SFSA.

3.2.1 Spill Detection

Because of the operational environment and the relatively short operating cycle, (approximately 3 1/2 hours to transfer the fuel from a full Dracone to the beach), the best spill detection method is to utilize visual inspection by a manned small boat. This boat will continuously patrol from the Dracone to the beach. The estimated time for the



TABLE 3-1

Failure Modes and Associated Leak Rates

FAILURE MODE	LEAK RATE	REMARKS
1/8" diameter hose leak	2 gpm	
Small gasket or packing gland leak	9 gpm	Fuel transfer pump
1/2" diameter hose leak	27 gpm	
Hose failure	800 gpm	Fuel transfer line between pump and beach
Hose failure	900 gpm	Fill hose between Dracone and LST
Hose Failure	2000 gpm	Fill hose between Dracone and tanker



inspection tour from the Dracone to the beach is five minutes (assuming a boat speed of about five knots). This yields an expected time to detect that a fuel spill is occurring of five minutes. The estimated time to signal the beach to stop the fuel transfer pump is one minute and the additional time required to stop this pump is estimated to be one minute. This yields a total expected spill time of seven minutes. The estimated spill time for the hose failure (rupture) is five minutes because of the likelihood that a spill rate of this magnitude will be detected by beach personnel or by the boat patrol by means other than close visual inspection.

3.2.2 Spill Location

Hose leaks and/or ruptures can occur between the fuel transfer pump and the beach, between the Dracone and the fuel transfer pump, and between the Dracone and the supply ship when the Dracone is being filled.

The particular location of the leak and/or rupture will have an effect upon the size of the spill because of differences in the pumping rate and the amount of fuel in the hose sections that are affected.

Table 3-2 summarizes the failure modes, their location, and the expected spill volumes.

3.2.3 Spill Size

Several factors influence the estimate of the size of the spill. Obviously, the leak rate and the total spill time have a primary influence on the amount of fuel spilled. Additionally, the spill size will be effected by the volume of fuel in the appropriate hose sections. For example, in the event of a hose rupture between the fuel transfer pump and the beach the expected spill volume is calculated as 800 gpm times five minutes plus the contents of the entire 2500 ft length of the fuel transfer hose (3700 gal) for a total of 7700 gallons. On the other hand, the spill due to a leak in this line is estimated to be the leak rate times the spill time plus the contents of three of the 50 foot hose sections. This results from the assumption that the patrol boat crew will lift the affected section out of the water and thus prevent the loss of the entire contents of the hose.

During filling operations, the "T" fitting attached to the Dracone's towing suction hose will be lifted out of the water in order to mate the fuel supply ship's discharge hose with the "T" fitting. During filling operations, a lifting line should remain attached to the "T" fitting so that, in the event of a failure of the fuel ship's discharge hose, the towing suction hose can be lifted out of the water.



TABLE 3-2

Failure Modes and Expected Spill Volumes

FAILURE MODE	LEAK RATE	LOCATION	EXPECTED SPILL TIME	EXPECTED SPILL VOLUME
1. 1/8" diameter hose leak	2 gpm	Fuel Transfer Line Between Pump and Beach	7 min	235 gal
2. 1/2" diameter hose leak	27 gpm	Fuel Transfer Line Between Pump and Beach	7 min	400 gal
3. Hose failure	800 gpm	Fuel Transfer Line Between Pump and Beach	5 min	7700 gal
4. Small gasket/packing gland leak	9 gpm	Fuel Transfer Pump	7 min	130 gal
5. Hose failure	900 gpm	Fill Hose Between Dracone and LST	2 min	1850 gal
6. Hose failure	2000 gpm	Fill Hose Between Dracone and Tanker	2 min	4050 gal
7. 1/2" diameter hose leak	9 gpm	Suction Hose Between Dracone and Pump	7 min	135 gal
8. Dracone bladder failure	-	-	-	135,000 gal



This will limit the amount of fuel spilled as a result of the fuel hose failure. Fire water from the supply ship can be used to disperse the spilled fuel so that a boat can be dispatched to close the Dracone valve. The estimated spill time for this case is two minutes which when combined with a spill rate of 900 gpm and the volume of fuel in the fill hose yields an expected spill volume of 1900 gallons.

3.2.4 Summary of Spill Calculation Assumptions

1. Primary method of spill detection is by use of a manned small craft to patrol the SFSA assembly from Dracone to the beach.
2. A major failure of the Dracone bladder will result in the spill of its entire contents (approximately 135,000 gallons).
3. A hose failure between the Dracone and the beach will result in the spill of the entire volume of the hose (approximately 3700 gallons) after pumping is stopped.
4. A hose leak between the Dracone and the supply ship will result in the spill of the volume of the fill hose (approximately 50 gallons) after pumping is stopped.
5. A hose leak in the suction hose between the Dracone and the fuel transfer pump will result in the spill of the volume of the suction hose (approximately 75 gallons).

