REGIONAL STUDY OF MILITARY BULK POL DISTRIBUTION SYSTEMS AND STORAGE FACILITIES, HAWAII
AMENDMENT 3

RED HILL COMPLEX FIRE, LIFE SAFETY, AND ENVIRONMENTAL RISK ASSESSMENT / ANALYSIS
VOLUME I OF II

FINAL SUBMITTAL

Critical Infrastructure

Critical Infrastructure

Critical Infrastructure

Prepared for

DEPARTMENT OF THE NAVY
PACIFIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
Pearl Harbor, Hawaii

Prepared by

WILLBROS ENGINEERS, INC.
Tulsa, Oklahoma

August 1998

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RED HILL COMPLEX
STRUCTURAL ANALYSIS
FIRE, LIFE SAFETY AND ENVIRONMENTAL RISK ASSESSMENT/ANALYSIS
AMENDMENT 3
FINAL SUBMITTAL
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ABBREVIATIONS AND ACRONYMS

AFFF	Aqueous Film Forming Foam
AISC	American Institute of Steel Construction
AVGAS	Aviation gasoline
BBLs	barrels (42 U.S. gallons for fuel)
CINCPACFLT	Commander-in-Chief, Pacific Fleet
CFR	Code of Federal Regulations
DFM	Diesel Fuel Marine (F-76)
DOD	Department of Defense
EL	Elevation above sea level
FISC	Fleet Industrial Supply Center (formerly Naval Supply Center - NSC)
FSC	FireSafety Consultants
HT	Harbor Tunnel
JIGPAC	Joint Intelligence Group, Pacific
JP-5	Jet Propulsion Fuel, Grade 5
KVA	kilovolt-ampere
LAT	Lower Access Tunnel
MFA	Masa Fujioka and Associates
MOV	Motor Operated Valve
NEC	National Electric Code
NFPA	National Fire Protection Association
P.I.	Point of intersection
POL	Petroleum, Oil, And Lubricants
PWC	Public Works Center
Sta.	Station normally 100' markers in surveying
UL	Underwriters Laboratories
V	volt
WEI	Willbros Engineers, Inc.

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SECTION 1
SUMMARY

1.1 Introduction

The Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawaii, awarded a contract to Willbros Engineers, Inc. on November 23, 1990 to conduct a comprehensive study of DOD petroleum facilities and develop a plan for modernization of the Air Force and Navy bulk POL wholesale storage and distribution system on the Island of Oahu. In June, 1992 PACDIV awarded Willbros Engineers Amendment No. 3 to the contract to conduct a comprehensive study of the Red Hill Fuel Tunnel Complex and provide a Fire, Life Safety and Environmental Risk Assessment/Analysis.

1.2 Scope of Work

The scope of work, as set forth in Section 2 of the report, defines the area to be studied as the Red Hill Fuel Tank/Tunnel Complex including the Critical Infrastructure Critical Infrastructure The primary objective of the Study is to assess existing safety, fire protection conditions and systems and provide recommendations and alternatives for improvement and correction of deficiencies. Potential environmental impacts shall also be investigated and evaluated. The scope then goes on to list nine more specific areas to be assessed as follows:

(1) Potential catastrophic failure of:

- (a) Fuel tanks
- (b) Pipeline, valves, and associated pipeline components
- (c) Other facility equipment

(2) Relocation of existing tunnel fuel piping underground to reduce fire hazards.

(3) Evacuation of facility during an emergency, including adequacy of egress and ingress for fire fighters and emergency crews, i.e., adits, elevators, etc.

(4) Fire safety and prevention for future construction contracts.

(5) Existing electrical systems/equipment as a source of ignition and potential hazards.

(6) Ecological evaluation of:

- (a) Contamination of well water under the Red Hill Complex by a fuel spill.

(b) Adequacy of existing tunnel walls, floor, and doors to contain a massive fuel spill.

(c) Other potential environmental hazards to the Red Hill Complex or surrounding environment.

(7) Fire extinguishing systems for the Red Hill Complex:

(a) AFFF foam-water

(b) Gaseous inerting

(c) High expansion foam

(d) Other feasible alternatives

(e) Adequacy of existing utilities to support these systems

(8) Compartmentalization of tunnel for fire and safety separations:

(a) Existing tunnel doors

(b) Existing french drains system in floor

(c) Alternatives to existing systems

(9) Ventilation system relative to the above work elements.

1.3 Description of Facilities

A detailed description of facilities is contained in Section 3 and Figures 3-1 and 3-3 provide an isometric view of the facilities. The Red Hill Storage facility consists of Critical Infrastructure Critical Infrastructure locate Critical Infrastructure from Pearl Harbor and connected to a Critical Infrastructure at Pearl Harbor by gunite lined tunnels. Fuel can be brought to Critical Infrastructure and Critical Infrastructure Critical Infrastructure and then Critical Infrastructure pipelines in the Harbor Tunnel and Lower Access Tunnel to Critical Infrastructure The elevation of the base of the storage tanks is approximately Critical Infrastructure and the tanks are Critical Infrastructure height. The tunnels grade downward from the tanks to the pumphouse Critical Infrastructure store JP-5 and F-76 (diesel fuel marine) and are isolated from Critical Infrastructure by a concrete bulkhead in the Lower Tunnel installed in the 1960s when these tanks were converted to AVGAS service. Critical Infrastructure are used to store only JP-5 at present.

Figure 3-3 d Critical Infrastructure Critical Infrastructure

1.4 Background

In order to address the fire and life safety aspects of this Study, Willbros Engineers subcontracted with FireSafety Consultants (FSC) of Houston, Texas to conduct an on-site survey of the Red Hill complex and provide recommendations on this specialized area of the Study. Willbros Engineers' electrical engineer worked directly with FSC to evaluate "existing electrical system/equipment as a source of ignition and potential hazards".

In addition, Willbros Engineers subcontracted with Masa Fujioka and Associates (MFA) in Aiea, Hawaii to provide the specialized knowledge needed for evaluating environmental hazards and ecological evaluation of the contamination of well water in the event of a fuel spill.

Willbros Engineers subcontracted with Concrete Coring Company to core the concrete at Critical Infrastructure Critical Infrastructure locations and utilized Law Engineering, Inc. of Tulsa to run compressive strength tests of these cores. Structural evaluation of tunnel doors and development of various leak scenarios and corrective measures are provided by Willbros Engineers.

1.5 Study and Report

1.5.1 Site Investigation

This report addresses all items specifically included in the Scope of Work. The Study was conducted as follows:

a. The site investigation by Willbros Engineers, FireSafety Consultants and Masa Fujioka and Associates was conducted from May 2 through 11. It began with an on-site kickoff meeting at PACDIV with the PACDIV Project Design Engineer (PDE), and Fire Protection engineer attending, along with all the study participants. A debriefing on completion of the on-site investigation was held at FISC with the above participants, along with the FISC Fuels Officer and Fuels Superintendent.

b. The site investigation included the coring of concrete bulkheads and their keyed connection into the tunnel wall at Critical Infrastructure selected by Mr. Gammon, the FISC Fuels Superintendent. These Critical Infrastructure are shown on Figure 3-3 as Critical Infrastructure in the Lower Access Tunnel just upgrade of the PWC water pump station. Critical Infrastructure on the Critical Infrastructure side of the PWC pump station and is Critical Infrastructure Original construction drawings describe this Critical Infrastructure just upgrade of the Critical Infrastructure and the Critical Infrastructure tunnel and approximately Critical Infrastructure

c. The site investigation also included reviewing and reproducing key construction and as-built drawings to be used in the Study and field inspections.

d. Minutes of the debriefing meeting were submitted to PACDIV on 29 July, 1994 by Willbros Engineers and site investigation notes are included in Sections 4, 5 and 6 of this report.

e. No asbestos was encountered during the site investigation.

1.5.2 Study Scenarios

Since there are an infinite number of possibilities of failure that could occur at an installation such as the Red Hill Complex, Willbros Engineers developed two "worst case" scenarios to guide the fire and life safety, environmental and structural participants in the Study.

a. Scenario One has Critical Infrastructure the tank with the highest elevation Critical Infrastructure discharging its entire contents through Critical Infrastructure at an average rate of Critical Infrastructure Sub-scenarios in scenario one include:

- Tunnel flooding to the closed door at Critical Infrastructure with all other doors open.
- Tunnel flooding to Critical Infrastructure which is closed before fuel reaches it.
- Tunnel flooding to Critical Infrastructure which is closed before fuel reaches it.

b. Scenario Two has a similar discharge from Critical Infrastructure into the lower tank tunnel at the same discharge rate, Critical Infrastructure In this scenario, however, a new door has been installed in the tunnel Critical Infrastructure and this door is closed before fuel reaches it.

1.6 Current Conditions

None of Critical Infrastructure are currently operational. Trip mechanisms are broken and the doors are tied off with ropes to prevent accidental closure during passage of the train. The trip mechanisms are not the fail-safe type and are dependent on power from the lighting circuit to operate.

Flapper valves on the under-the-bulkhead drain lines are broken. Under door closure conditions, these inoperative valves would let fuel pass under the door at high velocity with no means of shut off.

The doors are not built as originally designed and would not withstand the pressures which would result from Critical Infrastructure Fuel leakage of any volume from Critical Infrastructure would flow unabated down the lower access tunnel and would proceed down this tunnel where it would be stopped Critical Infrastructure It would simultaneously flow into the PWC Pump Station and down the Critical Infrastructure until it reached the Critical Infrastructure At this point it would begin to enter the Critical Infrastructure Critical Infrastructure The fuel would also continue down the Harbor Tunnel and flow into Critical Infrastructure and possibly out Critical Infrastructure Flow out of Critical Infrastructure would also occur, depending on the volume of fuel released and the percolation. Percolation would occur all along the tunnel length with the most serious effect being the contamination of the water aquifer in the region of the PWC Pump Station. A closable barrier between the tanks and the tunnel does not now exist.

The general maintenance of pipelines, pipeline supports, tunnel arch supports and electrical conduits in the tunnel is sub-standard. Photo RH-3-35 in Appendix B is a typical illustration. A drain gutter which runs the length of the Lower Tunnel in the Red Hill tank area contains oil soaked muck and free oil and provides an ideal mechanism for spreading a fire from Critical Infrastructure of the Lower Tunnel up to Critical Infrastructure Critical Infrastructure The gutter has Critical Infrastructure where more fuel can be found in puddles on the floor from dripping valves.

The tunnel also has numerous penetrations in the ceiling and at the floor-to-wall joint. Fuel could easily escape the confines of the tunnel, even under gravity conditions. In general, the concrete tunnel floors are in good condition except for some holes where the concrete was thin over the ends of the railroad ties which are now rotted away.

Considering the large quantity of fuel stored and the layout of the facility, the potential for a fire emergency is large. There is currently no fixed fire protection installed in the underground fuel facility. The only fire protection is by means of portable fire extinguishers and valved outlets for connections of fire hose by responding fire department personnel. Communication throughout the underground facility for operations and/or fire department is inadequate and no voice/alarm communication system is installed to warn personnel of emergency conditions. Response time by the Federal Fire Department to a remote location in the underground facility could be as much as 30 minutes. Fire department personnel would have to haul in hose packs, breathing equipment and foam concentrate through adits, down stairways and up tunnels with no assured means of transport.

Egress from Critical Infrastructure is limited to using the elevator in this area. At present, the reliability of the electrical power supply under emergency conditions is questionable and to ensure the safety of personnel, a backup source is needed to provide power for emergency lighting, elevators, etc.

Existing conditions can be summarized by stating the Red Hill Complex Critical Infrastructure each one with the Critical Infrastructure with:

a. No means of secondary containment to contain or prevent the spread of leaking fuel.

b. No fixed fire protection.

c. Response time and access for fire department personnel/equipment poor. Poor communication and no alarms.

d. Sub-standard maintenance of key facilities.

e. Lighting and power of questionable reliability under emergency conditions.

f. Inadequate egress for personnel in the Critical Infrastructure

g. Tunnel penetrations that would reduce the capability of containing and recovering spilled fuel.

h. Vital water aquifers under the Red Hill Complex that would be contaminated by a large fuel spill.

1.7 Conclusions and Recommendations

1.7.1 General

The conclusions and recommendations will be grouped under three categories as follows:

a. Fire and Life Safety

b. Environmental

c. Potential Catastrophic Failure and Structural Analysis

More detailed discussion of recommendations and costs is provided in Sections 4, 5 and 6 of this report.

1.7.2 Fire/Life Safety Assessment

1.7.2.1 Conclusions

The overall Fire Protection Program for the Red Hill complex is very fragmented between FISC, PWC, PACDIV, and the Federal Fire Department. It is important that FISC take prime responsibility for this program and improve housekeeping, routine inspections, and preventative maintenance for the fire protection equipment and systems.

Consideration should be given to contracting with an outside fire protection company to handle detailed inspection of special hazard systems on an annual basis. Such systems would be the AFFF systems, Halon 1301, and UV (ultraviolet) flame detection systems.

A strong Fire Prevention Program should be instituted by FISC to improve housekeeping (clean up existing fuel spills and residue on tunnel floors and drain trenches), assure operability of all drop-track doors to provide acceptable fire and/or fuel separation, and assure availability and operability of all fire protection equipment/systems.

FISC, in conjunction with the Federal Fire Department, should develop Pre-Fire Plans for use by FISC and fire department personnel in responding to fire and other emergency conditions.

1.7.2.2 Recommendations

A detailed discussion of the recommendations appears in Section 4 of this report. The following represents the overview of these recommendations.

a. **Secondary Containment of Fuel and Fire Protection**

1. Install an oil-tight door and bulkhead at **Critical Infrastructure**
Critical Infrastructure

2. Replace the existing drop-track doors.

b. **Fire Suppression**

There is no fixed fire suppression system in the tank storage area. A fixed suppression system (zoned AFFF deluge system) should be installed for protection of the **Critical Infrastructure**
AFFF is the recommended agent of choice for use in suppressing hydrocarbon fires due to its

swift control time. This system will reduce potential damage to the facility, reduce potential environmental concerns, and improve the overall life safety concerns.

c. **Emergency Power Supply**

There is a major concern regarding the electrical power feeds to the tunnel complex. A secondary power supply is needed and the following equipment should be connected to an emergency generator: emergency lighting, exit lights, fire alarm panels, elevators. FISC advised that PACDIV has active design on this subject and construction funds have been requested.

d. **Emergency Voice/Alarm Communication**

An approved emergency voice/alarm communication system should be installed throughout the underground facility. This system should provide signal notification to alert occupants of fire or other emergency. It is understood a contract to provide communication for the Red Hill facility is being prepared for solicitation.

e. **Preventative Maintenance**

Numerous devices, e.g., drop-track doors, door releases, float valve mechanism have not been properly maintained and were found to be inoperable. Operational equipment, as well as fire protection equipment and devices, need improved attention.

f. **Fire Department**

Pre-Fire Plans indicating response to different fire/emergency scenarios need to be developed and put into place.

g. **Egress**

There is only one method of egress from the lower tank level in the new tank section; using the elevator. A secondary method of egress should be provided by installing a man-door in the lower bulkhead separating the two sections. FISC advised that PACDIV has active design on this subject.

h. **Manual Firefighting**

The Fuel Department is relying too much on outside support from the fire department. Red Hill requires the installation of fire hose stations, 150 lb. Purple K wheeled fire extinguishers, and dedicated self-contained breathing apparatus for their own personnel.

i. **Fire Protection of Pipeline Supports**

Apply sprayed-on fireproofing on steel pipeline supports to provide a minimum one hour fire resistance rating. Pipe supports in the tank area and galleries are the most critical.

j. **Housekeeping**

In the lower access tunnel, the trench area contains considerable accumulation of fuel residue and needs to be thoroughly cleaned.

k. **Ventilation**

The ventilation system will need further review to assure adequate ventilation for the lower tank storage area if additional separation is provided. Since doors on any new separation will normally be open, the effect on ventilation should be minimal. FISC advised that PACDIV has an active design on this subject.

l.. **Overall Fire Protection Program**

The Fire Protection Program appears to be very fragmented. The Fuel Department (FISC) needs to assume a stronger, more centralized role in overall responsibility for the Fire Protection Program.

1.7.3 Environmental

1.7.3.1 Conclusion

This Study evaluates the environmental impact associated with a major release from the fuel storage and distribution system at Red Hill. The Study reviews the environmental setting in the fuel storage area and along the distribution tunnel, discusses pertinent regulations, and focuses on two fuel release scenarios.

Scenario One involves a release of Critical Infrastructure which flows down the entire distribution system and discharges at a number of areas including the pump station for a drinking water well, and several surface discharges. In Scenario One fuel contaminates drinking water, ecologically important groundwater, surface water including Pearl Harbor, surface soils, and impacts human health and the environment. Scenario Two involves a similar release Critical Infrastructure however, in this scenario, a new water-tight door located at the base of the tank storage area closes and prevents fuel from flowing down the entire distribution system. In this scenario, drinking water is impacted, but not as severely as in

Scenario One. The Scenario Two release also impacts surface water, soil, humans, and flora and fauna, but to a much less degree than Scenario One.

The Study concludes that an uncontrolled massive fuel release from the Red Hill fuel storage and distribution facility would cause irreparable damage to the drinking water source below the site. Also, the cost of clean up would be prohibitive, long term, and may not be completely successful. The Study further concludes that the advantages of preventive measures to avoid a catastrophe far outweigh the cost and environmental effects of a massive or even short-term fuel release.

It is recommended that precautions be taken to protect the drinking water below the site. If a release of fuel was to occur, it would be best to contain it before it flows down the LAT. If containment did not occur at the end of the tanks, additional precautions should be taken to protect the PWC pump station. Water-tight doors should be repaired, designed, and maintained, especially near the PWC pump station, to divert the fuel away from the water pumping station down the tunnel.

Additional recommendations include:

a. Seal the manhole cover of the well in the PWC pump station and install water-tight doors before (upgradient) of the pump station.

b. Install doors or thrust block to prevent a release from reaching the PWC pump station.

c. Install U-clamps on Critical Infrastructure in tunnel to restrain movement of this line in case of earthquake, per Figure 5-7.

d. Install a tank level monitoring system.

e. Make hourly visual checks of the tanks, tunnels, and pipelines.

f. Repair and routinely test the water-tight doors.

g. Seal off the two former drainage tunnels to Critical Infrastructure

h. Seal off the doorway to Critical Infrastructure

i. Install secondary confinement thrust block below Critical Infrastructure

j. Repair and clean out french drain in Harbor Tunnel.

k. Clean out and test product in open trench near sump for tanks.

l. Seal the water riser shaft at Critical Infrastructure to prevent a release from reaching the surface.

m. Emergency evacuation procedures for Critical Infrastructure and workers at Red Hill.

n. Floor drains in the Harbor Tunnel and Pump House should be periodically cleaned out to ensure they are working properly.

o. The tunnel floor has many holes, some of which were formed by water damage and others man made. Efforts to seal the holes in the floor and walls should be undertaken as precautionary measures, but the possibility of sealing all holes in the floor and walls of the tunnel seems unlikely.

1.7.4 Potential Catastrophic Failure and Structural Analysis

1.7.4.1. Conclusion

Scenario One

Fuel discharging from Critical Infrastructure Critical Infrastructure will be fully discharged Critical Infrastructure

The on-site investigation has revealed that Critical Infrastructure would not function if a large catastrophic failure (such as Critical Infrastructure occurred.