3.3 Probability of Fuel Spills

While the expected size of a spill given that a spill occurs is an important indication of the hazard associated with operation of the SFSA, this does not present the total picture. Another indication of the degree of the hazard is an estimate of the chance that spill of the types previously described will occur. An estimate of the chance of occurrence of these events is obtained by evaluating the probability of occurrence during the operating period of the SFSA of one or more of each of the failure modes given in Table 3-2. This information is summarized in Table 3-3.

The probability values shown in Table 3-3 indicate that the occurrence of spills from operation of the SFSA is not very likely. The probabilities of occurrence of these events are all approximately 0.01 or less. This is primarily due to the fact that the operating period requirement of two weeks is relatively short so that even the chance of hose leaks and ruptures is not too likely.

A major failure of a Dracone bladder will result in a spill volume that is significantly larger than spills that are likely to be produced from other sources. The chance of this occurring in other than a warfare condition is judged to be so remote as to effectively exclude this



TABLE 3-3

Failure Modes and Probabilities

FAILURE MODE	LOCATION	PROBABILITY OF FAILURE
1/8" diameter hose leak	Fuel Transfer Line Between Pump and Beach	.013
1/2" diameter hose leak	Fuel Transfer Line Between Pump and Beach	.01
Hose failure	Fuel Transfer Line Between Pump and Beach	.0067
Small Gasket or Packing Gland Leak	Fuel Transfer Pump	.001
Hose Failure	Fill Hose Between Dracone and Tanker	.0067
Hose Failure	Fill Hose Between Dracone and Tanker	.0067
1/2" diameter hose leak	Suction Hose Between Dracone and Pump	.01
Dracone Bladder Failure		<.001 (estimate)



event from consideration as a reasonable spill producing event. This judgement has been verified by the Dunlop Limited representative in the US who reports many years of trouble-free service from Dracone bladders when handled with reasonable care. However, in time of war, Dracone bladder failure could occur as a result of hostile action. Under these circumstances, the profile of the Dracone in the water probably makes it a difficult target for attack by a conventional weapon fired from the beach or aircraft. A more likely source of damage would be from a water based attack either by small boats or swimmers. Assuming that the amphibious operating area is a relatively secure area, damage to the Dracone from hostile action is not very probable.



SECTION FOUR
SPILL HAZARD CONSEQUENCES

In the previous section of this report, the potential for spills from the SFSA have been identified. In this section of the report, the potential for an ignition of a spill is discussed and the consequences of the spills are quantified.

4.1 Ignition Sources

The potential for ignition subsequent to spills of a flammable fuel depends on many factors including the following: volatility of the fuel, amount of fuel spilled, location of ignition sources, environmental conditions at the time of the spill, and spill control procedures utilized.

Table 4-1 presents the flash ignition temperatures of the candidate fuels for the SFSA. The lower the ignition temperature, the easier the fuel is to ignite. Both motor gasoline and JP-4 have a flash ignition temperature that is below ambient in most climates. Thus, these fuels are easily ignited by common ignition sources; match, spark, etc. Diesel and JP-5 have flash temperatures above ambient and are more difficult to ignite than gasoline or JP-4. In fact, it is difficult to ignite diesel or JP-5 with a single match.

Many possible ignition sources exist for a fuel spill fire, but the most common sources are: static electricity discharge; electrical wiring and equipment sparks; and work crews in the area. Of the many possible causes of static discharges, the least recognized cause is due to the streaming potential of the flow of a low dielectric material through a nozzle.

If a fuel release occurs due to either collision or hostile action, the probability of ignition is very high. Ignition can be caused by the energetics of either the collision or hostile actions. Further, either of these release mechanisms could also result in shorting of electrical cables which could also result in ignition of spilled fuels.

In summary, we estimate the probabilities of ignition of a spill in a qualitative manner as follows:



TABLE 4-1
FLASH IGNITION TEMPERATURES

<u>Fuel</u>	<u>Flash Temperature</u>
Diesel (Arctic Formulation)	38°C (100°F)
DFM	60°C (140°F)
JP-5	35° to 63°C (95° to 145°F)
JP-4	-23° to -1°C (-10° to + 30°F)
Motor Gas	-43°C (-46°F)



Fuel Type	Release Mechanism	Ignition Probability
All fuels	Collision/hostile action	High
Motor gasoline, JP-4	Dracone leak and/or hose release	50/50
Diesel, JP-5	Dracone leak and/or hose release	Low

4.2 Spill Fire Consequences

For any fuel release, there is a possibility that the spill will be ignited. The resultant fire could damage or destroy the SFSA pumping equipment or other bladders in the area due to direct flame contact. Damage may also occur to objects outside the flame due to the incidence of thermal radiation from the fire.

A pseudo-theoretical approach based on radiative heat transfer has been developed to calculate heat radiation levels downwind of a fuel fire. The radiant heat flux from the fire can be computed from the radiant flux at the flame surface and the view factor between the flame and the exposed object. This is given by:

$$q = F\tau q_{sm}(1 - e^{-bD})$$

where: q = the incident radiant flux at any point
 q_{sm} = maximum surface flux of the flame for a large fire
 F = the geometric view factor
 D = fire diameter
 b = extinction coefficient related to the absorption of radiation within the flame
 τ = atmospheric transmissivity

The maximum surface flux for gasoline, diesel and jet fuel were approximated to be 35,000 BTU/hr-ft², 27,000 BTU/hr-ft² and 35,000 BTU/hr-ft², respectively. The extinction coefficients for each fuel were estimated to be 0.055 ft⁻¹. The view factor is dependent on the size of the fire, the relative orientation and distance between the fire and the exposed object. Detailed calculation models for view factors are available from literature sources. [2,3]



Flame size is the combination of pool diameter and flame height. The flame height can be calculated from the equation given by Thomas [4]:

$$L = 42(D)[Q/\rho_a(gD)]^{1/2} 0.61$$

where: L = length (height) of the flame
 D = diameter of the pool
 Q = mass burning rate
 ρ_a = air density
 g = gravitational acceleration

Linear burning rates for gasoline, diesel and jet fuel are all approximately 0.25 in/min.

Large buoyant flames can be strongly affected by winds. The wind tilts the flame with an angle that can be computed by the equation given by Welker and Sliepceovich [5]:

$$\frac{\tan\theta}{\cos\theta} = 3.2 \left(\frac{Du\rho_a}{\mu_a} \right)^{0.07} \left(\frac{u}{Dg} \right)^{2.07} \left(\frac{\rho_g}{\rho_a} \right)^{-0.6}$$

where: θ = angle of tilt of the flame (measured from the vertical)
 D = flame diameter
 u = wind speed
 μ_a = viscosity of air
 ρ_a = density of air
 ρ_g = density of fuel vapors
 g = gravitational acceleration

Water vapor in the air reduces the incident radiant flux on a target by absorbing some of the radiant energy. The amount by which the flux is reduced depends on the relative humidity and the separation distance between the target and the flame. Therefore, the incident radiant flux on a given point from a given fire decreases as the relative humidity increases.

Energy Analysts has built into its fire radiation computer program all of these factors. Table 4-2 is a reproduction of the typical computer output for the fire radiation program. The symbols in the table identify the following:

XPLUS - Fires exposed to wind become elliptical in shape at their base. XPLUS is computed to assure that the fire radiation calculations start outside the fire as the geometry of the fire base changes with wind speeds



```

*****
* ENERGY ANALYSTS, INC. COMPUTER ANALYSIS *
* P.O. BOX 1508 *
* 1215 WESTHEIMER DR *
* NORMAN, OKLAHOMA 73069 *
*
* FIRE-RAD FIRE RADIATION MODEL *
*****

```

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---- CASE NUMBER 4 ----
---- DS422

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```

INPUT DATA :
FUEL IS DIESEL
WIND SPEED IS 29.3 FT/SEC
                20.0 MPH
FLAME DIAMETER IS 100.0 FT
TARGET HEIGHT IS 0. FT
MASS FLUX IS .01840 LB/SEC-FT-FT
MASS RATE IS 144.51 LB/SEC
PIPE/POOL DIAMETER IS 100.00 FT
PERCENT HUMIDITY IS 50.00
AMBIENT TEMPERATURE IS 70.00 DEG F
BLACK BODY FLAME TEMPERATURE IS 1610.0 DEG F