If Critical Infrastructure was closed before fuel reached it, the resulting hydrostatic head would Critical Infrastructure Assuming a 10% impact factor, the pressure would Critical Infrastructure Structural analysis indicates that the bulkhead would probably withstand the pressure, but the steel door would fail.

If Critical Infrastructure was closed before fuel reached it, the resulting hydrostatic head would Critical Infrastructure Critical Infrastructure (no impact factor). Structural analysis indicates that the bulkhead would hold but the steel door would fail.

Scenario Two

Installation of a new oil-tight door Critical Infrastructure would have many advantages, including keeping large quantities of fuel from entering the tunnels downgrade of this point, therefore making it unnecessary to protect a myriad of openings and facilities such as the PWC Pump Station and wells (which supply drinking water to Oahu) from this large volume of fuel. Secondary containment for

Critical Infrastructure would be required in Critical Infrastructure if the bulkhead in the lower tunnel separating these tanks from Critical Infrastructure remains as is.

1.7.4.2 Recommendations

a. Construct a new oil-tight bulkhead and door at Critical Infrastructure in the narrow portion of the tunnel to confine any catastrophic failures to Critical Infrastructure

b. Refurbish existing Critical Infrastructure to act as containment for tunnel pipeline leaks. This will adequately protect Critical Infrastructure as well as the pumphouse, from the fuel leaks in the tunnel pipelines and provide a back-up for the new door for less than full tank failures.

c. Consideration should be given to application of fireproofing material to the critical pipe supports to provide a one hour fire resistance rating to prevent Critical Infrastructure from falling and breaking the lines at the point where they enter the concrete under each tank.

Maintenance recommendations on pipelines, pipeline supports and in-leakage of water problems have been addressed in previous WEI reports and projects have been initiated in these areas. To further reduce the environmental risk it is recommended that defective areas of the tunnel gunite, especially the wall to floor joint be repaired, openings in the gunite be plugged, clean outs in drain lines be installed and drains opened up, fuel and muck be removed from open drain gutters, and corroded arches be replaced. Unsafe corroded gratings over drain gutters should be replaced.

d. Install secondary containment Critical Infrastructure Both these projects are considered low priority to be done only after all above work is accomplished.

e. Construct 18" high diversionary wall at PWC pump station entrance to prevent relatively small pipeline leaks from entering the pump station.

f. Inspect/seal all penetrations/pipes in the lower tunnel valve galleries to prevent a massive fuel spill from migrating to the area outside the steel tank liner and thereby collapsing the liner.

g. If secondary containment in the upper tunnel Critical Infrastructure s not capable of retaining fuel, consider reducing the filling height in Critical Infrastructure This is equivalent to the Critical Infrastructure and will prevent fuel from entering the upper tunnel in case of a catastrophic leak in Critical Infrastructure

h. Strongly recommend that pipelines not be relocated out of the tunnel to an underground right-of-way but FISC should maintain existing pipelines, pipeline supports, valves and tunnel structure, drains and drain gutters in a good state of repair and cleanliness. The Harbor Tunnel and LAT have served as a conduit for Critical Infrastructure for over 50 years. The purpose of the tunnels was probably to provide bomb-proof and sabotage-proof protection for these vital pipelines. The tunnels have done an outstanding job of protecting the pipelines from corrosion as evidenced by only 2 minor leaks having occurred during this period, according to reports. The lines installed in the tunnel allow visual and ultrasonic inspection and, therefore, have some of the advantages of aboveground pipelines. The lines remain in excellent condition except for some specific problem areas where water has been allowed to drip on the lines. In addition, the lines have required little painting, no cathodic protection, no cathodic surveys and have never had to be moved for freeways or other developments. If the lines had been installed underground, many relocations would have occurred as they have occurred on the Critical Infrastructure

Although war conditions are now remote, unfortunately, terrorism is not dead. The Critical Infrastructure Critical Infrastructure e far better protected from terrorism in the tunnels than if they were installed near and under public roads enroute to Pearl Harbor.

The relocation would cause a certain amount of environmental disruption in an environmentally sensitive area and, of course, would require an environmental impact assessment/study.

In addition to the many disadvantages of relocating the line underground, the greatest deterrent would be the cost of accomplishment.

Willbros Engineers believes the hazards of leaks and fire would be increased considerably by replacing the tunnel pipelines with underground lines and strongly recommends the lines remain in tunnels and be properly maintained.

i. Provide oil-tight door/bulkhead in Critical Infrastructure to provide secondary containment for Critical Infrastructure (if lower tunnel bulkhead between Critical Infrastructure remains as is).

1.8 Summary of Estimated Cost of Recommended Corrective Measures

A summary of estimated construction cost for recommended corrective measures is contained in Table 1-1.

TABLE 1-1

SUMMARY OF ESTIMATED CONSTRUCTION COSTS

	PROJECT	ESTIMATED COST
1.	AFFF Fire Suppression System	$ 650,000
2.	Emergency Voice/Alarm Communication System	$ 250,000
3.	150 lb. Wheeled Dry Chemical Fire Extinguishers	$ 22,000
4.	New Man Door at Lower Access Tunnel (Bulkhead between Critical Infrastructure	$ 15,000
5.	Fire Protection of Pipeline Supports	$ 128,000
6.	Self-Contained Breathing Apparatus	$ 6,000
7.	Fire Hose Stations and Fire Hose Packs	$ 11,700
8.	Construct oil-tight bulkhead/door, Critical Infrastructure	$ 100,270
9.	Refurbish Critical Infrastructure to confine tunnel pipeline leaks.	$ 17,152
10.	Construct oil-tight bulkhead/door, Critical Infrastructure	$ 42,251
11.	Construct oil-tight bulkhead/door at Critical Infrastructure Critical Infrastructure	$ 44,551
12.	Construct flow diversion wall at PWC Pump Station entrance	$ 2,800
13.	Inspect/Seal all penetrations/pipes in lower tunnel valve galleries	$ 2,240
14.	Lower fill height in Critical Infrastructure	$ 0
15.	Repair defective areas of tunnel gunite, plug openings, replace corroded arches, install drain clean outs,clean drains/gutters, replace unsafe gratings.	$ 60,470
	Total	$ 1,352,434

SECTION 2
SCOPE OF WORK

The scope of work for the Fire, Life Safety and Environmental Risk Assessment/Study was provided by Amendment 6 of the Regional Study of Military POL Distribution Systems and Storage Facilities, Oahu, Hawaii. A copy of this amendment is provided as Exhibit 2-1.

AMENDMENT NO. 3 TO THE STATEMENT OF ARCHITECT-ENGINEER SERVICES FOR REGIONAL STUDY OF MILITARY BULK POL DISTRIBUTION SYSTEM AND STORAGE FACILITIES, HAWAII

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1. SCOPE OF WORK

General Requirements:

a. The A-E shall conduct a comprehensive study of the Red Hill Fuel Tunnel Complex and provide a fire, life safety, and environmental risk assessment/analysis. The study shall include preliminary construction cost estimates for recommendations and alternatives and economic analysis for major alternatives. The scope of work for this study shall be the entire Red Hill Fuel Tank/Tunnel Complex, including the Critical Infrastructure Critical Infrastructure at Critical Infrastructure The primary objective of this study is to assess existing safety and fire protection conditions and systems and provide recommendations and alternatives for improvement and correction of deficiencies. Potential environmental impacts shall also be investigated and evaluated.

b. In addition to the General Requirements, the A-E shall include an assessment of the following elements:

(1) Potential catastrophic failure of:
(a) Fuel tanks.
(b) Pipeline, valves, and associated pipeline components.
(c) Other facility equipment.

(2) Relocation of existing tunnel fuel piping underground to reduce fire hazards.

(3) Evacuation of facility during an emergency, including adequacy of egress and ingress for fire fighters and emergency crews, i.e., adits, elevators, etc.

(4) Fire safety and prevention for future construction contracts.

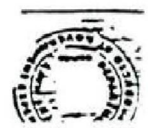
(5) Existing electrical systems/equipment as a source of ignition and potential hazards.

(6) Ecological evaluation of:

(a) Contamination of well water under the Red Hill Complex by a fuel spill.

(b) Adequacy of existing tunnel walls, floor, and doors to contain a massive fuel spill.

(c) Other potential environmental hazards to the Red Hill Complex or surrounding environment.



(7) Fire Extinguishing Systems for the Red Hill Complex:

(a) AFFF foam-water.

(b) Gaseous inerting.

(c) High expansion foam.

(d) Other feasible alternatives.

(e) Adequacy of existing utilities to support these systems.

(8) Compartmentalization of tunnel for fire and safety separations:

(a) Existing tunnel doors.

(b) Existing french drains system in floor.

(c) Alternatives to existing systems.

(9) Ventilation system relative to the above work elements.

c. Wherever applicable, a systems safety engineering approach shall be allowed to analysis provided.

d. The existence of asbestos materials is a possibility. If asbestos material is encountered, survey/identify the asbestos material in accordance with reference (w) and applicable codes, rules, and regulations.

2. <u>SUBMITTALS</u>

a. Submittals will be made by the A-E at the 95% and final stages. Review will be made and the resulting comments forwarded to the A-E within 14 days. The final submittal shall include all marked-up review comments of the previous submittals and all review comments sheets marked up by the A-E to indicate the action taken by the A-E. Calculation and backup data shall be submitted with the 95% and final submittals.

b. Submittals Quantities

(1) 95% Design. Six copies of report.

(2) Final. Originals and ten copies of all items.

c. Submittal Schedule

(1) 95% Design	60 days after award of contract
(2) Final	14 days after receipt of 95% review comments

3. PROJECT MANAGEMENT

a. Project Design Engineer PDE. The PDE and technical point of contact for this project is Mr. Roy Kaneshiro, telephone (808) 474-5331. Arrange for technical contacts and conferences through the PDE. Keep the PDE and the project specialist informed of progress and problems encountered. The A-E will designate an individual who is directly responsible for, and is the contact on all matters pertaining to this contract.

b. Project Contract Specialist. The Contract Specialist assigned to this project is Mr. Melvin Yoshimura, telephone (808) 474-5406. This person is the representative of the Contracting Officer and is the Administrator of the contract.

SECTION 3
DESCRIPTION OF FACILITIES

3.1 Red Hill Tanks

The underground fuel storage complex at Red Hill is located about Critical Infrastructure of Pearl Harbor in a ridge of volcanic rock known as Red Hill. This ridge extends southwesterly toward Pearl Harbor and provides protective cover, not only for the underground storage, but also for a portion of the Critical Infrastructure which Critical Infrastructure Figures 3-1, 3-2 and 3-3 are isometric drawings showing the relationship of the Critical Infrastructure

The fuel storage facility consists of —— underground tanks constructed in subterranean vaults hollowed out of rock. Each vault has the form of a vertical cylinder closed top and bottom by hemispherical domes. The diameter of each tank is Critical Infrastructure and the overall height from bottom to top is Critical Infrastructure The capacity of each tank is approximately Critical Infrastructure of either JP-5 jet fuel or diesel fuel marine (DFM).

The base of the fuel storage tanks is approximately Critical Infrastructure higher elevation than the entrance to the Critical Infrastructure A release of fuel from any of the Critical Infrastructure tanks or a pipeline rupture in the tunnel would allow a gravity flow of fuel into the pump room. The volume of Critical Infrastructure Critical Infrastructure

The —— tanks at Red Hill are Critical Infrastructure Critical Infrastructure with the Critical Infrastructure tanks in the Critical Infrastructure and the numbers increasing toward the Critical Infrastructure There are Critical Infrastructure The upper access tunnel is near the dome area of each tank and the lower access tunnel has its floor about Critical Infrastructure the tank bottoms. Both the upper and lower access tunnels have short spur tunnels which branch to a valve gallery at the bottom centerline of each tank.

3.2 Upper Access Tunnel

The upper access tunnel extends from Critical Infrastructure There is a Critical Infrastructure Critical Infrastructure A bulkhead separates Critical Infrastructure Critical Infrastructure This bulkhead has a man-door for egress from one area to the other in the upper tunnel. There are Critical Infrastructure which travels from the upper tunnel level to the lower tunnel level. Critical Infrastructure must be used to get from the lower tunnel on one side of the bulkhead to the lower tunnel on the other side. The more Critical Infrastructure has explosion-proof equipment and machinery, and has a vestibule at each tunnel level for the protection of workers while waiting Critical Infrastructure in case of fire or other emergency.

Approximately Critical Infrastructure from the upper tunnel level there is a tunnel providing primary access to the area containing Critical Infrastructure this tunnel leads to Critical Infrastructure The Critical Infrastructure in this section of tanks provides the only egress from the Critical Infrastructure

At the upper access tunnel level there is a Critical Infrastructure above the upper dome of each tank. On top of each tank there is an opening through a steel cover manhole in which there is a smaller hole for tank gauging.

3.3 Lower Access Tunnel (LAT) and Harbor Tunnel

The lower access tunnel extends from the tank area approximately Critical Infrastructure Critical Infrastructure The tunnel grades downward from the Critical Infrastructure with grades varying from Critical Infrastructure There are Critical Infrastructure in the Lower Access Tunnel: Critical Infrastructure carrying diesel fuel marine; Critical Infrastructure carrying JP-5 jet fuel; Critical Infrastructure carrying diesel fuel marine.

About Critical Infrastructure from the tank area is Critical Infrastructure which provides the Critical Infrastructure Critical Infrastructure At the junction of the Lower Access Tunnel and the Harbor Tunnel (main tunnel), there is a water pumping station operated by Public Work Center (PWC). This pumping station, with deep wells in the lava rock, provides a part of the fresh water reserve supply for the Naval Base. At this location there is also Critical Infrastructure Within Critical Infrastructure there is a 6-inch water line providing fire protection water to the upper and lower access tunnels. A 500,000 gallon, above ground, concrete water tank provides the water supply.

From the wye intersection at the PWC water pump station, the Harbor Tunnel runs approximately Critical Infrastructure Critical Infrastructure down to the Critical Infrastructure A typical cross section of the Critical Infrastructure is Critical Infrastructure Critical Infrastructure The tunnel walls are gunite lined.

To prevent uncontrolled flow of fuel from the tank area down through the main tunnel due to a ruptured valve or pipe break, there are two normally open drop-track bulkhead doors installed in strategic locations in the tunnel. One door is in the lower access tunnel just before the wye intersection at the PWC water pump station, Critical Infrastructure on Fig. 3-1. Critical Infrastructure These doors are automatic self-closing, but the release devices on all of the doors were found to be inoperative at the time of the survey. **Critical Infrastructure** s not oil-tight or drop-track. **Critical Infrastructure** Fig. 3-1 is the location of the proposed new door and bulkhead.

Critical Infrastructure There is **Critical Infrastructure** **Critical Infrastructure** which intersects at the **Critical Infrastructure** however, this spur is secured for reasons of security but could be used during large tunnel construction projects. While this tunnel has very stout security doors, it is not oil-tight.

Critical Infrastructure

Critical Infrastructure

WILLBROS ENGINEERS, INC.

DRAWING APPROVALS		
DRAWN KLW	DATE 06-19-98	
CHECKED	DATE	
ENGINEER CT/JR	DATE 06-22-98	
APPROVED		

RED HILL COMPLEX
SCHEMATIC

SCALE	PROJECT NO.	DRAWING NO.	REV.
NTS	50253	FIGURE 3-1	0

Critical Infrastructure

Critical Infrastructure

c:\users\lwang

09-JUL-1998

WILLBROS ENGINEERS, INC.

RED HILL COMPLEX
ENLARGED SCHEMATIC

DRAWING APPROVALS	DRAWN KLW	DATE 06-19-98
	CHECKED	DATE - -
	ENGINEER CT/JR	DATE 06-22-98
	APPROVED	

SCALE	PROJECT NO.	DRAWING NO.	REV.
NTS	50253	FIGURE 3-2	0

Critical Infrastructure

Critical Infrastructure

WILLBROS BUTLER ENGINEERS, INC.

RED HILL COMPLEX
ISOMETRIC SKETCH

DWN.	DATE					
CHKD.	DATE					
ENGR. JWR	DATE 6/22/98	SCALE	PROJECT NO.	DRAWING NO.	REV.
APPROVED		NTS	50253	FIGURE 3-3	0

SECTION 4
FIRE AND LIFE SAFETY RISK ASSESSMENT/ANALYSIS

4.1 General

FireSafety Consultants was contracted by Willbros Engineers, Inc. to perform a fire and lifesafety risk assessment/analysis of the Red Hill Tank/Tunnel Complex. The primary objective of this study was to provide recommendations and alternative approaches for improving current conditions and/or correcting any deficiencies.

A field survey of the Red Hill Complex was conducted during the period May 2-11, 1994. The field survey team for fire protection consisted of John Echternacht, FireSafety Consultants, Kenneth Echternacht, FireSafety Consultants, and Terry Forehand, Willbros Engineers. Daily survey notes and photographs are included as Appendices to this report and provide a record of the field investigation.

This study includes an assessment of all areas of fire and life safety risk assessment/analysis outlined in the Scope of Work as defined in Section 2.0 of this report.

4.2 Codes, Regulations, and Standards

4.2.1 General

The purpose of this section is to identify the applicable codes, regulations, and standards used for conducting the risk assessment/analysis for the Red Hill Complex.

Such codes, regulations, and standards include local, state and federal government codes, nationally recognized codes and standards, industry practices, and applicable military standards. A listing of these codes, regulations, and standards is included in Section 4.2.2. Section 4.4 provides an evaluation of the facility and its components against the listed regulations and what is considered good engineering, maintenance and operating practice.

4.2.2 Applicable Codes, Regulations, and Standards

4.2.2.1 Categories of Codes, Regulations, and Standards

A general listing of the categories of codes, regulations, and standards is given below.

- Local Codes, Regulations, and Standards

- State Codes, Regulations, and Standards
- Federal Codes, Regulations, and Standards
  (Code of Federal Regulations [CFR])
- American Petroleum Institute (API)
- National Fire Protection Association (NFPA)
- National Electrical Code (NEC)
- Navy Manuals

4.2.2.2 Specific Codes Within Categories of Codes, Regulations, and Standards

Specific codes within the categories of codes, regulations, and standards specified in Section 4.2.2 are addressed below.

a. Local Codes, Regulations, and Standards

No specific local Honolulu city and county fire protection codes, regulations, or standards have been identified that pertain to USN facilities.

b. State Codes, Regulations, and Standards

No specific State of Hawaii fire protection codes, regulations, or standards have been identified that pertain to USN facilities.

c. Federal Codes, Regulations, and Standards (Code of Federal Regulations [CFR])

The Code of Federal Regulations (CFR) contains the federal codes, regulations, and standards which apply to DOD Bulk Fuel Storage Terminals. The CFR is divided into titles which are subdivided into chapter and parts. Titles and parts are abbreviated in this document for convenience. For example 29CFR1910 means Title 29 of the Code of the Federal Regulations, Part 1910. Fire protection and safety regulations which apply to the Navy facilities are given below.

Title 29 - Labor
Chapter XVII; Parts 1900 to 1910;
Occupational Safety and Health Administration, Labor
Part 1910.106 - Flammable and Combustible Liquids

d. American Petroleum Institute (API)

The American Petroleum Institute (API) presents categories which contain standards, recommended procedures, and publications which apply to petroleum facilities. The categories that apply to fire protection and safety are listed below.