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```

COMPUTED DATA : BENDING ANGLE IS 53.7 DEGREES
FLAME HEIGHT IS 145.5 FT
SURFACE FLUX IS 26889.7 BTU/HR-FT*FT
PARTIAL PRESSURE H2O IS .0126 ATM
MINIMUM XT IS 60.0 FT

```

XT (FT)	Q(VERT) (*****)	Q(HORIZ) BTU/HR-FT*FT	Q(MAX) *****	QACTUAL	THETAMAX (DEGREES)
104.49	11589.9*	18275.7*	21640.9	16693.1	57.6
156.74	7926.6	10975.7	13538.7	10028.1	54.2
235.11	4725.3	3241.1	5730.0	4061.4	34.4
352.67	1469.6	393.5	1521.4	1029.5	15.0
529.00	460.3	60.1	464.2	299.8	7.4
793.51	166.1	12.1	166.5	102.9	4.2
1190.26	65.1	2.9	65.1	38.6	2.5

* MIGHT BE UNRELIABLE

TABLE 4-2

Fire Radiation Model Computer Output

- TARGET HEIGHT - Height of target relative to the base of the flame
- XT(FT) - Separation distance from target to center of fire
- Q(VERT) - Computed radiant heat flux on a vertical target
- Q(HORIZ) - Computed radiant heat flux on a horizontal target
- Q(MAX) - Computed radiant heat flux for a target rotated such that it receives the maximum possible radiant heating
- Q ACTUAL - Q(MAX) corrected for humidity in the air

The footnote on the table indicates the target is at or near the edge of the fire and could be engulfed in the fire.

Fire radiation calculations have been made for the various sizes of fuel spills on water.

4.2.1 Fires Subsequent to Spills on Water

Heat radiation profiles subsequent to fuel spills onto water have been calculated for spill diameters of 50, 100, 200 and 500 feet. Table 4-3 presents key radiant heat flux isopleth distances for targets at grade. The key radiant heat flux levels correspond to the following damage potential:

- ° 1600 BTU/hr-ft² - bare skin will sustain second degree burns in 30 seconds.
- ° 4000 BTU/hr-ft² - minimum for ignition of most combustible materials.
- ° 10,000 BTU/hr-ft² - potential equipment damage.

From the table, it can be seen that personnel will have difficulty approaching these fires for manual fire fighting purposes. The only possible way this approach could be made is from the upwind side of the fire. The specification that no bladder mooring will be located closer than 1000 feet from another mooring will probably be acceptable from a fire exposure standpoint for a short duration since the 4000 BTU/hr-ft² level occurs at a distance less than 1000 feet. It is our recommendation that a moored Dracone full of fuel which is exposed to a fuel spill fire should be removed to a temporary safe location as quickly as possible. It should be noted that personnel involved in this relocation task should be provided full fire exposure protective equipment. Full fire exposure protective equipment should include a coat, gloves and boots designed to protect fire fighting personnel from fire exposure. The protective equipment should also include an impact resistant helmet with a radiant heat reflecting face shield.



TABLE 4-3

HEAT RADIATION ISOPLETHS (ft) OF SPILLS ON WATER (FOR TARGET HEIGHT = 0ft)

	<u>1,600 BTU/hr-ft²</u>			<u>4,000 BTU/hr-ft²</u>			<u>10,000 BTU/hr-ft²</u>		
	0mph	20mph	40mph	0mph	20mph	40mph	0mph	20mph	40mph
<u>Gasoline</u>									
Dia. 50 ft	135	175	200	79	140	180	41	110	160
100 ft	250	320	340	150	240	290	80	180	250
200 ft	450	550	580	270	410	480	160	290	410
500 ft	1000	1120	1180	630	750	900	360	540	740
<u>Diesel Fuel</u>									
Dia. 50 ft	123	175	195	69	138	170	32	94	140
100 ft	230	310	340	130	235	285	66	155	225
200 ft	410	540	580	240	400	470	130	260	360
500 ft	880	1080	1200	540	740	940	190	450	660
<u>Jet Fuel</u>									
Dia. 50 ft	135	180	200	80	145	180	41	110	160
100 ft	265	320	350	155	250	295	82	175	250
200 ft	470	560	600	280	430	510	160	300	410
500 ft	1000	1200	1200	630	820	960	360	540	730



SECTION FIVE

HAZARD CONTROL RECOMMENDATIONS

In Section Three of this report, the spill hazards were identified by type of failure and the probability of each type of spill was estimated. Also, in that section, an attempt was made to estimate the quantity of fuel that would be spilled. The probability of individual spills was found to be low, principally because of the short expected duration of operation of the SFSA. This section will deal with our recommendations for handling the consequences of fuel spills should they occur.

5.1 Spill Detection

Generally, the detection of fuel spills may be accomplished by manually patrolling and watching or by remote detection devices. The remote spill detectors can be classified according to their operating mode into direct and indirect detectors. Direct detectors are usually buoy-mounted and in direct contact with the marine environment. The fuel spill is detected due to a change of certain physical responses of the detector in the presence of fuel in the water. Surface characteristics of sea water would change if oil is spilled on water and could be detected by indirect detection. Infrared or ultraviolet light sources can be used.

There are several types of commercial spill detectors available. The use of the indirect scanning detector is dependent on the mounting of a light source and a receiver. The configuration of the SFSA is not such that the source and receiver can be easily mounted appropriately for use of this type of detector. Sunlight reflection from the water can cause stray signals to indicate the presence of fuel when it is not there.

The direct buoy mounted detectors are very localized detectors. The only way complete and dependable detection can be accomplished with this type of detector is with large numbers of sensors strategically located. Several of these detectors require daily checks of alarm fuses to assure continued detector operation. We have been advised by manufacturers and those familiar with the use of these detectors that these devices will not survive in the sea state specified in the Statement of Work for this project.

Based upon our analysis of spill scenarios presented in Section Three and the disadvantages with spill detector use in this application, we strongly recommend the use of a continuous roving watch in a small boat to assist with spill detection. The primary function of this watch is to detect those small leak rate component failures that can produce large spill volumes if they go undetected for appreciable periods of time.



For the SFSA, the roving watch is to conduct an inspection of the idle Dracone mooring locations and then travel along the path of the hose to shore and return along the hose. As discussed in Section Three, at a 5 knot patrolling speed, it is estimated that it will take about 10 minutes to make a complete round trip tour. This roving inspection is to be conducted continuously while fuel is being transferred from the SFSA, except during the short time while the watch is being changed. Section Three deals with the estimated spill volumes based on this patrol scheme. The idle Dracone mooring area should be patrolled every hour.

In order to assist in ensuring that the roving boat watch is making its inspection in the prescribed manner, it is recommended that the patrol boat make radio contact with the shore personnel responsible for monitoring the Dracone operation at the beach station. This contact should be made at approximately 15 minute intervals and the boat location and the patrol party's current activity should be reported.

Assistance in the detection of a rupture of the fuel transfer hose could be accomplished by installing a pressure sensor in the discharge hose of the pump. We do not believe the additional instrumentation arrangements this would require are justified by the small improvements in detection time expected for the pressure sensors. We believe that personnel on the beach should be responsible for monitoring shore fuel storage level and that unexplained irregularities in this level should be investigated.

5.2 Fire Detection

Consideration was given to equipment which could be utilized in addition to the roving boat watch for spill fire detection. Fire detector types for possible use include ultraviolet sensors, rate-of-temperature-rise sensors, and high temperature sensors, e.g., thermistors. Ultraviolet sensors detect the presence of larger than normal amounts of ultraviolet radiation when a flame is present. They are in common use in many petroleum facilities. These sensors have had trouble in the past differentiating between fires, lightning, arc welding and sunlight reflection off the water.

Rate-of-temperature-rise, high temperature and thermistor detectors are seldom used in petroleum facilities because their location with respect to the fire is too critical. Consideration was given to the use of high temperature detectors for fire detection, but the manufacturers of these detectors do not recommend their use outdoors. We believe that the roving boat watch is the most reliable way of achieving fire detection.



5.3 Fuel Spill Isolation and Control

The isolation and containment of fuel spills is generally essential in order to limit the hazards of environmental pollution and fire associated with an offshore fuel storage arrangement like the SFSA. Systems and procedures for rapidly suspending fuel transfer operations when a spill is discovered and for controlling the results of an unignited spill will be discussed in this section.

5.3.1 Emergency Shutdown

When a spill producing event has occurred, one of the most important procedures to follow is to stop the fuel flow as quickly as possible. The Statement of Work for this project specifies that the SFSA pumping system will be operated from a beach station. In the event that a fuel spill is suspected by the each station operating personnel, they should immediately suspend fuel transfer operations and notify the roving boat patrol to verify the spill condition. If, on the other hand, the roving boat patrol discovers a spill, they should notify the beach station personnel to suspend pumping operations immediately.

5.3.2 Fuel Spill Containment and Recovery

Containment is a way of immediately controlling the consequences of a fuel spill. The purpose of containment is to localize the spill, thus minimizing the extent of pollution and to attempt to concentrate the spill into a thicker layer so as to make removal easier. Applicable containment methods include commercial floating booms, sorbent booms and barriers, air or water streams, bubble barriers and chemical barriers. Each of these systems is limited by environmental factors, such as wind, current and tide. Most of the time, booms are applicable in inner harbor or inland waterways. Unless the sea is calm, containment is usually ineffective and equipment will probably be destroyed. We have been advised by those knowledgeable in the pollution control field that at water currents of about 1 1/2 knots, the booms become ineffective as a containment means and that the resultant strain on them will cause them to be destroyed.