Safety and Fire Protection

- Publ 2003, Protection Against Ignition Arising out of Static, Lightning and Stray Currents
- Publ 2004, Inspection for Fire Protection
- Publ 2015, Cleaning Petroleum Storage Tanks
- Publ 2021, Guide for Fighting Fires in and around Petroleum Terminals
- Publ 2350, Overfill Protection for Petroleum Storage Tanks

e. National Electrical Code (NEC), 1993

f. Underwriters Laboratories, Inc. (UL), 1994

g. Factory Mutual Research Corporation (FM)

h. National Fire Protection Association (NFPA)

- NFPA 10, Portable Fire Extinguishers, 1990
- NFPA 11, Low Expansion Foam and Combined Agent Systems, 1988
- NFPA 12, Carbon Dioxide Extinguishing Systems, 1993
- NFPA 12A, Halon 1301 Fire Extinguishing Systems, 1992
- NFPA 13, Installation of Sprinkler Systems, 1991
- NFPA 14, Installation of Standpipe and Hose Systems, 1993
- NFPA 15, Water Spray Fixed Systems, 1990

- NFPA 16, Installation of Deluge Foam-Water Sprinkler Systems and Foam-Water Spray Systems, 1991
- NFPA 20, Installation of Centrifugal Fire Pumps, 1990
- NFPA 22, Water Tanks for Private Fire Protection, 1993
- NFPA 24, Installation of Private Fire Service Mains and Their Appurtenances, 1987
- NFPA 30, Flammable and Combustible Liquids Code, 1990
- NFPA 37, Installation and Use of Stationary Combustion Engines and Gas Turbines, 1990
- NFPA 70, National Electrical Code, 1993
- NFPA 72, National Fire Alarm Code, 1990
- NFPA 91, Installation of Exhaust Systems for Air Conveying of Materials, 1992
- NFPA 101, Safety to Life from Fire in Buildings and Structures, 1994
- NFPA 101M, Alternative Approaches to Life Safety, 1988
- NFPA 329, Handling Underground Releases of Flammable and Combustible Liquids, 1992

i. Navy Manuals

- NAVFAC DM-22, Petroleum Fuel Facilities, August 1982
- NAVFAC MO-230, Maintenance and Operation of Petroleum Fuel Facilities, August 1990
- MIL-HDBK-1008b, Fire Protection for Facilities Engineering, Design and Construction, 15 January 1994
- MIL-HDBK-1022, Petroleum Fuel Facilities, 30 June 1997

j. Other Codes, Regulations, and Standards

- Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, September 1988

- NFPA Fire Protection Handbook, 17th Edition

4.3 Fire, Life Safety, Electrical Risk Assessment

4.3.1 Fire Protection

4.3.1.1 General

Fire protection for the underground fuel storage and tunnel complex at Red Hill consists of water supplied from a 500,000 gallon concrete aboveground tank located Critical Infrastructure Water supply to the upper access tunnel is provided through a new 6 inch line which is also routed through Critical Infrastructure Critical Infrastructure to supply the lower access tunnel. The old 6 inch riser in the Critical Infrastructure has been abandoned in place (installed a wedge-type plug valve to isolate riser from the supply).

The water supply for Red Hill is for manual fire fighting purposes only with hydrants (valved outlets) located every 50 feet in the tank area and every 250 feet in the tunnel section. No hose stations or self-contained breathing apparatus are provided for Fuel Department personnel (see Section 4.6.2.5 for recommendations).

In the case of a major fire or other emergency condition, reliance is placed on response by the Federal Fire Department. Response time to a remote location in the underground facility could be as much as 30 minutes. It should be further noted that the fire department must bring their own hose packs, breathing equipment, and foam concentrate when responding to such an emergency situation.

Communications throughout the underground facility for operations and/or fire department personnel is totally lacking. The existing telephone system is not in service.

4.3.1.2 Red Hill Fuel Storage Area

The underground fuel storage facility consists of Critical Infrastructure containing Diesel Fuel Marine (DFM) and JP-5 fuels as described in Section 3.1. The most likely fire scenario for this area is the release and subsequent ignition of unconfined combustible liquids resulting from a damaged tank valve or ruptured piping in the tank gallery area.

There is currently no fixed fire protection installed in the underground fuel facility. The Cardox 22-ton low pressure carbon dioxide system that was installed in the early 1960s for protection of the upper and lower tunnel areas Critical Infrastructure has been taken out of service and abandoned in place. The storage tank is still located Critical Infrastructure but has been emptied; all piping and nozzles are still in place. The existing heat detection system for this system is also not in service.

The only fire protection provided is by means of portable fire extinguishers and valved outlets for connection of fire hose by responding fire department personnel. The fire protection water line in the upper and lower access tunnels is a 6-inch line.

Without a fixed fire protection system installed in this area, a fire could cause massive damage to the facility and present major life safety concerns. Smoke and heat conditions would make egress extremely difficult and the possibility of a manual interior fire fighting attack by the Federal Fire Department would be virtually impossible. It is for these reasons that an automatic AFFF system should be installed in this area.

AFFF is the recommended agent of choice for use in suppressing hydrocarbon fires due to its swift control time. This system will reduce potential damage to the facility, reduce potential environmental concerns, and improve the overall life safety concerns.

4.3.1.3 Lower Access Tunnel (Including Adits)

The only fire protection for this area are portable fire extinguishers and valved outlets for fire hose as noted above.

4.3.1.4 Harbor Tunnel

At the Critical Infrastructure adjacent to the PWC water pump station there is a twin agent hose reel unit (500 lbs. Purple K dry chemical and 100 gallons of premixed AFFF). This unit is mounted on a rail car and is moved by rail to areas of temporary construction to provide standby manual fire fighting capabilities.

The entire length of the Harbor Tunnel is protected by a water line with valved outlets located approximately every 250 feet for connection of fire hose. Line sizes for the water supply vary from 6 inches from the Critical Infrastructure then a 20-inch line and next a 32-inch PWC potable water line for water supply.

4.3.1.5 Fire Protection Systems

This section reviews the characteristics and operating principles of the various types of the suppression systems for consideration to protect the Red Hill Complex.

4.3.1.5.1 Aqueous Film Forming Foam (AFFF)

Aqueous film forming foam (AFFF) is obtained from synthetic fluorochemical surfactants. Foaming agents, stabilizers, and solvents are added to form the concentrate. AFFF is unique because it allows a film of water to form on a hydrocarbon fuel surface. It extinguishes fire by suppressing fuel vapor due to the presence of the aqueous, or watery, film. AFFF comes in both 3% and 6% concentrations.

The air-foams generated from AFFF solutions possess low viscosity, have fast spreading and leveling characteristics, and, like other foams, act as surface barriers to exclude air and halt fuel vaporization. These foams also develop a continuous aqueous layer of solution under the foam, maintaining a floating film on hydrocarbon fuel surfaces to help suppress combustible vapors and cool t he fuel substrate. This film, which can also spread over fuel surfaces not fully covered with the foam blanket, is self-healing following mechanical disruption and continues to spread as long as there remains a reservoir of nearby solution.

AFFF fluidity and film strength on kerosene makes it particularly suitable for jet aircraft (JP-5) fuel spill fire fighting.

Actually, AFFF has many mechanisms that work together to help extinguish a fire. They come from the aqueous film, the mechanical foam, and the water content. The aqueous film suppresses vapors, improves the spreading ability of the foam, and tends to reseal itself when distributed. The mechanical foam suppresses vapors and separates the fuel from the air. The water content has a cooling effect.

AFFF is widely used in fighting hydrocarbon fires due to its swift control time.

There is currently no fixed fire protection system installed in the Red Hill fuel storage area.

4.3.1.5.2 Gaseous Systems

The two most widely used gaseous agents are carbon dioxide and Halon 1301.

Carbon Dioxide

Carbon dioxide is an inert, non-corrosive, electrically non-conductive extinguishing agent used on fires involving flammable liquids and fires involving electrically energized equipment.

Carbon dioxide is a gas under normal conditions of temperature and pressure, but is easily liquefied by compression and cooling. As the pressure increases, the density of the vapor over the liquid increases. On the other hand, the liquid expands as the temperature goes up and its density decreases. At 87.8

degrees F (31 degrees C) the liquid and vapor have the same density and, of course, the liquid phase disappears. This is called the critical temperature for carbon dioxide. Below the critical temperature, carbon dioxide in a closed container is part liquid and part gas. Above the critical temperature, it is entirely gas.

Carbon dioxide cannot exist as a liquid at pressures below 60 psig (75 psi absolute). This is the triple point pressure where carbon dioxide may be present as a solid, liquid or vapor. Below this pressure, it must be either a solid or gas, depending on the temperature. This latter point is critical in system design. The pressure drop of agent flowing through piping is mainly due to increasing friction losses and partly due to the pressure in the pipeline; if allowed to drop below 60 psig the liquid may convert to solid carbon dioxide (dry ice) and literally plug the pipe or discharge nozzles.

The relative density of carbon dioxide gas, when compared with dry air at 32 degrees F and atmospheric pressure, is 1.529. In other words, carbon dioxide is about 1 ½ times heavier than air.

Although carbon dioxide is only mildly toxic, it can produce unconsciousness and death when present in fire extinguishing concentrations (34 – 50% by volume in air). The personnel hazard is more related to suffocation or a reduction in the oxygen content. In concentrations above 9 percent, most persons will lose consciousness within a few minutes. Breathing a higher concentration could render a person helpless almost immediately.

As a result of the above considerations, fixed-automatic systems utilizing carbon dioxide require that a time delay be incorporated into system design to allow sufficient time for personnel evacuation prior to release of agent.

Carbon dioxide is stored under pressure as a liquid and, when released, is discharged into the fire area principally as a gas. As a guide, one pound of it may be considered as producing 8 cubic feet of free gas at atmospheric pressure. When released onto burning materials, it envelops them and dilutes the oxygen to a concentration which cannot support combustion.

Carbon dioxide is effective for extinguishment of Class A combustibles, Class B flammable liquids, and Class C energized electrical equipment. It is a "clean agent" in that it will not damage equipment or leave a residue. Some cooling effect is realized upon agent discharge, but you should not encounter "thermal shock" to equipment if the system is properly designed.

Carbon dioxide systems are classified according to the manner in which the agent is stored; either low pressure (bulk storage) or high pressure (individual cylinders).

A low pressure carbon dioxide system utilizes a large insulated and refrigerated storage tank. The carbon dioxide is maintained at 300 psi by keeping the temperature at approximately 0 degree F. Low pressure systems are normally provided when the quantity of agent required exceeds 2000 pounds.

A high pressure system utilizes one or more cylinders manifolded together. The pressure at 70 degrees F is approximately 850 psi. Protection of hazards using flammable or combustible liquids requires a design concentration of 34% and hazards containing electrical equipment requires a design concentration of 50% by volume.

In accordance with NFPA Standard #12, a total flooding system requires that a minimum 30% design concentration be achieved within two minutes and the total design concentration be achieved within seven minutes.

The major disadvantage of using carbon dioxide in occupied areas is the hazard to personnel.

Since carbon dioxide is a suffocating agent, the requirement exists to evacuate the hazard area prior to system discharge. Such a delay allows added time for a fire to increase in magnitude and intensity.

A further consideration is that leakage or dissipation of agent into other occupied areas could create an additional life safety problem.

However, a properly designed system will take all of the above factors into consideration. Carbon dioxide is a clean agent, three dimensional, does not require drainage or clean-up, is relatively inexpensive, readily available, and is very effective for protection of enclosed hazard areas.

Halon 1301

Halon 1301 is an inert gas. It has a vapor pressure of 199 psig and a boiling point of minus 72 degrees F. Although its vapor pressure would adequately expel the agent, the pressure decreases rapidly with a temperature fall to 56 psig at 9 degrees F and 17.2 psig at –40 degrees, F., therefore, in fixed piped systems, the agent container is super pressurized with nitrogen to 360 psig. Finally, the heat of vaporization of Halon 1301 is relatively low, which means that saturated liquid will immediately vaporize into a gas upon discharge.

A major advantage of Halon 1301 is its effectiveness as a fire suppression agent at very low concentrations. A 5% concentration of Halon will extinguish most flammable liquid fires and most Class A combustible incipient surface fires. Personnel can safely be exposed to design concentrations up to 7%

for short periods of time without any harmful effects. Therefore, where personnel exposure exists, the utilization of Halon 1301 is further justified.

Although Halon 1301 does not represent a life safety concern, in recent years the fire protection industry has become aware of the potential depletion of the global ozone layer by chlorofluorocarbon (CVC) emissions; emissions which include the halon generated fire suppression agents. Thus, current use of the halon generated agents are on a restricted bases.

4.3.1.5.3 High Expansion Foam

High expansion foam concentrates are obtained from surfactants that do not contain fluorochemicals. As their name suggests, they possess expansion ratios ranging from 100:1 to 1000:1. Most other foam concentrates are classified as low expansion foams with expansion ratios of approximately 10:1.

High expansion foam requires special application hardware. It is particularly suited as a flooding agent for control and/or extinguishment of Class A and Class B fires in confined spaces. The foam is an aggregation of bubbles mechanically generated by the passage of air or other gases through a net, screen, or other porous medium that is wetted by an aqueous solution of surface active foaming agent.

4.3.1.5.4 Other Feasible Alternatives

Water Deluge System

Water is without doubt the oldest fire extinguishant employed by man. It is a two-dimensional extinguishant and is usually available in vast quantities.

A water deluge system consists of a system of pipes provided with open heads or nozzles that will distribute water onto the fire. A deluge system requires a separate detection system for automatic operation (as with all other systems described above).

Water suppression systems are effective for controlling flammable liquid fires, but for rapid flame knock-down and providing total extinguishment, the system becomes much more effective when a foam concentrate is added.

Dry Chemical System

Dry chemical is primarily used in the hydrocarbon processing industry due to its recognition as an extremely efficient agent in extinguishing fires in flammable liquids.

Dry chemical possesses the ability to control fires by a rapid knock-down of the flame front. However, it will not provide securement of a flammable liquid spill or pool fire. Therefore, the agent must be properly applied to achieve total extinguishment.

Dry chemical is one of the most effective agents for extinguishment of three diemensional flammable liquid fires and gas pressure fires. Dry chemical has the further added advantage of concise experimental data to support the design criteria in this latter application.

Although total flooding dry chemical systems have been designed and installed, the most effective use of the agent is based upon a local application technique. Therefore, this agent is better suited for protection of flammable liquid fires by using large capacity wheeled extinguisher units.

4.3.1.5.5 Fire Alarm System

As part of the field survey, NAVFAC Specification Number 14-89-24-16 (construction contract no. N62471-89-C-2416) were reviewed. This contract is to provide a fire alarm system for the upper and lower access tunnel areas at Red Hill.

The scope of work includes providing a new intelligent addressable fire alarm system consisting of explosion-proof heat detectors throughout the upper and lower access tunnel areas (25-foot maximum spacing), manual pull stations, fire alarm horns, and elevator recall for firefighters' emergency service. The system will fully annunciate to provide separate alarm and trouble lamps for each zone alarm initiating circuit. This will provide system annunciation for operating personnel and the fire department to properly access the condition and location of the fire.

It is recommended that the fire alarm system, as proposed, be utilized for automatic actuation of the AFFF systems to be provided for the lower access tunnel areas. The fixed pipe AFFF system will be designed to provide protection for the Critical Infrastructure Critical Infrastructure etc.). This arrangement is compatible with the proposed zone arrangement for the fire alarm system; e.g., Fire Alarm Zone 28 is the heat detection zone Critical Infrastructure Fire Alarm Zone 27 Critical Infrastructure etc. For example, if a fire was detected in the valve galleries or adjacent tunnel areas of Critical Infrastructure Fire Alarm Zone 28 would be actuated and the AFFF system Critical Infrastructure would be tripped. If the fire spread from one zone to the next, that respective fire alarm zone would be actuated and the respective AFFF system would be tripped. Provisions will also be provided for manual actuation of each respective AFFF system.

4.3.2 Lifesafety

Primary entry and exiting from the Red Hill complex are as follows:

Critical Infrastructure

There are Critical Infrastructure between the upper access and lower access tunnels: Critical Infrastructure Critical Infrastructure

Limited access to the upper tunnel is provided by Critical Infrastructure Also secondary egress from the Harbor Tunnel is provided by Critical Infrastructure near the PWC water pump station. Critical Infrastructure s sealed and locked, thus not providing either entrance or egress from the Harbor Tunnel.

The lifesafety evaluation of the Red Hill complex has been based primarily on a review of NFPA 101, *Life Safety Code*. In accordance with Section 30-7.3, Underground Structures, an existing underground structure with an occupant load of 100 or fewer persons in the underground portions of the structure is exempt from the exiting requirements of NFPA 101.

However, due to the uniqueness of this facility, a combination underground structure, a mine (tunnel structure), and underground fuel tank, additional consideration should be given to emergency evacuation as follows:

- At the time of the survey, the entrance to Critical Infrastructure was barricaded and padlocked. Provision should be made to be able to evacuate Critical Infrastructure during an emergency. It should also be available for egress of fire fighting personnel.
- The only means of egress from the lower tunnel Critical Infrastructure A second means of egress should be provided for this area by installing a man-door in the existing bulkhead separating Critical Infrastructure (See FISC Special Project R4-86.)
- The Critical Infrastructure requires a vestibule (horizontal fire separation) at each tunnel level for the protection of workers while waiting Critical Infrastructure in case of fire or other emergency.

- Emergency lighting and exit signs shall be connected to the emergency power supply as discussed in Sections 4.3.3.3 and 4.6.2.3.

- Although the occupancy level in the underground facility during normal operations is limited, it is recognized that a higher occupant load may occur during special site visits or during future construction contracts. With implementation of the above three recommendations and administrative control to limit the occupancy to 100 or fewer persons, it is felt that the existing means of egress from this facility will be adequate. However, if more than 100 persons are required to be in this underground facility, additional considerations from NFPA 101 must be applied.

- Prior to any site visit by non-operating personnel, it is imperative that a briefing be given regarding the layout of the facility, means of egress, and emergency procedures.

As discussed in Section 4.3.1, due to the layout of this facility and the large quantity of fuel being stored, the potential for a fire emergency is large. Further, as discussed in Section 4.4, the lifesafety of FISC personnel due to a potential catastrophic release of fuel also presents a major concern. Therefore, in the event of a fire or fuel release in this underground facility it is imperative that personnel be notified immediately of such an emergency condition.

It is recommended that an early warning emergency voice/alarm communication system be installed throughout the underground facility. This system will replace the existing (out of service) telephone system. This system will provide 2-way emergency voice communication for operations and/or firefighter communications well as audible/visual alarm notification for emergency evacuation purposes .

4.3.3 Electrical

4.3.3.1 General

The lower tank area electrical system originates in the PWC water pump station. There are two different electrical systems within the lower tank area; one system installed during the original construction and the other installed during the modification of Critical Infrastructure to proposed Avgas service.

4.3.3.1.1 PWC Water Pump Station

The PWC water pump station electrical distribution system is used to operate the water pump station electrical system and to provide electrical power to the lower tank area.

The incoming electrical system to the PWC water pump station originates from a single 12,000V source located Critical Infrastructure

The 12,000V is transformed to 480V and 208V. From the 480V and 208V system a feed is taken to a junction box "A" which is located outside of the PWC water pump station adjacent to the old entrance to the water pump station from the Harbor Tunnel. From junction box "A" the 480V and 208V is taken underground to junction box "B" located in the lower access tunnel (lower tank area). From this point, the 480V and 208V are in separate conduits and run to the panels located outside of the gauger's station.