Due to high volatility and very low flash point, spills of gasoline and JP-4 are very hazardous. Aging is required until the spill area has been declared to be nonhazardous by a safety officer using combustible gas detectors.

Recovery of crude oils is usually accomplished by using skimmers or sorbents or by manual recovery. Each of these methods can be used to a certain extent as the cleanup operation progresses, and each has



specific limitations depending on geographic location, quantity of the spill, the properties of the fuel and ambient climate conditions.

A skimmer is a mechanical device designed to remove oil from the water surface without causing major alterations in its physical or chemical properties. They can be classified according to their operation principals into five categories:

1. weir-type devices
2. suction devices
3. centrifugal devices
4. submersion devices, and
5. sorbent surface devices.

The effectiveness of any skimmer depends on a number of factors including the type of oil spilled, the thickness of the spill, the presence of debris, the location of the spill, ambient climate conditions and calmness of the sea. A thorough knowledge of the advantages, limitations and applicabilities of the available skimmer systems is required to select a suitable skimmer system.

Sorbents are any materials which will recover oil through either absorption or adsorption. There are three basic classes of sorbents:

1. natural organic materials such as hay, straw, peat moss and sawdust
2. mineral-based materials such as vermiculite, perlite and volcanic ash, and
3. synthetic polymeric sorbents, such as polystyrene, polyurethane, polyester foam and rubber.

Sorbents are manufactured in three forms: granular, mat and sorbent boom. The most effective sorbent is polymeric foam, plus it can be reused after the fuel is squeezed out. Generally, sorbents do not play the primary role in oil spill cleanup operations and are most commonly used for final cleanup of trace amounts of oil or to remove oil from areas which are inaccessible to skimmers.

Manual recovery of oil with buckets, shovels and similar equipment is frequently used for small spills which occur in ports and rivers or near populated areas. Available manpower and disposal facilities are the limiting factors in manual recovery.

An appropriate recovery approach may require the use of these methods individually or simultaneously, or in sequence. This may be different for each individual spill incident.



It is our belief that the method of spill management should be appropriate to the use of the SFSA. If the SFSA is being used in a training deployment in any U.S. navigable waters, the spills occurring during this deployment will fall under the jurisdiction of the "National Oil and Hazardous Substance Pollution Contingency Plan", dated March 1980 [6]. The Regional Response Team and Contingency plan established for the region of interest under the regulation will be applicable. The on-scene coordinator will be responsible for the decision of how the spill should be handled. It is also our understanding that specified US Navy commands are responsible for preparing contingency plans for controlling fuel spills in specific areas.

The plans will specify the procedure to be followed for spill management in the training deployment. However, we believe that the methods to be described for spill management for nontraining deployment are also appropriate for training deployment. If the SFSA is part of an actual amphibious assault operation, we believe the approach to spill management should follow the outline described below.

The difficulty in using fuel containment booms in the operational sea states specified for this project, the necessity to allow spills of gasoline and JP-4 to age prior to any attempts to cleanup these spills and the possible enemy action in the area do not make spill containment and cleanup desirable. The low surface tension of gasoline, JP-4 and JP-5 and the moderate surface tension of marine diesel lead to relatively rapid spreading of these fuels when spilled. This rapid spread makes confinement difficult. For these rapidly spreading fuels, by the time fuel containment has been accomplished, the fuel spill will be very thin. Combining this fact with the need to allow volatile fuels to age prior to spill cleanup causes any attempt to cleanup these spills to be very inefficient. Because of this, we do not recommend that attempts be made to confine the spill for cleanup purposes.

We recommend that the spill be allowed to spread to as large an extent as judged safe by the officers in charge. This spreading will increase the spill surface area which will enhance spill dispersal; thus, reducing the probability of ignition and further complications.

Dispersal can be aided by agitating the spill. This agitation can be accomplished with the use of fire water monitor nozzles on a utility/fire boat to be discussed in the next section. Fire water nozzles available for the craft used to fill the Dracones can also be used for spill control purposes should a spill occur while the Dracone is being filled.