4.3.3.1.2 Lower Access Tunnel (Original System)

The lower access tunnel electrical system is the original electrical feed for Critical Infrastructure Critical Infrastructure which connects this area with the upper access tunnel.

The electrical feed originates in Critical Infrastructure The 480V and 208V circuits connect to their respective breaker panels across from the gauger station. These two feeds are in separate conduits that are located in the tunnel and were installed during original construction.

The 208V system feeds the following areas and devices:

a. Critical Infrastructure lights and receptacles

b. Critical Infrastructure lights and receptacles

c. Critical Infrastructure lights and receptacles

d. Critical Infrastructure lighting

The electrical feed for the Critical Infrastructure lights and upper access tunnel lights and receptacles is thru the Critical Infrastructure

The solenoid which operates the bulkhead door is connected to the Harbor Tunnel lighting circuit.

The 480V system feeds the following areas:

a. Breaker panel between Critical Infrastructure

b. Welding receptacles next to the above breaker panel.

c. Welding receptacles in the Critical Infrastructure

d. Critical Infrastructure

The 480V system in the tank area and the Harbor tunnel is fed from one circuit breaker in the 480V lighting panel Critical Infrastructure

4.3.3.1.3 Lower Tunnel Area Additions

The following items were added to the electrical system when the Asteroid system was installed:

a.. Motor operators added to the valves for Critical Infrastructure at the Critical Infrastructure at Critical Infrastructure The electrical feed for the motor operated valves are tapped from the 480V circuit in Critical Infrastructure

b. Motor operators added to Critical Infrastructure adjacent to Critical Infrastructure and next to the original Critical Infrastructure The electrical feed is from a junction box located adjacent to the sump area. This junction box is original construction, and is installed to terminate the incoming and outgoing 480V and 208V conduits and cables. In addition, the power for the sump pumps is tapped from this junction box.

c. Motor operators added to Critical Infrastructure between Critical Infrastructure Critical Infrastructure

4.3.3.1.4 Lower Access Tunnel Critical Infrastructure

These electrical modifications were made when Critical Infrastructure were revamped for Avgas use in the early 1960's. The incoming power is 12,000V from the PWC water pump station. The 12,000V is transformed down to 2400 V and 480V.

The 2400V circuit operates the motor/pumps and the 480V is to power motor operated valves, elevators and other miscellaneous equipment. A portion of the 480V is transformed to 208V for lighting and receptacles in the upper and lower tunnel areas. The conduit and wire from the electrical equipment to the tank area is run through the bulkhead.

4.3.3.1.5 Lower Access Tunnel, Critical Infrastructure (Additions)

A breaker was added to the 480V system to provide power to Critical Infrastructure The wire and conduit is installed in Critical Infrastructure

4.3.3.2 Electrical Classification

Both the diesel marine fuel (DFM) and the JP-5 have flashpoints of 140°F (60°C) and Reid vapor pressures of 0 psi. As such they classify as Class IIIA combustibles liquids. The possibility of an ignition of DFM or JP-5 by electrical equipment is considered to be remote. With such liquids the rate of vapor release is considered to be nil at normal temperatures of handling and storage. When heated, these liquids will release more vapors and thereby slightly increase the level of hazard. However, the most hazardous condition would be encountered by a release of this fuel in an atomized state (due to pinhole type release under high pressure conditions).

4.3.3.2.1 Fuel Tank Area

Red Hill lower tank level for this section starts with the Critical Infrastructure and ends at the upper end of the Lower Access Tunnel.

The area is ventilated with the exception of the Critical Infrastructure Each gallery contains Critical Infrastructure Critical Infrastructure several manual valves, sample table, tank water bleed off and waste trough. The waste trough in the floor contains sediment and other unknown solids and liquids. The water bleed-off for each tank is in piping located in the water trough. It should be noted that there are fuel leaks during normal operation, there is an open fuel sampling area, and there is reduced ventilation in the valve galleries off the Lower Access Tunnel.

Therefore, in accordance with Table 5-9.5.3 of NFPA No. 30-1996 and Table 515-2 of NFPA No. 70-1996, each valve gallery at each tank is considered a Class 1, Division 2 location from the valve body extending 5 feet in all directions and up to 3 feet above the floor within 25 feet horizontally from the edge of any valve.

The floor trough that runs in the lower tank level area of the Lower Access Tunnel falls in the category of "Pits with Adequate Ventilation" (NFPA-30 Table 5-9.5.3) and, therefore, is classified as a Class 1, Division 2 location for the entire space within the trough due to the trough being below grade. Additionally, the space up to 18 inches above grade within 15 feet horizontally from any edge of the floor trough shall be considered a Class 1, Division 2 area per the category entitled "Drainage Ditches, Separators, Impounding Basins." (NFPA-30 Table 5-9.5.3)

The sump pump area will be classified as follows:

- The pump pit, pumps and sump are located below grade relative to the tunnel floor and, therefore, the entire pump pit and sump are classified similar to the drain trough described above; Class 1, Division 2.

- The area above the pump pit and adjacent to the pump pit will be Class 1, Division 2 within 5 feet of the surface of the pumping facilities, extending 25 feet horizontally from any surface of the facilities and upward 3 feet abovegrade.

Equipment in the sump area is installed for a Class I location, except for the telephone set which is not explosion-proof.

4.3.3.2.2 Harbor Tunnel and Lower Access Tunnel

The Harbor Tunnel (for purposes of this classification section) begins at Critical Infrastructure Critical Infrastructure The Critical Infrastructure Critical Infrastructure

The Harbor Tunnel contains lighting, receptacles, distribution centers for lighting, telephone communications, and the circuit for the Critical Infrastructure The tunnel also contains Critical Infrastructure Critical Infrastructure for DFM, Critical Infrastructure for JP-5, and Critical Infrastructure for DFM. The pipelines are welded, and valves are located at the Receiving Pumphouse, at Critical Infrastructure at the Critical Infrastructure Critical Infrastructure From this point, the lines proceed up the Lower Access Tunnel and valves are located near Critical Infrastructure Critical Infrastructure The fuel pipelines are Critical Infrastructure in concrete saddles and Critical Infrastructure supported by steel supports.

The Harbor Tunnel also serves as a corridor for a 32-inch PWC water line. A narrow gauge railroad in both tunnels provides transportation between the Red Hill storage and the receiving pumphouse.

The tunnel is ventilated so there is a movement of air; there were no fuel odors noted at the time of the field survey.

The lighting and communications systems are in a deteriorated condition due to age, lack of available spare parts, and very little maintenance performed on the systems.

The Harbor Tunnel and Lower Access Tunnel classification was arrived at using NFPA No. 30-1996, Flammable and Combustible Liquid Code Table 5-9.6.3, NFPA No. 70-1996, National Electric Code (NEC) Table 515-2, and MIL-HDBK-1022, Petroleum Fuel Facilities.

a. Under the category entitled "Indoor Equipment" or "Pumps, Bleeders, Withdrawal Fittings, Meters and Similar Devices", the valve areas in the Critical Infrastructure at the receiving pumphouse, the Critical Infrastructure the intersection at the Critical Infrastructure and in the Critical Infrastructure at Critical Infrastructure between tank pairs are considered a Class 1, Division 2 location from the valve body or flanges extending 5 feet in all directions, and up to 3 feet above floor level or grade within 25 feet horizontally from the edge of any valve.

b. Paragraphs 2.10.1.1 and 2.10.1.2 of Mil-HDBK-1022 for adequately ventilated spaces requires an electrical hazardous classification of Class 1, Division 2 within 5 feet of the surface of pumps, air relief valves, withdrawal fittings, meters, valves, screwed fittings, flanges and similar devices extending 25 feet horizontally from any surface of the devices and upward 3 feet above grade. Therefore, all areas in Critical Infrastructure which fall in these zones will be considered Class 1, Division 2 areas.

c. The remaining areas of Critical Infrastructure are considered non-classified areas except for the trough and sump areas cited in Section 4.3.3.2.1.

4.3.3.3 Emergency Lighting

There is a major concern regarding the electrical power feeds to the tunnel complex. At present the reliability of the electrical power supply under emergency conditions is questionable. Therefore, to insure the safety of personnel in the underground facility it is required that an emergency generator be provided to supply backup power to emergency lighting, elevators, the emergency voice/alarm communication systems, and the drop-track door release devices (unless solenoid is replaced with normally energized solenoid for door release upon loss of power).

4.3.4 Ventilation

The Red Hill complex being evaluated is located underground with practically no natural ventilation. Mechanical ventilation is provided by Critical Infrastructure Critical Infrastructure These units provide a good flow of air to all areas of the fuel storage and tunnel complex. Combined capacity of Critical Infrastructure

The ventilation systems are connected for automatic shutdown upon closure of the drop-track doors.

Provision should be made (if it doesn't currently exist) for the mechanical ventilation system to have manual override capability such that fire department personnel can restart the system under emergency conditions.

In addition, fire department personnel will respond to a fire emergency with portable smoke ejectors to be positioned in strategic areas as required.

Due to the configuration of this facility, a smoke control system is not feasible or recommended.

4.4 Potential Catastrophic Failure

4.4.1 General

The Potential Catastrophic Failure analysis section, provides, as its principal purpose, an analytical study which quantifies the hydraulic characteristics for potential fuel spills within the Red Hill complex. The hydraulics section of the study presents case studies of potential fuel spill(s) based on the most likely causes of failure. In each case study examined, the duration of spill is quantified based on the amount of product spilled and the type and size of rupture. Numerical estimates of flow quantity, flow velocity, and time of flow between the spill site and selected locations within the Lower Access Tunnel (LAT) and the Harbor Tunnel (HT) are provided and discussed.

For the purposes of the hydraulics analysis section of the study, two categories of catastrophic failure were examined. The hydraulic analyses focused on the quantification of the following failure categories:

(a) Fuel Tanks;

(b) Pipelines, valves, and associated pipeline components;

For each of the above categories a worst case was modeled. The worst case was based on failure category and the equipment location. Along with the worst case scenario other lesser cases were also considered so as to provide a range of failure potentialities. For each case modeled the duration, volume, and flow velocity and quantity were modeled for both source and for receiving tunnel. The quantification was obtained through a mathematical modeling of each of the failure categories.

4.4.2 Fuel Tank Failure Category

For the fuel tank failure case studies, the worst case spill would be expected to occur from a tank failure at the upper most tank unit of the **Critical Infrastructure**

a. The underground fuel storage tanks are located approximately Critical Infrastructure f Pearl Harbor within the Red Hill ridge, a volcanic ridge line running in an approximate southwest-northeast direction. The tank complex consists of Critical Infrastructure vertically oriented cylindrical tank units with approximate dimensions of Critical Infrastructure inside diameter, Critical Infrastructure in height from tank bottom to top as measured along the central longitudinal axis. Each tank has a fuel volume capacity of approximately Critical Infrastructure When full, the elevation head is approximately Critical Infrastructure for each unit.

b. The tanks are located in Critical Infrastructure the LAT running upgrade from Critical Infrastructure at the lowest base elevation -- Critical Infrastructure are the farthest upgrade with tank base elevation of Critical Infrastructure

c. The Critical Infrastructure upgrade-most units--tank pairs Critical Infrastructure are separated physically from the Critical Infrastructure by a concrete wall (lower access tunnel) and fuel-tight door (upper access tunnel).

d. For the worst case spill the upper most tank units with potential for free flow flooding into the LAT and HT was chosen. The Critical Infrastructure have the highest base elevation of the tank grouping open to the LAT and HT of Critical Infrastructure (see Table 4-1.).

4.4.2.1 Tank Rupture - Orifice Flow Model

Flow of fuel discharging from a tank to the atmosphere through a rupture in the tank, line, or valve is determined by the size and the shape of the orifice at the point of rupture and the height of the fluid level above the rupture point (fluid elevation head). (In the case of the Red Hill, the complex is underground but at ambient atmospheric pressure.) In order to systematically quantify a potential rupture for the Red Hill facility, the size of orifice was limited to two possibilities: Critical Infrastructure break. These size choices correspond to Critical Infrastructure

For the purpose of the analysis the orifice shape was assumed to be circular in cross-section. No reduction in size or change from circular shape was made; i.e., partial breaks and/or irregular fractures in either pipe or valve sections were not considered. Orifice flow reduction due to partial breaks and/or irregular fractures can be estimated by either reducing the orifice coefficients and/or reducing the estimated flow velocity and volume by constant percentage factor.

At the orifice (rupture point), the total fluid head is converted into kinetic energy as expressed by Eq. 4.1.

$$Vo = Cv(2gh)^{1/2} \qquad 4.1$$

Where,

V_o = the expression for the velocity at the point of discharge expressed in English units (feet per second--fps),

g = the acceleration due to gravity; 32.2 ft/(sec-sec),

h = the height or head of the fluid level above the point of rupture.

The orifice coefficients governing the discharge are:

$$Cv = Cd/Cc \qquad 4.2$$

Cv, Cd, Cc are the orifice coefficients for velocity, discharge, and contraction, respectively. For the parameterization used to model the discharge for a tank rupture the following coefficient values were used:

$$Cv = 0.62;\ Cd = 0.63;\ Cc = 0.984127$$

The coefficient values used to model the tank rupture correspond to a sharp-edged orifice.

The volume discharge was determined using Eq. 4.3 as follows.

$$Qo = (CcAo)Vo \qquad 4.3$$

Where,

Qo = the orifice discharge--volume flow in cubic feet per second (cfs), and

Ao = the unit cross-sectional area of the orifice (feet-squared).

It should be emphasized that the velocity of tank discharge and, correspondingly the volume flow Qo, are time dependent for the failure cases studied. I.e., because the fluid head lowers as a function of the time elapsed following rupture and the fluid level (head) is not maintained at a constant level, the values returned by the model for Vo and Qo as well as the tank draw down time, To, represent averages, not instantaneous values. Fluid velocity is proportional to head and would decrease as the level of the fluid is lowered.

The time to empty the tank, To, is found using the following expression.

$$To = \frac{2At\,[(h1)^{1/2} - Ih2)^{1/2}\,]}{CdAo(2g)^{1/2}} \qquad 4.4$$

At = the inside diameter of the tank.

4.4.2.2 Orifice Flow Model Results

In order to provide a range of tank failure estimates four case studies were modeled. The worst case failure mode considers a break in Critical Infrastructure at the base of Critical Infrastructure for a full-tank condition (Case Study 3). Lesser failure conditions studies conducted included Critical Infrastructure rupture for a half-full condition (Case Study 4) and Critical Infrastructure ruptures for full- and half-full conditions (Case Studies 1 and 2, respectively). The four case studies modeled are listed in Table 4-1. below.

Table 4-1

Orifice Flow Case Studies – Defined

Case Study No.		Tank Condition
1	Critical Infrastructure	Full
2		Half
3*		Full
4		Half

NOTE: Asterisk (*) denotes worst case condition.

The physics of the orifice discharge are summarized for the four cases studied in Table 4-2 and Table 4-3, to follow. The points of interest to the physics of the problem are the following:

a. The velocity of the discharge jet is strictly a function of the fluid head (refer to Eq. 4.1). As such, from the standpoint of the fluid jet velocity, the size of the rupture is not important.

b. However, the size of the rupture does determine the degree of impact from the standpoint of the volume flow, Qo. Both the volume of fuel spilled per unit time and the time needed to empty the tank are direct functions of orifice cross-sectional area. As such, the down tunnel flooding potential increases with an increase in the size of the break. From the standpoint of down tunnel flooding, a rupture of the maximum sized Critical Infrastructure from a full tank will result in the maximum flow volume delivered to the tunnel and the tank draw down time will be minimum.

Table 4-2

Orifice Flow Case Studies

Tank Discharge With Variable Head Flow Estimates

Critical Infrastructure

NOTE: Asterisk (*) denotes worst case condition.

Table 4-3

Orifice Flow Case Studies

Tank Discharge With Variable Head

Time to Discharge Tank

Critical Infrastructure

NOTE: Asterisk (*) denotes worst case condition.

4.4.3 Open Channel Flow Model

Given the discharge velocity, Vo, and volume flow, Qo, at the point of tank rupture, the next task in quantifying the failure mode is to parameterize the boundary condition linking the flow states of orifice jet at the rupture point to open channel flow through the LAT and HT channel.

4.4.3.1 Open Channel Flow Model Summarized

As a summary, the model predicts orifice velocity magnitudes associated with either Critical Infrastructure Critical Infrastructure in the range of Critical Infrastructure for initial tank fluid levels Critical Infrastructure

Critical Infrastructure represent initial tank fluid levels of approximately half-full and full, respectively. Orifice velocities of that order of magnitude are classed as supercritical flow. However, once the flow jet strikes the open channel it cannot retain its supercritical state; the flow state is converted to subcritical. Correspondingly, the maximum in fluid depth associated with the supercritical fluid is limited by the critical depth, Dc. Following the change in energy state to subcritical the fluid depth level must increase to a depth characteristic of subcritical flow. For the case studies analyzed, the transition in flow depth would be expected to occur by means of a hydraulic jump near or at the point of impact of the discharge jet with the tunnel floor.

Typically, the depth of free-falling supercritical fluids is equal to the critical depth. Thus, the determination of the critical depth, Dc, is fundamental to establishing the boundary condition needed to initialize the subcritical flow.

The expression used to determine the critical depth, Dc, is given by the following.

$$Dc = (Qo^2 / Gwt^2)^{1/3} \qquad 4.5$$

Where,

Wt = the channel width.

Once the flow converts to the subcritical flow state the hydraulic characteristics can be parameterized using the standard Manning's Equation for open channel flow.

$$Vi = \frac{1.49}{n} (Rh)^{2/3} \; (So)^{1/2} \qquad 4.6$$

Vi = the velocity of the open channel flow for channel reach i,

= the Manning's roughness coefficient,

So = the channel slope (ft/ft), and

Rh = the hydraulic radius defined by Eq. 4.7A.

The hydraulic radius is the ratio of the wetted area to the wetted perimeter of the cross-section of the flow.

$$Rh = Aw/Pw \qquad 4.7A$$

Where,

$Aw = D(Wt)$ 4.7B

= the wetted cross-sectional flow area of the channel,

and

$Pw = 2(D) + Wt$ 4.7C

= the wetted perimeter of the flow cross-section.

D = the fluid depth for the subcritical flow.

To calculate the down-tunnel flow, the Manning's Equation (Eq. 4.6) is solved directly for each reach using the known invert slope, So, and the calculated value for the hydraulic radius, Rh. However, Eq. 4.6 cannot be solved until an estimate of the subcritical fluid depth, D, is obtained. The problem associated with obtaining a direct solution of Eq. 4.6 for the initial run is the following.

1. The hydraulic radius, Rh, is indeterminate until an accurate estimate for the subcritical depth, D, is obtained.

2. The actual depth of fluid, D, following the hydraulic jump is unknown.

4.4.3.2 Numerical Iteration Algorithm Method Used to Initialize the Subcritical Flow

The method of solution developed for the given tunnel flow problem is an iterative scheme using the following steps.

Step 1 To initialize the open channel flow, Eq. 4.6 is solved to obtain V(0). The critical depth boundary condition, Dc, is used for the initial estimate of fluid depth. The initial value obtained for V(0) is used as the zeroth estimate used to initialize the iterative algorithm.

Step 2 The hydraulic radius, Rh(0), is solved using the following expression using the zeroth estimate of V(0) and the known value of channel grade, So.

Step 3 To estimate the unknown fluid depth, Dx(1), a polynomial expression for Dx was derived using Eq. 4.8A.

$$Rh(0) = \frac{(Nqo)^{3/2}}{(1.49\ So^{1/2}\ Aw(0))^{3/2}} \qquad 4.8A$$

Where, Qo and So are known and Aw(0) is estimated using Eq.4.7B. At this stage the value of the critical depth, Dc, is substituted for the unknown subcritical depth, D.

The polynomial used to estimate Dx is the following.

$$(Wt)^{5/2} \quad (1.49/n)^{3/2} \quad (So)^{3/4} \quad (Dx(1))^{5/2} \quad -(2Qo)^{3/2} \quad (Dx(1))-(Wt)(Qo)^{3/2}= 0 \qquad 4.8B$$

For the initial numerical step, Dx(1) is set equal to Dc.

Step 4 The initial estimate for Dx(1) is then used to calculate new estimates V(1), the wetted geometry parameters--Aw(1) and Pw(1), and Rh(1).

Step 5 Trial Q(1) is computed using Eq. 4.8C and compared to Qo using an error differencing algorithm, Eq.4.8D.

$$Q(1) = V(1)Aw(1) \qquad 4.8C$$

and

$$\text{ERR FCTN} = (Qo - Q(1))/Qo \qquad 4.8D$$

If the ERR FCTN is less than or equal to a preset error limit the algorithm is terminated. (For the present analyses, the limit was specified as 1 %).

Step 6. If the error limit is exceeded, then the new estimate for Dx is obtained using the following.

$$Dx(2) = Dx(1) + (\text{ERR FCTN})(Dx(1)) \qquad 4.8E$$

The iteration process then proceeds back to Step 2 and repeats the iteration procedure until the solution achieves closure to a value of Q(i) less than the specified limit.

Once a closure solution has been achieved for a given reach, the iteration process steps forward, spatially, to the next reach of the series set.

4.4.3.3 Tunnel Geometry

From the standpoint of modelling the geometry of the tunnel system, the total path length within the Red Hill tunnel complex, LAT and HT, can be treated as a single set of series connected reaches. As such, the volume discharge, Q, of the open channel flow remains constant throughout the extent of the tunnel.

$$Qt = Qi = Q_1 = Q_2 = \ldots = Qn \qquad 4.9$$

Qt = the Manning's open channel volume flow,

and

Qi = the volume flow through reach number i where i referes to any reach i through n.

Furthermore, the boundary condition linking the supercritical orifice discharge flow to the subcritical Manning's open channel flow requires conservation of volume discharge. I.e.:

$$Qt = Qo \qquad 4.10$$

Thus, the formulation requires the conservation of mass throughout. However, it is recognized that mass losses will occur due to infiltration into porous sections of bedrock, loss to the underdrain system, etc.; but for the time scale involved in this failure analysis, mass is considered conserved.

The cross-sectional areas and geometries of the LAT and HT sections of the pipe tunnel are approximately equal and constant throughout from the upper tank section to the terminus at Critical Infrastructure Critical Infrastructure The only variable controlling changes in flow velocity between reaches is the change in grade of the tunnel invert.

Table 4-4 below presents the reach geometry used for the failure analyses.

Table 4-4
Lower Access Tunnel (LAT) and Harbor Tunnel (HT)
Model Reach Geometry

Reach	Critical Infrastructure
1	
2	
3	
4	
5	
*6	
*7	
8	
9	
10	
11	
12	
13	
14	

NOTE: Starred items (*) denote stations with dual numbering.
1. Elevation of tunnel floor.

For the model geometry, the total channel length is subdivided into a set of series connected reaches based on channel (tunnel) invert grade. The LAT and HT were divided into 14 reaches of constant unwetted cross-sectional area. The length of individual reaches was determined by breaks-in-grade. Table 4-4 includes the individual reach definitions of length, invert elevation at the beginning and end points of the given reach, invert grade, and physical features located within the length of the reach.

4.4.3.4 Open Channel Flow Model Results

The open channel model is run for reach 2 through reach N, where N signifies the terminal reach specified. If the total LAT/HT channel is run, the terminal channel section is reach 14. Vi is determined using the Manning's Equation, Eq. 4.6; the fluid depth and associated wetted geometry of the given reach is next determined using the iteration algorithm method detailed earlier in Section 4.4.3.2.

As discussed in Section 4.4.3.2, solution closure is obtained, as before, by comparing the computed volume flow estimate, Qi, versus Qt (Eqs. 4.8C - 4.8E). The single difference in operation is the choice of the initial estimate of fluid depth. For the initialization of the open channel flow model, the depth was specified by the critical depth, Dc, for Iteration Step 1. For reaches 2 through N, the initial estimate used for fluid depth is the fluid depth calculated for the preceding reach.

$$Dxi(0) = Dxi\text{-}1(0) \qquad 4.11$$

To understand the physics of the flow it is helpful to use the analogy of flow through a river channel. For a river comprised of a single channel flowing from a single point source, the volume flow Q will be constant as long as there are no additional sources or sinks of fluid along the length of the flow path. If the river flow is constrained to a single, uniform channel then the only variable controlling changes in velocity from one reach to another is the change in channel invert grade. Because of the conservation of mass the following conditions hold:

$$Q = V \times Aw = \text{constant} \qquad 4.12A$$

Thus the functional relationships can be written as,

$$V = f(Rh,So), \text{ and}$$

$$Rh= f(Aw) \qquad 4.12B$$

If when passing from one reach to the next the invert grade, So, increases, then it follows that the amplitude of the velocity, V, will increase proportionally. Conversely, the wetted cross-section, Aw, decreases. If the grade, So, decreases; then the velocity V decreases and the wetted area, Aw, increases.

Consider the following example:

(1) Reach 1: slope 1 = steep; V1 = fast

(2) Reach 2: slope 2 is milder than slope 1;

therefore, V1 > V2

(3) Q = V1 x Aw1 = V2 x Aw2 = constant;

therefore, Aw1 < Aw2

For mild sloped bottoms, the river runs slower and deeper; steep sloped bottoms, the river runs faster and shallower.

4.4.4 Worst Case Discussion

Tables 4-5, 4-6, 4-7, and 4-8, to follow, presents the flow results for the total LAT/HT channel for Case Studies 1 through 4, corresponding to tank rupture Cases 1 through 4. Table 4-7 indicates the worst case scenario.

1. The slope from Reach 1 through Reach 2 (from Critical Infrastructure is relatively steep. Therefore, the velocity of fuel flow through these section is relatively fast (Critical Infrastructure Critical Infrastructure As such the depth of fuel in these sections somewhat low; Critical Infrastructure

2. The milder grade sections, Reaches 3 through 6 (from Critical Infrastructure down to the section immediately Critical Infrastructure would be expected to run full of fuel Critical Infrastructure Critical Infrastructure As such, it is particularly important that personnel be evacuated from these areas. The time of flow to the head of Reach 3 Critical Infrastructure will occur within Critical Infrastructure following the spill of fuel from Critical Infrastructure

3. The time of flow to the PWC water pump station (Reach 7) and the Critical Infrastructure is estimated to be Critical Infrastructure following the onset of the initial spill.

4. For the worst case spill Critical Infrastructure and full-tank--the time of flow to the Critical Infrastructure (Reach 14) is Critical Infrastructure This time would represent the minimum response time needed to evacuate personnel from this building.

Table 4-5

Case 1 - Open Channel Flow Results

Fuel From Critical Infrastructure Rupture - Full Tank

Flow through LAT and HT to Pump House 59

Reach	Sta.	Length (ft.)	Invert Elevation (ft.)	Fluid Depth (ft.)	Fluid Velocity (fps)	Elapsed Time (min.)	Location
1							
2							
3							
4							
5							
*6							
*7							
8							
9							
10							
11							
12							
13							
14							

Critical Infrastructure

NOTE: Starred items (*) denote stations with dual numbering.

Table 4-6
Case 2 - Open Channel Flow Results
Fuel From Critical Infrastructure Rupture - Half-Full Tank
Flow through LAT and HT to Pump House 59

Reach	Sta.	Length (ft.)	Invert Elevation (ft.)	Fluid Depth (ft.)	Fluid Velocity (fps)	Elapsed Time (min.)	Location
1							
2							
3							
4							
5							
*6							
*7							
8							
9							
10							
11							
12							
13							
14							

Critical Infrastructure

NOTE: Starred items (*) denote stations with dual numbering.

Table 4-7

Case 3 - Open Channel Flow Results

Fuel From Critical Infrastructure Rupture - Full Tank

Flow through LAT and HT to Pump House 59

(Worst Case Scenario)

Reach	Sta.	Length (ft.)	Invert Elevation (ft.)	Fluid Depth (ft.)	Fluid Velocity (fps)	Elapsed Time (min.)	Location
1							
2							
3							
4							
5							
*6							
*7	Critical Infrastructure						
8							
9							
10							
11							
12							
13							
14							

NOTE: Starred items (*) denote stations with dual numbering.

NOTE: Fluid Depth = Critical Infrastructure

Table 4-8

Case 4 - Open Channel Flow Results

Fuel From Critical Infrastructure Rupture - Half-Full Tank

Flow through LAT and HT to Pump House 59

Reach	Sta.	Length (ft.)	Invert Elevation (ft.)	Fluid Depth (ft.)	Fluid Velocity (fps)	Elapsed Time (min.)	Location
1							
2							
3							
4							
5							
*6							
*7							
8							
9							
10							
11							
12							
13							
14							

Critical Infrastructure

NOTE: Starred items (*) denote stations with dual numbering.

NOTE: Fluid Depth = Critical Infrastructure

4.5 Cost Analysis

PACDIV Cost Estimate Worksheet (See Appendix C) has been used to summarize the material and labor costs for implementing the five major recommendations identified in this report.

Exhibit 4-1 provides details for the AFFF fire suppression system.

Exhibit 4-2 provides details for the Emergency Voice/Alarm Communication System.

Exhibit 4-3 provides details for the Wheeled Dry Chemical Fire Extinguishers.

Exhibit 4-4 provides details for the Self-Contained Breathing Apparatus.

4.6 Conclusions and Recommendations

4.6.1 Conclusions

The overall Fire Protection Program for the Red Hill complex is very fragmented between FISC, PWC, PACDIV, and the Federal Fire Department. It is important that FISC take prime responsibility for this program and improve housekeeping, routine inspections, and preventative maintenance for the fire protection equipment and systems.

Consideration should be given to contracting with an outside fire protection company to handle detailed inspection of special hazard systems on an annual basis. Such systems would be the AFFF systems, Halon 1301, and UV (ultraviolet) flame detection systems.

A strong Fire Prevention Program should be instituted by FISC to improve housekeeping (clean up existing fuel spills and residue on tunnel floors and drain trenches), assure operability of all drop-track doors to provide acceptable fire and/or fuel separation, and assure availability and operability of all fire protection equipment/systems.

FISC, in conjunction with the Federal Fire Department, should develop Pre-Fire Plans for use by FISC and fire department personnel in responding to fire and other emergency conditions. See Exhibit 4-5 for a suggested format for a Facility Pre-Fire Plan.

4.6.2 Recommendations

4.6.2.1 Secondary Containment of Fuel and Fire Separation

The ability to contain a large fuel spill and provide fire separation at Red Hill and the associated tunnels is far less now than when the facility was constructed. Meanwhile, the impact of an uncontained spill would be much graver. Oil-tight doors which were probably operational when new are no longer functioning.

Specifically, they are not adequate structurally, are probably not oil-tight, and they are not fail-safe in their closure. The solenoid for automatic release is normally de-energized (NDE) and must receive power to operate. Upon power failure, the doors will not close. The release circuit is connected to the lighting circuit so, if the tunnel lights are turned off, there is no power to the solenoid. Their location allows considerable, unnecessary spreading of a large spill rather than containing it near its source and away from water wells and aquifers.

It is recommended that secondary containment of fuel be provided in the Lower Access Tunnel at the area just below the sump pit downgrade of Critical Infrastructure at approximately Critical Infrastructure This containment would require a new bulkhead and automatic door Critical Infrastructure capable of withstanding the fuel static pressure and with the provision for retrieving the fuel similar to the method used on existing Critical Infrastructure Critical Infrastructure This containment would retain fuel from a major tank leak in the tank area and away from important water supplies at the PWC well. The door would allow passage of the rail locomotive and cars and should incorporate the latest design methods which would simplify and increase reliability over existing oil-tight doors.

Critical Infrastructure should be upgraded or replaced to confine pipeline failures only; and, as a minimum, should be converted to a fail-safe operation.

4.6.2.2 Fire Suppression

There is no fixed fire suppression in the tank storage area. The highest hazard is to be found in the lower access tunnel at the valve gallery area for each tank. Due to the quantity of fuel stored in the Red Hill complex and the potential for a fuel release in this area, it is recommended that a fixed aqueous film forming foam (AFFF) deluge system be installed at the lower tank storage area. Zoned, open-head deluge systems will be automatically actuated by rate compensation thermal detectors. Exhibit 4-1 provides a more detailed description of the proposed AFFF fire suppression system.

Comments

This recommendation is based upon the experience and engineering judgment of a professional fire protection engineer. The unique configuration of this facility and the potential for fuel release mandate the installation of fixed fire protection.

4.6.2.3 Emergency Power Supply

There is a major concern regarding the electrical power feeds to the tunnel complex. To insure the safety of personnel in the tunnel complex the following recommendations must be implemented:

a. Install the 125KW generator outside Critical Infrastructure

b. Install a new power feed from the utility company Critical Infrastructure This will become the primary power for the upper and lower Tunnel.

c. Install an automatic transfer switch to start the generator when the primary A.C. power is lost. The switch should automatically transfer to the primary source when the power is restored.

d. Install a new 480V lighting panel in Critical Infrastructure This panel would Critical Infrastructure lower tank area, and a new lighting transformer.

e. Install a new lighting transformer and lighting panel in Critical Infrastructure This transformer and panel would Critical Infrastructure ighting receptacles, fan, etc. in the upper tank area.

f. Install a new 480V circuit in the shaft of Critical Infrastructure to supply the lower tank area.

g. Install a 480V A.C. manual transfer switch with the primary source from the upper tank level and a backup source from the PWC water pump station area. The backup source will be from power panel "P" located in the transformer room. As described in an earlier section the power feed is from the 13.8 KV feed from the PWC water pump station.

h. Install 480V lighting panel in the lower tank area. This panel will feed the following:

   1. An existing 30 KVA transformer, which is currently being feed from Panel "P". This transformer provides for lighting and receptacles in the area for Critical Infrastructure

   2. Existing motor operators in the area for Critical Infrastructure The current feed is from Panel "P".

   3. Existing power panel for 480V circuits in the area fo Critical Infrastructure This feed would replace the current feed from the PWC water pump station.

   4. New 480/208V transformer to feed the existing 208V power panel. This panel powers lights and receptacles in the area fo Critical Infrastructure

By installing the equipment described above and shown on sketches #1 and #2 a reliable power supply will be provided to insure safe operation of the facilities.

4.6.2.4 Emergency Voice/Alarm Communication

Communications during an emergency condition in the Red Hill complex are of major concern. At present there is only limited capability.

An approved emergency voice/alarm communication system must be installed throughout the underground facility. This system would provide signal notification to alert occupants of fire or other emergency. The evacuation signal should be the standard fire alarm evacuation signal described in NFPA 72, *National Fire Alarm Code.* Notification signals for occupants to evacuate should be by both audible and visible signals. In addition a two-way telephone communication service should be provided for the use of operating and fire department personnel. The communication should operate between the central control room and all areas of the underground facility. The system must be suitable for a Class I, Division 2 location.

4.6.2.5 Preventive Maintenance

Numerous devices, e.g., drop-track doors, door releases, float valve mechanism have not been properly maintained and were found to be inoperable. This area needs improved attention. In addition it is recommended that more frequent monitoring of tank levels be conducted; i.e., on an hourly basis rather than once per shift. Also Operations personnel should conduct periodic walk throughs of the tank storage area to receive early notification of a problem area.

Fire protection system maintenance is conducted by PWC on a monthly and semi annual basis. This covers fire suppression and fire alarm equipment systems. However, during interviews with PWC personnel, it appears that special hazard systems such as the UV flame detection system has never been properly serviced. Also the AFFF concentrate should be sampled on an annual basis and there was no evidence that this is being done. Consideration should be given to bring in an outside contractor on an annual basis with expertise in these specific areas.

4.6.2.6 Fire Department

Fire department personnel are familiar with the facility. They conduct an annual simulated fire drill. However, site interviews indicate that there are no prepared Pre-Fire Plans indicating response to different fire/emergency scenarios. Exhibit 4-5, attached, provides a suggested format for the development of a Facility Pre-Fire Plan.

The fire inspectors conduct monthly visual inspections of the fire equipment to assure that it is in place and appears to be functioning. They prepare a written report of their observations and any deficiencies which is turned over to the Fire Warden (Fuel Department Superintendent) to provide a more detailed follow-on inspection and correct deficiencies.

On an annual basis the Federal Fire Department conducts a simulated fire drill. Their normal dispatch to the Red Hill Complex consists of two engine companies and one ladder company; equipment comprises two 1000 gpm pumper trucks and one ladder truck. They also respond with hose packs, self-contained breathing apparatus, and other emergency equipment.

The Fire Department maintains 6000 gallons of 3% AFFF concentrate and also has a foam truck with 1000 gallons of AFFF.

Fire Department personnel consist of 100 persons on duty at all times.

4.6.2.7 Egress

Major projects by outside contractors consist of "hot work" (cutting and welding), dismantling piping, and cleaning of tanks. Contracts with outside contractors require that a competent contractor person be responsible for assuring safe conditions; perform inspections to assure gas-free conditions.

Present operating procedures require that the Inspection Branch of the Federal Fire Department issue all "hot work" permits.

Outside personnel periodically tour the Red Hill Complex (e.g., Navy League, POL conferees, and others). During such tours, these visitors enter the facility at Critical Infrastructure go through the heavy blast door at the upper tunnel, look into Critical Infrastructure then exit the facility. The visitors do not use the Critical Infrastructure nor do they go through any portion of the lower tunnel.

There is only one method of egress from the lower tank level in the new tank section, using the elevator. It is strongly recommended that a secondary method of egress by provided by installing a man-door in the lower bulkhead separating the two sections.

At present the entrance to Critical Infrastructure is barricaded and padlocked. Provision should be made to be able to evacuate from this adit during an emergency. It should also be available for egress of fire-fighting personnel.

Emergency lighting and exit signs shall be connected to the emergency power supply as discussed in Sections 4.3.3.3 and 4.6.2.3. Emergency illumination shall meet the performance requirements of NFPA 101, Section 5-9.

During normal operations, the occupancy level is very limited (less than 20 persons). However, it is recognized that a higher occupant load may occur during special site visits or during future construction contracts. With implementation of the above three recommendations and administrative control to limit the occupancy to 100 or fewer persons, it is felt that the existing means of egress from ;this facility will be adequate. Furthermore, a site briefing should be given to all non-operating personnel regarding the layout of the facility, means of egress, and emergency procedures prior to entering the Red Hill Complex.