It is important that attempts be made to keep the spreading fuel spill from reaching the beach. This restricted spreading can be accomplished by directing spill movement with the use of the same fire water monitor nozzles mentioned earlier for spill agitation. In order to direct the spill movement, the utility/fire boat will need to be positioned between the spill and the beach. Care must be taken to



ensure that the boat is not located in such a way as to become an ignition source for the spill. The general capabilities of the fire/utility boat will be discussed in Section Six.

The fire water monitor nozzles on the fire/utility boat can also be used for fire exposure protection to exposed equipment and personnel. There may be a need to direct a burning spill away from manpower and/or equipment using fire water streams in a similar manner as when directing unignited spills. These streams, operated in a fog mode, may be used to protect personnel as they attempt to tow a fire exposed Dracone to safety. We do not recommend fighting a fire which does not expose manpower or equipment because the combustion of the fuel spilled is a quick means of spill removal if control of the fire is maintained.



SECTION SIX

MANPOWER AND EQUIPMENT REQUIREMENTS

The equipment requirements which will be recommended for the hazard control in this project are not numerous. The only equipment which is recommended is a fire/utility boat. The purpose of this boat can be fulfilled by modifying one of the three amphibious craft already assigned to the project as discussed in the Statement of Work for this project. The requirement for the utility/fire boat could also be fulfilled by purchasing a dedicated service craft appropriately designed.

The utility/fire boat should have capabilities for lifting sections of hose out of the water to control spills as discussed in Section Three. The utility/fire boat should have at least two search lights for assistance in night spill detection. We believe that the boat should have about 2,000 gpm of pumping capacity piped to two fire water monitors. We believe this pumping capacity should be portable so that it can be transferred to another utility boat if one is out of service. The alternative to this is to provide two utility/fire boats.

The fire water pumping capacity can be provided by a number of "portable" systems. These systems vary widely in cost and weight. The only system known to be portable in a "off-the-shelf" availability is the Firefly Self-Contained Firefighting Module, manufactured by:

Aviation Power Supply, Inc.
3111 Kenwood Street
Burbank, CA 91505
(213) 842-5207

The Firefly I self-contained module is equipped with 6-10 sections of 8 feet long, 6 inch diameter suction hose, 2 floating suction strainers, 4 sections of 50 feet length, 5 inch diameter hose and 2 portable deluge monitors with nozzles. The fire pump is a gas turbine driven two speed, two stage, high suction lift pump of 2000 gpm capacity at 150 psi pressure. The module can hold about 4-5 hours of diesel fuel. The unit occupies a volume of 162.5 ft³ and weighs about 2600 pounds. The cost of the unit is about \$245,000.

Portable water pumping units could also be provided by such companies as:

Viking America, Inc.
Post Office Box 897
Montrose, CA 91020
(213) 249-2038



These units would probably cost about \$100,000, and would weigh between 10,000 and 15,000 pounds. The weight of these units is a disadvantage and must be evaluated in terms of the vessels available for this service, and the means available for transfer of the unit between vessels should that be necessary.

The details of arrangement of the unit and the monitor nozzles in the vessel to be used will be a matter which must be evaluated once the specific units to be available for this service are determined.

Manpower and Training

The systems recommended in this report for fuel spill containment and fire suppression require a minimum of additional manpower. The self-contained firefighting module recommended for installation on one of the SFSA service craft will require at most two additional boat crew members.

All members of the boat crews should be trained in standard US Navy firefighting procedures. These personnel should receive the training available at one of the US Navy firefighting schools. Additional training in fuel spill containment and dispersal should be provided for all boat crew personnel. Operators of the self-contained firefighting module should receive a formal course of instruction from the equipment manufacturer. This course should include both operation and maintenance procedures and should be approximately one week in duration.



SECTION SEVEN

Reliability and Availability Analysis

Figure 7-1 shows the block diagram for analysis of reliability/availability of the SFSA fuel system. The system can be considered to consist of four components; the Dracone, the suction hose, the electric pump and the discharge hose. The component reliability and availability are given by:

$$R = e^{-\lambda t} \quad \text{and} \quad A = \frac{MTBF}{MTBF + MTTR}, \quad \text{respectively.}$$

Where:

R = Reliability

A = Availability

λ = Failure rate

t = Time of use, 336 hours

MTBF = Mean time between failure

MTTR = Mean time to repair

The reliability of this system can be expressed as:

$$R_S = R_D R_{SH} R_{EP} R_{DH}$$

Where:

S = System

D = Dracone

SH = Suction hose

EP = Electric pump

DH = Discharge hose

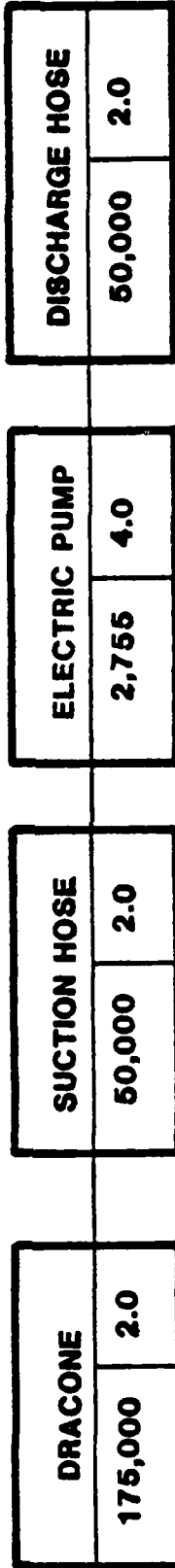
Each component reliability is given as:



Figure 7.1

SFSA RELIABILITY/AVAILABILITY

BLOCK DIAGRAM



$$R_D = e^{-(.0000057)(336)} = .998$$

$$R_{SH} = e^{-(.00002)(336)} = .993$$

$$R_{EP} = e^{-(.00036)(336)} = .886$$

$$R_{DH} = e^{-(.00002)(336)} = .993$$

Therefore:

$$R_s = (.998) (.993)^2 (.886) = .87$$

and the system reliability requirement of 85 percent is satisfied.

In a similar manner, system availability is given by:

$$A_s = A_D A_{SH} A_{EP} A_{DH}$$

Component availabilities are:

$$A_D = \frac{175,000}{175,002} = .99999$$

$$A_{SH} = A_{DH} = \frac{50,000}{50,000} = .9996$$

$$A_{EP} = \frac{2755}{2759} = .9986$$

Therefore, the availability of the fuel system is:

$$A_s = (.99999) (.9996)^2 (.9986)$$

$$A_s = .9985$$

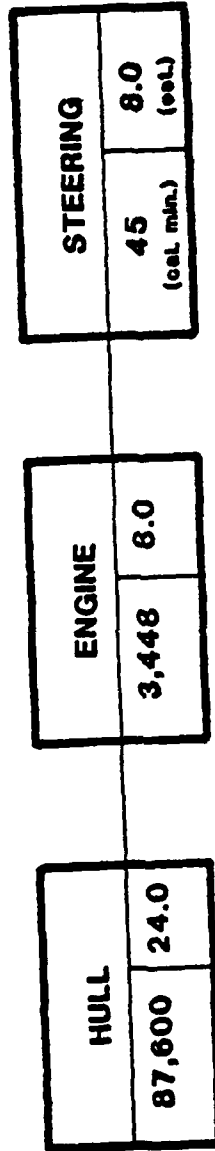
which clearly exceeds the system availability requirements of 85 percent.

The patrol craft to be used to patrol the SFSA fuel assembly area for spill detection and control can be represented for reliability/availability purposes as consisting of three systems. These are 1) hull, 2) engine, and 3) steering system, shown in the block diagram in Figure 7-2. Data describing the mean time between failures (MTBF) and mean time to repair (MTTR) for small boat hulls is not easily obtained. Since boat hulls are static devices and under normal operations are not subject to conditions that would cause failures, it will be conservatively assumed that the MTBF and MTTR data is ten years and one day (assumes transfer of equipment to another boat), respectively. MTBF and MTTR data for diesel engines given in Tables 8-3 and 8-4 of the report "Cargo Fire Hazards and Hazard Control for the Offshore Bulk



Figure 7.2

PATROL CRAFT RELIABILITY/AVAILABILITY BLOCK DIAGRAM



Fuel System" are used for the small boat engines. These data for small boat steering systems are also not easily obtained. This will be handled by calculating the worst case MTBF that could be allowed for the steering system and still meet the reliability and availability criteria for the system.

The steady state availability can be calculated as follows:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

$$A_H = \frac{87,600}{87,624} = .9997$$

$$A_E = \frac{3448}{3456} = .9977$$

Where:

H = Hull

E = Engine

For a required system availability of 0.85, we have:

$$A_{\text{sys}} = A_H A_E A_S$$

$$A_S = \frac{0.85}{(.9997)(.9977)} = .8522$$

Where: S = Steering and sys = System

If we estimate the MTTR for the steering system to be approximately 8 hours, i.e. the same as for the engine, then:

$$.8522 = \frac{\text{MTBF}_S}{\text{MTBF}_S + 8}$$

$$\text{and: } \text{MTBF}_S = 46 \text{ hours}$$

This calculation indicates that the mean time between failures for the steering system could be very short and still allow the system meet the availability requirements.

The system reliability requirements can be used to determine the necessary MTBF for the steering equipment. This is accomplished by noting that the required system reliability is 0.85 and that:

$$R_{\text{sys}} = R_H R_E R_S$$

$$R_S = \frac{0.85}{R_H R_E}$$



$$\text{and } R_H = e^{-\lambda_H t} = e^{-(.0000114)(336)} = .9962$$

$$R_E = e^{-\lambda_E t} = e^{-(.00029)(336)} = .9072$$

$$\text{Now, } R_S = e^{-\lambda_S t} = \frac{.85}{(.9962)(.9072)} = .9406; \text{ therefore,}$$

$$\lambda_S = 1.82 \times 10^{-4}$$

$$\text{and MTBF} = \frac{1}{\lambda_S} = 5495 \text{ hours}$$

Therefore, for reliability considerations, the mean time between failure for small boat steering systems must be greater than that determined by the availability requirement. This MTBF of 5495 hours is not an exceptionally long time for equipment of this type. Based upon this analysis, we believe that the use of a manned small boat for spill detection and control will not violate the reliability and availability requirements for the SFSA.



SECTION EIGHT

SUMMARY

A series of hazards associated with the operation of the SFSA have been identified. These hazards result primarily from fuel spills and fuel fires that result when these spills are ignited. Spills are important because of the pollution that may result and because of the potential for fires that may destroy equipment and pose a danger to personnel.

An analysis of the probabilities of occurrence of the various spill producing events shows that because of the relatively short operating period, spills are not very likely to occur.

The type of fuels that are being handled are such that if a spill does occur, the fuel tends to spread rapidly on the surface of the water; therefore, confinement of these spills by booms and subsequent cleanup does not appear to be practical.

Consequently, based upon these findings, we recommend the following actions:

- The use of a manned small craft to patrol the SFSA from Dracone to the beach to assist in spill detection.
- Installation of a portable fire fighting system on the patrol craft to assist in spill confinement and dispersal and fire fighting.
- Standard US Navy fire fighting training be provided for all SFSA support craft personnel. Special fuel dispersal training and portable fire fighting system training should be provided for all system operators.



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