As noted in Section 4.6.2.8, self-contained breathing equipment should be provided to allow personnel in the complex breathable air during the evacuation period. Dedicated units should be provided in the

Critical Infrastructure

4.6.2.8 Manual Firefighting

The Fuel Department is relying too much on outside support from the fire department. In a fire emergency the Federal Fire Department must respond with all needed firefighting equipment: fire hose packs, foam concentrate, self-contained breathing equipment, etc. The only equipment on-site are portable fire extinguishers and an emergency rail car located at the Critical Infrastructure at the underground water pump section. The rail car contains a twin agent hose reel system consisting of 500 lbs. Purple K dry chemical and 100 gallons of pre-mixed AFFF; the system is self-contained and pressurized by separate nitrogen cylinders. This rail car is used for emergency conditions, as well as fire watch equipment support during cutting and welding operations.

The Red Hill Complex requires the installation of fire hose stations, 150 lb. Purple K wheeled fire extinguishers, and dedicated self contained breathing apparatus for the usage of their own personnel.

Thirty-six (36) fire hose stations shall be located at each existing valve outlet (spaced every 50 feet in the tank area and 250 feet in the Harbor Tunnel). Each hose station shall consist of 100 feet of 1½-inch fire hose. A minimum of six hose packs (each with 100 feet of 1½-inch fire hose) shall be provided on the emergency rail car for manual firefighting response for a fire condition in the Harbor Tunnel.

Ten (10) 150 lb. Purple K dry chemical wheeled extinguishers shall be provided for manual firefighting for fuel spills and/or pressurized fuel fire (e.g., pin hole leaks in fuel piping). See Exhibit 4-3 for equipment location.

It is also recommended that twelve dedicated self-contained breathing apparatus units be provided for FISC and/or Fire Department personnel. See Exhibit 4-4 for location of these units.

4.6.2.9 Fire Protection of Pipeline Supports

Pipelines in the Harbor and Lower Access Tunnels are supported on unprotected steel racks. An exception is Critical Infrastructure DFM line which rests on concrete saddles for a large part of its length. Fire in the tunnels away from the tanks could rapidly weaken the steel racks and cause the Critical Infrastructure lines to drop and possibly rupture. Valves could be closed to reduce the extent of the problem. When the lines reach the tank area, they are totally dependent on steel supports. The large lines serving the tanks are supported on steel wide flange, column and beam supports. If these supports fail due to being heated by fire, the lines could drop and break at the tank entrance wall in the valve gallery and there would be no way to shut off the flow from the tank. In view of the potential of this worst case scenario, consideration should be given to the application of a sprayed-on fireproofing material on steel supports to provide a minimum of a one-hour fire resistance rating. Pipe supports in the tank area and galleries would be a higher priority than pipe racks in the tunnels.

4.6.2.10 Housekeeping

The floor around outlet valves in tank valve gallery shows periodic fuel spill/leakage and needs to be cleaned.

4.6.2.11 Ventilation

The ventilation system will need further review to assure adequate ventilation for the lower tank storage is provided when an additional bulkhead separation is provided between the tank area and the main tunnel. However, the door in this bulkhead will normally be open (and provided with an automatic closure device), as is the case with the existing doors so the ventilation will only be marginally affected.

4.6.2.12 Overall Fire Protection Program

The Fire Protection Program appears to be very fragmented. There are currently multiple areas of responsibility as noted:

Inspection	-	Federal Fire Department Fuel Department, Fire Warden
Maintenance	-	PWC

Engineering	-	PACDIV
		PWC
		Fuel Department
Firefighting	-	Fuel Department
		Federal Fire Department

The Fuel Department (FISC) needs to take a centralized role in the Fire Protection Program for the Red Hill Complex. Various parts of the program can be delegated to other departments as noted above (e.g., maintenance to PWC), but the overall responsibility for the Fire Protection Program must reside with a single entity – the Fuel Department.

EXHIBIT 4-1

AFFF FIRE SUPPRESSION SYSTEM

Due to the quantity of fuel stored in the Red Hill complex and the potential for a fuel release in the lower tunnel, it is recommended that a fixed aqueous film forming foam (AFFF) fire suppression system be installed to provide protection for this area.

It is proposed that Critical Infrastructure 600 gallon 3% AFFF bladder tank pressure proportioning systems be provided to supply foam solution to zoned open head deluge systems. The systems will be automatically actuated by rate compensation thermal detectors (to be provided under construction contract no. N62471-89-C-02416; Pro Critical Infrastructure Fire Alarm System for Red Hill POL Fuel Storage Facilities). Critical Infrastructure detection/deluge zones are recommended as follows:

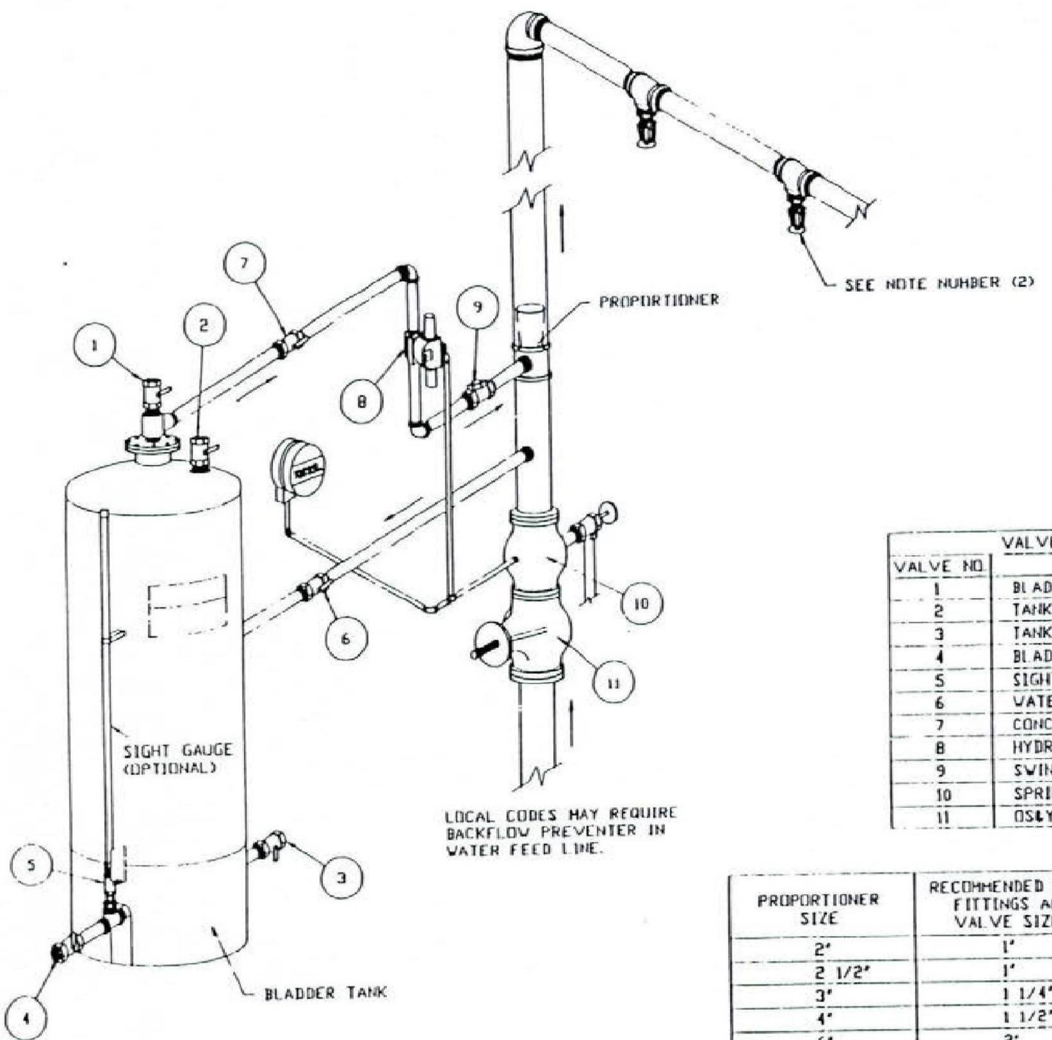
Critical Infrastructure

The design density for the AFFF system will be Critical Infrastructure of floor area. Total AFFF concentrate required for each system will be based upon the following calculations:

Area of coverage for each system:

Critical Infrastructure

Water supply to each AFFF system will be fed by the existing 6 inch water line located in the lower access tunnel. Each system will consist of a 600 gallon 3% AFFF bladder tank with required trim, 4 inch OS&Y valve, 4 inch deluge valve (connected to fire alarm system for automatic actuation), 4 inch foam proportioner, distribution piping, and open head sprinkler nozzles.



NOTES:

1. SPRINKLER VALVE MAY BE ALARM CHECK, DRY PIPE, PRE-ACTION, OR DELUGE TYPES AS REQUIRED BY SYSTEM DESIGN.

2. DISCHARGE DEVICE MAY BE SPRINKLER HEADS (AS SHOWN) OR OTHER TYPE DEVICE SUCH AS MONITOR NOZZLES, HANDLINE NOZZLES, OR FOAM CHAMBERS AS REQUIRED BY SYSTEM DESIGN.

3. ARROWS INDICATE DIRECTION OF FLOW.

4. RECOMMENDED INTERCONNECTING PIPE, FITTINGS, AND VALVE (SEE CHART, NUMBERS 6 THRU 9) SIZES TO BLADDER TANK ARE GIVEN CORRESPONDING TO PROPORTIONER SIZE.

5. PIPE, VALVES, AND FITTINGS MAY HAVE TO BE UPSIZED TO ENSURE NEAR 0 psi FRICTION LOSS TO MAINTAIN BALANCED PRESSURE OF WATER AND CONCENTRATE AT THE PROPORTIONER.

6. THE HYDRAULIC CONCENTRATE VALVE (VALVE #8) MAY BE ELIMINATED ON AN AUTOMATIC SYSTEM HAVING ONE PROPORTIONER PROVIDED THE PROPORTIONER IS LOCATED AT AN ELEVATION AT OR ABOVE THE BLADDER TANK FOAM CONCENTRATE OUTLET CONNECTION LOCATED AT THE TOP OF THE TANK.

VALVE DESCRIPTION		NORMAL POSITION	
VALVE NO.	DESCRIPTION	MANUAL SYSTEM	AUTO SYSTEM
1	BLADDER VENT/FILL - 1"	CLOSED	CLOSED
2	TANK SHELL VENT - 1"	CLOSED	CLOSED
3	TANK SHELL DRAIN - 1"	CLOSED	CLOSED
4	BLADDER DRAIN/FILL - 1"	CLOSED	CLOSED
5	SIGHT GAUGE (OPTIONAL) - 1/2"	CLOSED	CLOSED
6	WATER INLET	OPEN	OPEN
7	CONCENTRATE SUPPLY	CLOSED	OPEN
8	HYDRAULIC CONCENTRATE	---	CLOSED
9	SWING CHECK	---	---
10	SPRINKLER ACTUATION/ALARM	---	CLOSED OR OPEN
11	OS&Y	CLOSED	OPEN

PROPORTIONER SIZE	RECOMMENDED PIPE FITTINGS AND VALVE SIZES
2"	1"
2 1/2"	1"
3"	1 1/4"
4"	1 1/2"
6"	2"
8"	2 1/2"

TYPICAL BLADDER TANK SYSTEM PIPING REQUIREMENTS

Foam Fire Fighting Systems Specifications

Bladder Tank Proportioning System

1.0 The Foam Solution:

The foam solution shall be produced by introducing foam concentrate into the water stream by the balanced pressure proportioning method using a bladder (diaphragm) pressure tank and a modified venturi proportioner (ratio controller).

1.1 Bladder Tank:

Tank shall be a (vertical) ~~(horizontal)~~ cylindrical steel ASME coded pressure vessel with a nylon reinforced Buna-N bladder shaped to conform to the inner pressure vessel configuration. Tank shall be designed for working pressure of 175 psi (1207 kPa) and hydrostatically tested to at least 262 psi (1806 kPa). The tank interior shall be coated with a coal tar epoxy sealer for additional corrosion resistance. The bladder tank shall be UL listed or FM approved together with the type of foam concentrate and proportioner(s) being used in the system. The bladder tank is to have a minimum __600__ gallon capacity to provide sufficient foam concentrate for the time specified when the system is discharging foam solution at total maximum system flow. The bladder tank is to be complete with all necessary outlets and supports such as a continuous welded skirt equal to tank diameter or two saddle supports as appropriate. Associated trim on the bladder tank shall include bronze pipe and fittings, four 1 in. bronze ball valves with secured nameplate depicting the valve name and operating position, and a break-resistant polycarbonate sight gauge. The tank exterior shall be primed and painted red ~~(enamel)~~ (epoxy) for corrosion protection. The bladder tank, proportioner, and foam concentrate shall all be the products of a single manufacturer. The bladder tank shall be an Ansul Part No. __69010__ or equal.

1.2 Proportioner (Ratio Controller):

The foam proportioner(s) is to be a modified venturi type designed to accurately proportion and control the mixing of pressurized foam concentrate into a water stream. The proportioner shall have ~~either NPT threads (2 in. and 2 1/2 in. sizes) or~~ "between flange" type (~~3 in.~~, 4 in., ~~6 in. and 8~~ in. sizes) designed to fit between two 150 lb. pipe flanges. Proportioner(s) shall be sized for the specified flow rate(s) and either be UL listed or FM approved with the type of foam concentrate and bladder tank being used together in the system. A fixed metering orifice, secured with a stainless steel retaining ring, shall be sized according to the type and percentage of foam concentrate used. The proportioner(s) shall be an Ansul Part No. __69351__ or equal.

EMERGENCY VOICE/ALARM COMMUNICATION SYSTEM

As discussed in Sections 4.0 and 5.0 of this report the lifesafety of FISC personnel working in the Red Hill fuel complex is a major concern. Therefore, in the event of a fire or fuel release in this underground facility it is imperative that personnel be notified immediately of such an emergency condition.

It is recommended that an early warning emergency voice/alarm communication system be installed throughout the underground facility. This system will replace the existing (out of service) telephone system. It is proposed that a GAI-Tronics Model #271 hazardous area (intrinsically safe) telephone/fireman's telephone system with battery backup be installed. Ten (10) permanently installed telephone sets be located at strategic locations throughout the underground facility. The central panel for the fireman's telephone system will be located in the Receiving Pumphouse.

This system will provide 2-way emergency voice communication for operations and/or firefighter communications well as audible/visual alarm notification for emergency evacuation purposes . The system will be designed for a Class I, Division location.

EXHIBIT 4-3

150 LB. WHEELED DRY CHEMICAL FIRE EXTINGUISHERS

It is recommended that ten (10) Ansul 150 lb. Purple K (potassium bicarbonate) dry chemical wheeled fire extinguishers be provided in the underground fuel complex at the following locations:

Critical Infrastructure

TOTAL - 10 UNITS

SELF-CONTAINED BREATHING UNITS

There previously were self-contained breathing units located throughout the underground fuel facility at Red Hill. However, some time ago these units were removed at the instruction of the Environmental Safety Group.

Due to the delay in response time to the facility by personnel from the Federal Fire Department, it is critical that FISC personnel have the availability of self-contained breathing apparatus to assist in a safe evacuation of the facility in the event of an emergency condition.

It is recommended that twelve (12) minimum 30 minute capacity self-contained breathing units be provided in the underground fuel complex at the following locations:

Critical Infrastructure

TOTAL - 12 UNITS

EXHIBIT 4-5
SUGGESTED FORMAT FOR DEVELOPMENT OF A

FACILITY PRE-FIRE PLAN

ilding No.: 105-KE, 1713-KD & 1714-KE   Master Box No.: 1250 & 1310 Street Box

A Platoon   Area 100-K   Date January 1992

MC Entered   Contractor WHC   Th. _ _ F ___ Yr. 1993

Occupancy: Reactor Facility (deactivated)

Special Hazards: PCB oil, 4160V, Radiation and contamination, Argon cylinders. Plutonium fuel storage in basin.

Exposures: 1713-KE, 1714-KE, 119-KE, 117-KE, 1706-KER, 1706-KE, 1706-KEL, & 115-KE

Special Exposures:

Equipment Response: Engine #1 and Engine #2

Location of Electrical Disconnect: See floor plan (radiation zone) electrical equipment room.

Nearest Hydrant: #6 southeast, #7 east, and #8 northwest

Water Available: 3,000 GPM   Type of Automatic Alarm Systems: 12 Fenwal Heat detectors and wet sprinkler system - flow switch

Type Sprinkler Systems: SR 4" Wet pipe in corridor 1, flow switch, OS&Y valve and Auxiliary drains

COMPOSITION OF FACILITY

Critical Infrastructure

PLAN OF ATTACK

Engine #1 will respond to RFAR box #1250 and will use two 1 pre-connects for attack.

Engine #2 will respond and assist as needed and will also cover exposures.

NOTE: If a power outage occurs, all fire suppression water is lost, including hydrants.

[signature] 3-16-98
uilding Management Representative

[signature] 3-14-95
Fire Department Officer's Concurrence

1. ENTRY

Critical Infrastructure

2. ELECTRICAL SERVICE & HAZARDS:
Electrical equipment room 4160 V service. PCB-OIL - radiation zone - high voltage electrical shock. Entry to the electrical equipment room is by passing through basin storage area (radiation zone).

3. RADIATION - CONTAMINATION:
ZONE 1 on floor plan (RED). Storage basin, transfer area, miscellaneous storage area, wash pit, wash pad, storage area. Electrical equipment room and part of Room 3 off of Corridor 1.

Radiation and contamination signs are posted throughout the building from the basement area to the roof area.

4. TOXIC GASES - HAZARDOUS CHEMICALS:
Smoke and fumes from burning rubber and contaminated SWP clothing. PCB oil in electrical equipment Room. See information on back of this prefire plan.

5. PROTECTIVE CLOTHING:
Firefighters bunker gear, self-contained breathing apparatus. SWP clothing may be required to enter basin area.

6. RESCUE:
Rescue should be no problem in the nonradioactive or contamination areas. Basin area may create somewhat of a problem around the loadout area (radiation zone).

7. EXTINGUISHMENT:
Water, foam, dry chemical, CO2. (Approved fire extinguisher)

8. COMBUSTIBLES:
Class "A" -
Ordinary combustibles (wood, rubber, cloth paper, etc.)

Class "B" -
Flammable or combustible liquids (gases, grease or similar materials)

Class "C" -
Energized electrical equipment.

9. VENTILATION:
Exhaust fans from fire apparatus.
Cross ventilation (open doors)
Building exhaust system

10. SALVAGE OPERATIONS:
Normal firefighting salvage operations in areas that are not contaminated or in radiation zones.

RMU, Safety and Building Manager should be present during salvage and overhaul operations.

11. FIRE DETECTION AND PROTECTION EQUIPMENT:
One wet sprinkler Jr. system. 4" w/OSY valve, flow switch that activates alarm system. Sprinkler system is located in Corridor 1 overhead.

One inspector test valve located in storage room (Room 1A) in the northeast corner.

Three auxiliary drains: One in Room 3, one in Corridor 1 and one in corridor 10

Six auxiliary boxes -
Three located on west wall in basin area by loadout area (radiation zone)

Two located on north side of 105-KE outside area.

One located on wall just inside main door leading to Corridor 1

Twelve Fenwal Heat Detectors (self restoring)
Five in deactivated control room
Three in electrical equipment room (radiation zone)
Three in 1714-KE Building (Heat detector)
Four in 1713-KE Smoke Detector

12. HEATING AND VENTILATION:
Overhead space heaters (wall mounted thermostat). There are five roof ventilators.

13. ANNUNCIATOR AND/OR FIRE ZONES:
NO ANNUNCIATOR PANEL - only one zone

One sprinkler system flow switch; six auxiliary boxes and twelve fenwal heat detectors that will activate RFAR Box 1250. All will need to be checked to determine which caused the activation of RFAR Box 1250.

1. Box 1310 is a Street Box only
2. There is no panel
3. There are four smoke heads in building 1713-KE and 1714-KE.

Critical Infrastructure

Critical Infrastructure

Critical Infrastructure

SECTION 5
ENVIRONMENTAL RISK ASSESSMENT/ANALYSIS

5.1 General

This study evaluates the environmental impact associated with a major release from the fuel storage and distribution system at Red Hill. The study reviews the environmental setting in the fuel storage area and along the distribution tunnel, discusses pertinent regulations, and focuses on two fuel release scenarios.

5.2 Scope of Work

The scope of work for this study is to assess potential environmental impacts of the entire Red Hill Fuel Tank and Tunnel Complex. Specifically we have evaluated:

- The potential contamination of the aquifers beneath the site by a fuel spill;
- The potential impact of a fuel spill on the surrounding surface waters and biota;
- The adequacy of existing tunnel structures to contain a massive fuel spill;
- The potential for earthquake damage;
- The potential for other environmental hazards surrounding the Red Hill Complex.

5.3 Codes, Regulations and Standards

Federal, Military, and State regulations involving air, water, hazardous materials, USTs, health and safety, among others, were reviewed. Pertinent regulations, standards, and guidelines pertaining to the Red Hill Complex are listed below.

5.3.1 Pertinent Federal Regulations

- National Emissions Standards for Hazardous Air Pollutants (NESHAP), 40 CFR 61.

State of Hawaii Air Pollution Control and Air Quality Standards supersede federal NESHAP regulations for activities in the State. See Section 5.3.3.

- Resource Conservation and Recovery Act (RCRA), 40 CRF Paris 240 to 299.

These regulations provide management for hazardous waste and the safe disposal of discarded materials. Hazardous wastes should be packaged, labeled, stored, transported, treated, and disposed of in accordance with RCRA, military, and applicable state regulations.

- Federal Water Pollution Control Act, (FWPCA), 40 CFR Part 112-Oil Pollution Prevention.

The regulations were enacted to prevent discharges of oil into the navigable waters of the United States (e.g., Pearl Harbor and Halawa Stream) and to contain such discharges if they occur. The regulations endeavor to prevent such spills by establishing procedures, methods and equipment requirement of owners or operators of facilities engaged in drilling, producing, gathering, storing, processing, refining, transferring, distributing, or consuming oil.

- Comprehensive Environment Response Compensation, Liability Act (CERCLA) Toxic Chemical Release reporting: Community Right-To-Know 40 CFR 372, and Emergency Planning and Notification, 40 CFR 355.

CERCLA contains federal standards for submission of information relating to the release of toxic chemicals under section 313 of Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986. The information is intended to inform the general public and the communities surrounding covered facilities about releases of toxic chemicals.

- Occupational Safety and Health (OSHA) 29 CFR 1910 and National Institute for Occupational Safety and Health (NIOSH).

OSHA 29 CFR 1910 contains federal standards for health and safety involving tank cleaning including equipment, training, safe levels for chemicals, medical surveillance information for workers and additional safety and health standards. State safety and health regulations supersede federal regulations in Hawaii.

- Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST) 40 CFR 280 Part 280.

The tanks are not regulated by 40 CFR 280 per Subpart A 280.10 (c) Deferrals. The regulations state "Subparts B, C, D, E, and G do not apply to any of the following types of systems:... (5) UST systems with field-constructed tanks." Subpart G involves closure of USTs. Field-constructed tanks are regulated by Subpart A, titled "Program Scope and Interim Prohibition" and Subpart F, titled "Release Response and Corrective Action for UST Systems Containing Petroleum or Hazardous Substance". If a release occurred from the Red Hill tanks, Subpart F would need to be followed.

5.3.2 Pertinent DOD Guidelines

- Department of Defense (DOD) Directive 6050.1

The DOD Directive 6050.1 reflects compliance with several Federal regulations as summarized below and should be followed.

DOD Directive 6050.1 requires compliance with 40 CFR 280; thus, only Subparts A and F apply, as stated above.

DOD Directive 6050.1 required compliance with station and federal Air Toxics Programs, including control of volatile organic carbons (VOCs). Air permits as required by Federal, state or local air pollution control agencies must be obtained for constructing, operating, modifying, or demolishing stationary sources and compliance with ambient air quality concentrations is required.

DOD Directive 6050.1 policy concerning safe drinking water involves (1) compliance with applicable federal, state and local regulations, (2) providing appropriate public notification, (3) promoting water conservation, (4) implementation of testing requirements, and (5) maintaining management information.

DOD Directive 6050.1 has extensive hazardous waste policies involving disposal, transport, management plans, storage, reporting and recording keeping.

- OPNAVINST 5090.1A

Operation guide 5090.1 requires compliance with state regulations and the Federal Water Pollution Control Act. The Navy has both a Spill Prevention Control and Contingency (SPCC) Plan and Oil Spill Contingency Plan (OPCP) for Red Hill and Pearl Harbor. The Navy SPCC plan specifies spill prevention requirements for the Red Hill and Pearl Harbor area and the OPCP specifies equipment, personnel, and procedures for response to an oil spill.

5.3.3 Pertinent State Regulations

- Hawaii Administrative Rules (HAR) Title 12, Chapter 148, Lead Exposure in Construction: June 21, 1993.

The emergency standard for employee exposure to lead dust and fumes during certain high hazard construction operations also pertains to tanks formerly containing leaded fuel.

- Hawaii Occupational Safety and Health (HIOSH) Part II Chapter 60.

HIOSH is the Hawaii OSHA regulation which follows the federal standards for health and safety and in some cases is more stringent.

- HAR Title 11 Chapter 54 (Water Quality Standards)

The Station of Hawaii Water Quality Standards, as set forth in the HAR, Title 11, Chapter 54 regulate the quality of Hawaii's surface waters. State waters are classified into categories, with water quality standards for each category given. The general policy is to prevent degradation of water quality in any water body. These regulations would be applicable to any fuel release at Red Hill that may potentially enter a surface water body, such as Halawa Stream or Pearl Harbor.

- 340 E Hawaii Revised Status (HRS) Safe Drinking Water

Drinking water pumped from the Red Hill water pumping station is subject to meet all State Safe Drinking Water standards.

- 342 J HRS Hazardous Waste

Waste generated during maintenance or cleaning of equipment at the Red Hill complex may be subject to regulations requiring proper disposal as a hazardous waste.

- 128 D HRS Environmental Response Law (ERL)

The statute was enacted to serve as the Hawaii version of the federal "Superfund" program. The ERL authorized the Director of Health to perform cleanup of releases or threatened releases of hazardous substances, to order private parties to perform cleanups, and to recover costs incurred for cleanups performed by the State. The ERL also provides for civil and criminal penalties for failure to report releases as required. The ERL expressly lists oil as a hazardous substance. Oil is defined as "oil of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, oil mixed with wastes, crude oil, or any fraction or residue."

5.4 Environmental Setting

5.4.1 Site Description

5.4.1.1 General

The Navy Red Hill Fuel Storage Area (RHFS) is located in Red Hill, Oahu, Hawaii. Red Hill is a ridge that separates Moanalua and Halawa valleys along the southern coastal plain of Oahu. The highest elevation of the ridge at the inland boundary of Navy property is approximately 700 feet and the lowest, at the seaward boundary, is approximately 450 feet. The sides of the ridge fall steeply into the valleys on either side.

5.4.1.2 The Red Hill Tanks

The RHFS was constructed in the early 1940s. The fuel storage area consists of Critical Infrastructure underground storage tanks (USTs). The top of the tanks are at a minimum of Critical Infrastructure Critical Infrastructure

Critical Infrastructure have capacities of Critical Infrastructure and Critical Infrastructure have Critical Infrastructure capacity. Critical Infrastructure re separated from the Critical Infrastructure This wall was constructed to isolate Critical Infrastructure because, at that time, they contained AVGAS, a more flammable fuel than stored in the other tanks. Al Critical Infrastructure currently store diesel or JP-5 fuel.

There are two subsurface tunnels in the tank area; one runs along the top of the tanks and the other along the bottom of the tanks. There are Critical Infrastructure connecting these two tunnels. Critical Infrastructure Critical Infrastructure

Critical Infrastructure are vented by a shaft which daylights near the top Critical Infrastructure are vented by a ventilator shaft at the top Critical Infrastructure These tanks also have a vent intake/exhaust at Critical Infrastructure Critical Infrastructure are vented by a shaft which daylights at the top o Critical Infrastructure

5.4.1.3 The Red Hill Tunnels

The Red Hill tunnel system consists of Critical Infrastructure There are Critical Infrastructure o the tunnel and tank system at Critical Infrastructure

The Upper Access Tunnel (UAT) runs between the top of the tanks, with openings extending out to the tops of the tanks. The UAT is accessible from Critical Infrastructure (Figure 5-1).

The Lower Access Tunnel (LAT) runs between the bottom of the tanks, also with openings to the bottom of tanks. From Critical Infrastructure and then Critical Infrastructure for a distance of approximately Critical Infrastructure Critical Infrastructure The LAT then runs an additional distance of approximately Critical Infrastructure to Critical Infrastructure of Red Hill (Figure 5-1).

An abandoned diesel power plant is located in the LAT between the Critical Infrastructure A narrow steel door in the LAT marks the location and former entrance to the diesel power plant. The steel door is sealed but is not believed to be water tight.

The Harbor Tunnel branches from the LAT near the Water Pump Station and runs approximately Critical Infrastructure Critical Infrastructure (Figure 5-1). A Critical Infrastructure is located at the Pearl Harbor end of the tunnel.

The tunnels house Critical Infrastructure which runs down the LAT to its junction with the Harbor Tunnel, and then along the Harbor Tunnel to Pearl Harbor. The LAT/Harbor Tunnel system passes beneath Critical Infrastructure Critical Infrastructure before reaching Pearl Harbor Naval Reservation. The tunnels slope toward Pearl Harbor over their entire length, with the grade varying from a maximum at Red Hill beneath the tanks of Critical Infrastructure to a minimum near Pearl Harbor of Critical Infrastructure

The LAT/Harbor Tunnel system carries Critical Infrastructure with diameters of Critical Infrastructure Critical Infrastructure The Critical Infrastructure pipelines currently transport diesel fuel and the Critical Infrastructure line currently transports JP-5 to and from the Red Hill tanks and the Pearl Harbor Pump House. The tunnels also contain a 32-inch water pipeline. The 32-inch water line rises up out of the tunnel through a shaft in the Critical Infrastructure Critical Infrastructure

Critical Infrastructure is located in Pearl Harbor Naval Reservation and leads to the Pearl Harbor Pump House. The main Critical Infrastructure of the Pump House are the Critical Infrastructure is located Critical Infrastructure and is currently under control of Critical Infrastructure are located in Red Hill.

5.4.2 Geology

The majority of information on the geology of the Red Hill area is taken from Macdonald (1983), unless otherwise noted. Red Hill consists of basalts originating from the Koolau volcano, an unusually elongated shield built principally by eruptions along a northwest-trending rift zone. The end of activity of the Koolau volcano was followed by a period of volcanic quiet of at least 2 million years.

During this period of erosion, valleys more than 600 meters deep were cut into the Koolau range, and alluvium accumulated in the valleys as the island slowly sank at least 1,200 feet. The Moanalua and Halawa Valleys on each side of the Red Hill ridge are characterized by alluvial accumulations associated with the erosion of the Koolau Range. During the early stage of the Kaena stand of the sea (+95 feet), continuing erosion of the Koolau volcano resulted in a delta of silt and sand growing seaward from the foot of the ridges (e.g., Red Hill) and valleys (e.g., Moanalua and Halawa).

Following this period of alluvial deposition on the southern coastal plains of Oahu, volcanic activity resumed in the form of over 30 separate eruptions constituting the Honolulu Series. The eruptions of the Honolulu Series did not come in rapid succession, but were scattered over a period of hundreds of thousands of years.

Just east of Pearl Harbor lies a cluster of overlapping tuff cones including Aliamanu, Makalapa, and Salt Lake Craters. The Harbor Tunnel skirts the north slopes of Aliamanu and Makalpa Craters. Based on evidence of superposition of tuff products, the Aliamanu vent is the oldest. Formation of the cone blocked the former courses of the Moanalua and Halawa Streams and forced the streams to make wide detours to the sea. Well-bedded water-lain tuff of the Aliamanu eruption indicate that later stages of this eruption took place during the Kaena stand of the sea (Stearns and Vaksvik, 1935). Landward stages of calcareous reef deposition also took place during the Kaena sea stand.

Salt Lake and Makalapa vents appear to have taken place concurrently during the Waipio stand of the sea (-39 feet). In road cuts, the air-laid Salt Lake Tuff has been observed to rest on red soil (classified as erosional, not residual) on top of the Aliamanu tuff, indicating a period of erosion between the Aliamanu and Salt Lake-Makalapa eruptions. During the lower Waipio sea stand, the streams cut channels through the former deltaic deposits and coralline reef deposits that had been formed during the Kaena sea stand.

During the Waimanalo sea stand (+25 feet), the seaward air-laid Salt Lake-Makalapa tuffs were submerged. This tuff is overlain by limestone of the Waimanalo stand.

Pearl Harbor is essentially a series of drowned river valleys. The valleys of several streams, including the Halawa Stream, merged into a single master stream. The broadly rounded outlines of the individual lochs are the result of widening of the tributary valleys in the easily eroded, deltaic sediments during the Waipio stand of the sea. The present harbor entrance was kept narrow by the resistant coral reef. During higher sea stands, the broad tributary valleys were drowned to form the lochs of Pearl Harbor.

A geologic cross-section along the tunnel route is presented as Figure 5-2. This cross-section is a schematic only, as sufficient subsurface data are not available to delineate geologic formation boundaries. The ground surface and tunnel elevations have been taken from plans provided us, but the geologic formation boundaries below the tunnel are based on limited geological information and on a limited knowledge of topography in relation to past sea stand elevations.

5.4.3 Soils

The tunnel is known to have been constructed through rock over its entire route. However, soil maps for the area (Foote et al., 1972) indicate a number of different soil types along the tunnel route and nearby. Many of these soil types result from weathering of volcanic rock, and are likely present above the tunnel. The surface soil types and their properties would be significant in any areas potentially subject to leaking fuel. We have included a brief summary of the major soil types, beginning at Red Hill and following the tunnel route to Pearl Harbor. The soil map for the area, with the approximate location of the tunnel route, is presented as Figure 5-3.

Rock Land: Rock land (rRK) is made up of areas where exposed rock covers 25 to 90 percent of the surface. Rock outcrops and very shallow soils are the main characteristics. The rock outcrops are mainly basalt and andesite. This land type is nearly level to very steep. The crest of Red Hill is classified as rock land. Rock land also occurs in the area of the tuff cones.

Manana Series: Two soils of the Manana Series, silty clay loam (6 to 12 percent slopes; MoC) and Manana silty clay (12 to 25 percent slopes; MpD2), are mapped on the southeast slopes of Red Hill. This series is described by Foote (1972) as consisting of well-drained soils on uplands. These soils developed in material weathered from basic igneous rock. They are gently sloping to steep. MoC is noted to occur on smooth slopes in the uplands. In a representative profile the surface layer is dark reddish-brown silty clay loam about 8 inches thick. The subsoil, about 42 inches thick, is dusky-red, dark reddish-gray, and dark reddish-brown silty clay that has subangular blocky structure. The depth to the panlike sheet is 15 to 30 inches. Permeability of MoC is moderately rapid above the pan and moderate below. Runoff is medium and the erosion hazard is moderate. MpD2 is similar to MoC except that it is moderately steep, is eroded and has a silty clay texture in areas. Runoff is rapid and the erosion hazard is severe.

Lahaina Series: Two soils of the Lahaina Series, Lahaina silty clay (3 to 7 percent slopes; LaB) and Lahaina silty clay 7 to 15 percent slopes; LaC), are also mapped on the southeast slopes of Red hill, makai of the Manana soils. The Lahaina series is described by Foote (1972) as consisting of well-drained soils on uplands. These soils developed in material weathered from basic igneous rock, and are gently sloping to steep. LaB soil occurs on smooth uplands, exhibits moderate permeability, slow runoff, and only slight eroision hazard. In a representatvie profile the surface layer is dark reddish-brown silty clay about 15 inches thick. The subsoil, about 45 inches thick, is dusky-red, and dark reddish-brown subangular blocky silty clay and silty clay loam. The substratum is soft, weathered basic igneous rock. LaC soil is similar to LaB, except that runoff is medium and the erosion hazard is moderate.

Fill Land: Fill land is decribed to occur at the southwest end of Red Hill and also in Halawa Valley. This land type consists of areas filled with material from dredging, excavation from adjacent uplands garbage, and bagasse and slurry from sugar mills. This land type also occurs near Pearl Harbor, adjacent to the ocean.

Makalapa Series: Makalapa clay (2 to 6 percent slopes; MdB) is mapped in the area of Aliamanu and Makalapa Craters. This series consists of well-drained soils on uplands, formed in volcanic tuff. They are gently sloping to moderately steep. In a representative profile, the approximately 8-inch surface layer is very dark grayish-brown clay. The next layer, 18 to 36 inches thick, is very dark grayish-brown clay to silty clay loam that has subangular blocky structure. It is underlain by light-gray to dark grayish-brown, weathered volcanic tuff. Permeability and runoff of these soils are slow, and the erosion hazard is slight.

Kokokahi Series: Kokokahi very stony clay (0 to 35 percent slopes; KTKE) is noted in the area between the Makalapa clay in Makalapa Crater and Kamehameha Highway. This series is described to consist of moderately well-drained soils on talus slopes and alluvial fans. These soils developed in colluvium and alluvium derived from basic igneous rock and are moderately sloping to steep. The surface layer is very dark gray and dark gray clay about 14 inches thick. The next layer, about 12 inches thick, is dark grayish-brown clay that has subangular blocky structure. The substratum is grayish-brown and light brownish-gray clay 14 to more than 20 inches thick. There are many stones and boulders on the surface and throughout the profile. Permeability of KTKE soils is slow to moderately slow, runoff is medium to rapid and the erosion hazard is moderate to severe.

5.4.4 Hydrogeology

Based on topography, the direction of regional groundwater movement is estimated to be southwest, towards Pearl Harbor. According to Mink and Lau (1990), there are two aquifer sectors in the area of the Red Hill tanks and tunnel. Mink and Lau (1990) indicate that the Red Hill ridge delineates two aquifers, namely the Moanalua system of the Honolulu sector to the east of the ridge and the Waimalu system of the Pearl Harbor sector to the west of the ridge. Both of these systems extend to the ocean, with their boundary extending from Red Hill southwest to the ocean just east of Pearl Harbor Entrance. Figure 5-4 shows a map of the aquifers in the tunnel vicinity.

On either side of Red Hill ridge, the two aquifer systems are basal, unconfined freshwater aquifers occurring in horizontally extensive lavas. These two aquifers are the source of fresh drinking water to a large part of Oahu and underlie the tanks and the LAT. The aquifers are classified by Mink and Lau (1990) as irreplaceable with high vulnerability to contamination. It is likely that beneath Red Hill these two aquifer systems act as one aquifer; there does not appear to be a hydrogeological boundary beneath Red Hill between these two systems.

Nearer the ocean, the two aquifer systems are each characterized by a basal, unconfined sedimentary aquifer (near surface groundwater) overlying a basal, confined aquifer in horizontally extensive lavas. Critical Infrastructure Nearer Pearl Harbor, Critical Infrastructure Critical Infrastructure

In the seaward (makai) area of the Waimalu system (Pearl Harbor sector), the upper sedimentary aquifer is characterized by Mink and Lau (1990) as ecologically important, used for purposes other than drinking water, of low salinity (250-1000 mg/l Cl), and as irreplaceable with a high vulnerability to contamination. The lower confined aquifer is similarly characterized, with the exception of exhibiting a moderate vulnerability to contamination.

In the makai area of the Moanalua system (Honolulu sector), Mink and Lau (1990) characterize the upper sedimentary aquifer as not used for drinking water and not ecologically important. The sedimentary aquifer is further characterized as exhibiting moderate salinity (1000-5000 mg/l Cl), and as highly vulnerable to contamination but replaceable. The lower confined aquifer of the Moanalua system is characterized as currently used as a drinking water source, as irreplaceable with low vulnerability to contamination, and as fresh water (<250 mg/l Cl).

Red Hill is hydraulically bounded on each side of the ridge by deep alluvial fills associated with the South Halawa and Moanalua Stream valleys (hydraulically cross-gradient), and by the sedimentary caprock on the makai side (hydraulically down-gradient). The valley fill and the caprock act as groundwater barriers (Wentworth 1951).

The Navy Public Works Center (PWC) operates a water pumping station located near the Critical Infrastructure Critical Infrastructure The water pumping station pumps drinking water from Critical Infrastructure Critical Infrastructure well shaft with a bottom elevation of Critical Infrastructure Near the bottom of the well is a water development tunnel at Critical Infrastructure The water development tunnel is Critical Infrastructure Critical Infrastructure Critical Infrastructure A lava tube cross cuts the water development tunnel about 300 feet before the end of the tunnel. The length of the lava tube is unknown. There is continuous water flow at the end of the water development tunnel.

The water pumping station supplies drinking water for the Pearl Harbor Naval Reservation including housing. PWC reported pumping approximately 6 to 8 million gallons per day (MGD) during the summer months and 1 MGD during the winter months. The Red Hill well is considered a back-up source for the Navy while the main source of drinking water is from the Waiawa Shaft.

The nearest drinking water well, other than PWC's, is located less than one mile upgradient (north) from the site at Halawa Shaft. This is a municipal-owned water tunnel that supplies drinking water to Oahu and was constructed about the same time as the Red Hill Complex. The subsurface pipeline carrying the municipal water travels through a Critical Infrastructure Critical Infrastructure The BWS pipe tunnel begins Critical Infrastructure and is believed to end near Kaiser Hospital in Moanalua Valley. PWC has the ability to feed into or draw from the BWS pipeline at the Red Hill water pumping station.

The tanks, most of the Harbor Tunnel, and the LAT are located Critical Infrastructure Critical Infrastructure The Critical Infrastructure Critical Infrastructure This line was established by the State of Hawaii for protection of groundwater resources. The State of Hawaii Department of Health (DOH) Solid and Hazardous Waste Branch has developed clean-up criteria for contaminants using the UIC line as a boundary for allowable concentrations of specific constituents. Areas located above the UIC line generally have a more stringent clean-up criteria than areas located below (makai) of the line.

5.4.5 Surface Water

South Halawa and Moanalua Streams are the nearest surface waters to Red Hill. A portion of South Halawa Stream was redirected and channelized by paving with concrete during the 1970's. The paved portion of South Halawa Stream passes directly below Critical Infrastructure South Halawa Stream merges with North Halawa Stream west of Red Hill near Moanalua Freeway to form Halawa Stream. The stream then meanders back Critical Infrastructure before discharging into Pearl Harbor. Moanalua Stream discharges into Keehi Lagoon. Pearl Harbor is located approximately Critical Infrastructure Critical Infrastructure Pearl Harbor and Halawa Stream are included under the Federal Water Pollution Control Act as navigable waters of the United States. In addition, the State Department of Health has specific water quality standards for streams, such as Halawa and for Pearl harbor (HAR 11:54).

5.4.6 Climate

The annual average temperature in Honolulu, Oahu is 75ø Fahrenheit with seasonal variations ranging from 90ø in the summer to 69ø in the winter. Annual median rain fall at Red Hill is about 50 inches and slightly less than 30 inches at Pearl Harbor (DLNR, 1986).

Evapotranspiration losses vary over short distances on Oahu, due to the island's extreme variations in elevation, rainfall, cloud cover, amounts and character of vegetation, humidity, and exposure to wind. Average adjusted pan evaporation is approximately 80 inches per year for the Pearl Harbor area and approximately 70 inches per year for Red Hill (DLNR, 1985).

5.4.7 Population and Land Use

Land Use in the vicinity the Red Hill tank and tunnel complex includes military, industrial, commercial, educational, residential, and recreational. Also located in the vicinity of Red Hill are the State of Hawaii Animal Quarantine Station and the Halawa High and Medium Security Correctional Facilities, both in Halawa Valley. Moanalua Valley is mostly residential and Halawa Valley is mostly industrial. The densely populated residential area of Moanalua Valley abuts Red Hill and the Coast Guard housing development and Red Hill Elementary School are on Red Hill. The LAT and Harbor tunnels run beneath

Critical Infrastructure

5.4.8 Flora and Fauna

The majority of land comprising Red Hill and Pearl Harbor has been developed or disturbed with the possible exception of the uppermost slopes of Red Hill. Almost all of the area overlying the tunnels has been previously cleared and graded to accommodate existing and demolished structures. Although a biological reconnaissance has not been conducted, surrounding vegetation is expected to be composed largely of introduced plant species (haole koa, guava, Christmas berry, sword fern, foxtail, vervain, and broomsedge), although a few native species (ohia and koa trees) were observed on ridges and slopes of Red Hill. Surrounding landscaped areas are expected to contain bougainvillea, bermuda grass, royal poinciana, palms, monkeypod, and a variety of exotic species commonly used in Hawaii (Ogden, 1994).

Red Hill and Pearl Harbor are suspected to host a variety of bird species based on the character of the land which ranges from forested slopes to dryland to aquatic habitats. There are possibly threatened birds (Pacific golden plover) or endangered endemic birds (elepaio) found in the Red Hill area (Ogden, 1994). Most of the mammals suspected in the surrounding areas, such as mongoose, rats, and mice, are commonly associated with urban setting near undeveloped land. Feral pigs have been observed on the Red Hill site.

5.5 Evaluation of Environmental Hazards

5.5.1 Description of Methodology

To evaluate environmental hazards at the site, two catastrophic releases of fuel were simulated. Scenario One involved a massive release of fuel from Critical Infrastructure where the tunnel doors fail to contain the flow. Scenario Two also involved a massive release of fuel from Critical Infrastructure however, in this scenario a new door has been installed in the tunnel near Critical Infrastructure and this door is closed before fuel reaches it.

In evaluating the potential environmental hazards associated with each scenario, we looked at where the fuel would flow and what the environmental impact would be. We focused on the potential impact to groundwater, surface water, flora and fauna, and human populations. In the following sections the release scenarios are described in more detail, and potential environmental impacts are discussed.

In addition, we evaluated the potential for an earthquake to damage the tanks, tunnel, and fuel handling system.

5.5.2 Environmental Evaluation of Scenario One

5.5.2.1 Description of Scenario One

In Scenario One Critical Infrastructure if full and a discharge begins through Critical Infrastructure nozzle at an average rate of Critical Infrastructure All tunnel watertight doors fail to close or contain the flow except the door at Critical Infrastructure

In this scenario, the bulk of the fuel would drain into PWC's water pump station and flow out of Critical Infrastructure Based on elevations of the tunnel, the fuel would flow directly down the tunnel and reach the PWC pump station Critical Infrastructure The fuel would not flow out of Critical Infrastructure however, the Critical Infrastructure and the water pump station will flood. Other areas of flooding include the lower elevations of the Harbor tunnel Critical Infrastructure miscellaneous openings in the bottom of the tunnel and a release out of the water riser shaft at Critical Infrastructure The following volumes of fuel are estimated to flow out of these areas:

Location of Discharge	Percentage	Volume (bbl)
Critical Infrastructure	30	Critical Infrastructure
	10	
	30	
	10	
	10	
	10	
Total	100	

5.5.2.2 Scenario One: Potential Groundwater Contamination

Potential Contamination of Drinking Water Sources

Directly below the tanks, the LAT and the Red Hill portion of the Harbor Tunnel Critical Infrastructure Critical Infrastructure is a drinking water aquifer that is irreplaceable and highly vulnerable to contamination (Mink and Lau 1990). This aquifer currently supplies water to military housing and facilities in the Pearl Harbor area through the PWC pump station. Fuel released from the tanks, or flowing through the LAT and Red Hill portion of the Harbor Tunnel would likely migrate directly into this aquifer through the permeable basalt in which the tunnel and tanks occur.

In the Scenario One release approximately Critical Infrastructure are estimated to flow into the PWC water pump station. In addition, Critical Infrastructure are anticipated to flow into Critical Infrastructure and another Critical Infrastructure are anticipated to drain through openings in the bottom of the tunnel. It is possible that all or a portion of these amounts of fuel could eventually leach through the basalt and into the drinking water aquifer.

Of greatest concern is the Critical Infrastructure anticipated to flow into and completely flood the PWC pump station. As previously mentioned, the water pump station contains an unsealed manhole above the water well. The fuel could seep into the manhole and flow directly to the drinking water. In addition, the water development tunnel and the lava tube provide pathways for a fuel discharge to quickly spread over a large portion of the aquifer.

A steel unsealed door in the LAT near Critical Infrastructure leads to a riser shaft to the Critical Infrastructure Critical Infrastructure The shaft will fill with fuel and Critical Infrastructure will flood with approximately Critical Infrastructure Critical Infrastructure was not inspected and it is unknown if the floor Critical Infrastructure is watertight; however, it is likely that some portion of the fuel will eventually leach into groundwater beneath the Critical Infrastructure Critical Infrastructure Once the fuel reaches the Critical Infrastructure it will be able to spread quickly.

It is likely that there are openings (cracks, holes, etc.) in the bottom of Critical Infrastructure Critical Infrastructure that will facilitate migration of fuel into the drinking water aquifer. After a release of this magnitude, it is likely that a large amount of residual fuel contamination will remain in the unsaturated zone (basalt in this case) and leach into groundwater over a period of several years or more.

After the fuel has reached the drinking water aquifer beneath Red Hill, it should not migrate very far since the aquifer is bounded on three sides by groundwater barriers (Wentworth 1951). Valley fill in Moanalua and Halawa Valleys and the caprock on the makai side of Red Hill will probably contain the fuel in the area beneath Red Hill. It is unlikely that the fuel will flow mauka or upgradient since the regional groundwater flow is towards Pearl Harbor. If the groundwater pumps were in operation, the fuel would most likely flow towards the pumps. The fuels stored at Red Hill are less dense than water and would thus float on the groundwater surface; therefore, the release will not impact the deeper portions of the aquifer.

Once the drinking water is contaminated with this amount of fuel, few options exist. Conversations with PWC indicate Pearl Harbor will not be able to meet their requirements for water without the Red Hill source. An alternative source of water will have to be found. It is possible that the pumps could be used to remove the fuel from the aquifer. This should remove a significant amount of fuel, but the volume of fuel involved makes total removal unlikely. Even if the majority of fuel could be pumped out of the aquifer, drinking water will contain dissolved components of diesel and will have to be treated prior to consumption.

Potential Contamination of Ecologically Important Groundwater Systems

The aquifer beneath the majority of Critical Infrastructure occurs in sedimentary fill material and is not a drinking water source. In addition, this aquifer if not hydraulically connected to the drinking water aquifers; however, it is hydraulically connected to Pearl Harbor. Mink and Lau (1990) characterize this aquifer as ecologically important, used for purposes other than drinking water, of low salinity (250-1000 mg/l Cl), and as irreplaceable with a high vulnerability to contamination.

Discharges from the Scenario One release that would impact this aquifer include leaching of fuel trapped in low areas in the Harbor Tunnel and miscellaneous drainage from the many cracks and holes in the tunnel floor and Critical Infrastructure

Two former drain tunnels exist Critical Infrastructure These drains formerly discharged to Halawa Stream and were reportedly "sealed" off. There are steel plates in the tunnel at the locations of the former drain tunnels; however, it is unknown if the drains are watertight. Fuel may be able to seep into these drains and spread into the subsurface, leach into groundwater, and flow directly into Halawa Stream.

Evaluation of the french drain is being conducted during the Rail Study which is currently ongoing.

5.5.2.3 Scenario One: Potential Surface Water Contamination

The Scenario One release would also have a significant impact on surface water. As mentioned above the former drain tunnels Critical Infrastructure eportedly drain directly into Halawa Stream. In addition, fuel drainage from Critical Infrastructure could reach Halawa Stream and Pearl Harbor.

Of primary concern is the Critical Infrastructure that are anticipated to flow out of Critical Infrastructure s within Critical Infrastructure of Halawa Stream which discharges into Pearl Harbor. Fuel discharged from Critical Infrastructure may not flow directly into Halawa stream because of the cliff side Critical Infrastructure However, storm drains located Critical Infrastructure Critical Infrastructure probably lead to the stream or directly to Pearl Harbor.

Also of concern is the Critical Infrastructure Critical Infrastructure The area surrounding the shaft at the ground surface is covered with a concrete slab which is within Critical Infrastructure Fuel could seep around the concrete and rise onto the ground surface. The adjacent house and probably two neighboring houses will be in danger of being inundated with fuel. The fuel could also flow down the street and into the storm drains located along the curbside which probably drain into Halawa Stream and eventually into Pearl Harbor.

Fuel entering the Critical Infrastructure could also flow down the hillside and into South Halawa Stream, if the doors on the outside Critical Infrastructure are not water tight. It is also possible that fuel entering the ecologically important aquifer (see Section 5.5.2.2 above) will eventually seep into Pearl Harbor.

Once Halawa Stream and Pearl Harbor are impacted by a release of this magnitude, a major cleanup effort will have to be undertaken. State Water quality standards would be exceeded, and the impact on the freshwater and estuary environments would be significant.

The Pearl Harbor Oil Spill Contingency Plan (OSCP) provides procedures and methods for spills from the numerous fuel storage tanks and tankers at Pearl Harbor and Red Hill. The OSCP and the equipment required by it must be immediately enacted in the event of a surface release.

5.5.2.4 Scenario One: Potential Human Exposure

We have examined the potential human exposure according to exposure point. An exposure point is defined by the Environmental Protection Agency (EPA, 1989) as a location of potential contact between an organism (i.e., human, fauna, flora) and a chemical or physical agent (e.g., released fuel). Scenario One provides several exposure points for human exposure. including contact with contaminated drinking water, surface water, soil, and air, ingestion of contaminated foodstuffs, and direct contact with fuel.

Exposure to Contaminated Drinking Water

Human exposure to contaminated drinking water would occur according the Scenario One with the flooding of the PWC water pump station. The potential human consumption of contaminated drinking water would provide the worst-case health risk for human exposure. Dermal contact with contaminated drinking water and inhalation of water vapor would also provide a health risk. In the event of a spill the pumping station should be shut down immediately.

Exposure to Contaminated Surface Water

Human exposure to contaminated surface water would occur according to Scenario One with the migration of released fuel to Halawa Stream or to Pearl Harbor. As previously described, the Scenario One would result in releases from Critical Infrastructure Critical Infrastructure which would likely impact Halawa Stream and Pearl Harbor. Contamination of Halawa stream and Pearl Harbor provide potential dermal, ingestion, and inhalation exposure to contaminated water, as well as potential exposure from ingestion of contaminated fish or shellfish.

Exposure to Contaminated Soil

Human exposure to contaminated soil would occur according to Scenario One with the migration of released fuel across the ground surface in several areas, including releases from Critical Infrastructure Critical Infrastructure Fuel escaping from Critical Infrastructure will also flow down the incline in the opposite direction of the houses and onto the H1 Freeway. Human exposure to contaminated soil could occur through dermal or inhalation pathways.

Direct Contact with Fuel

In the Scenario One release there are several discharges where humans could have direct contact with the fuel, specifically Critical Infrastructure

There is a Critical Infrastructure In the release scenario, it is likely that some of the Critical Infrastructure of fuel discharged from Critical Infrastructure would flow Critical Infrastructure Critical Infrastructure

As stated previously, Critical Infrastructure from the house. People living in this house and probably the adjacent homes could come in direct contact with the estimated Critical Infrastructure that would flow out of Critical Infrastructure Fuel from Critical Infrastructure may also flow down onto the H1 Freeway where it would become a hazard to motorists.

Direct contact with fuel flowing out of the Critical Infrastructure is probably minimal since there are no residences or businesses along this side of Red Hill. People using this area would include workers at Red Hill, and people driving to and from the Halawa Correctional Facilities and the shooting range. In addition, any workers inside the Red Hill storage facility or tunnels at the time of the release would be severely impacted by the flowing fuel.

5.5.2.5 Scenario One: Potential Impact to Flora and Fauna

The impact to flora and fauna from the Scenario One release would be significant. Impact to terrestrial flora and fauna would occur where the fuel discharges at the surface, which includes Critical Infrastructure Critical Infrastructure The Scenario One release would also impact aquatic and marine flora and fauna from releases which reach Halawa Stream and eventually Pearl Harbor. Most of the vegetation in theses areas is introduced, as are the mammals. However, there are possibly threatened birds (Pacific golden plover) or endangered endemic birds (elepaio) found in the Red Hill area (see Section 5.4.8).

5.5.3 Environmental Evaluation of Scenario Two

5.5.3.1 Description of Scenario Two

Scenario Two involves a massive release of fuel from Critical Infrastructure nozzle at an average rate of Critical Infrastructure and assumes a new tunnel watertight door Critical Infrastructure closes before fuel reaches it. This door is located in the LAT Critical Infrastructure

In this scenario, the bulk of the fuel will flood the elevator and ventilation shafts, and the cavities around the outside of the storage tanks. Critical Infrastructure after the release began, the lower tunnel is flooded with Critical Infrastructure of fuel. Fuel will not flow out the top of the venitlation and elevator shafts. In Scenario Two the fuel remains in the vicinity of the Tanks and does not flow down the LAT and Harbor Tunnel.

5.5.3.2 Scenario Two: Potential Groundwater Contamination

Potential Contamination of Drinking Water Sources

Potential contamination of drinking water beneath Red Hill is significantly reduced in Scenario Two since the fuel does not reach the PWC pump station.

Large volumes of fuel contained in the vicinity of the tanks could drain through openings in the bottom of the tunnel. It is possible that a portion of the fuel could eventually leach through the basalt and into the drinking water aquifer. In addition, fuel in the cavities around the outside of the tanks would likely leach through the permeable basalt into the groundwater. It is likely that residual fuel contamination will remain in the unsaturated zone (basalt in this case) and leach into groundwater over a period of several years or more.

As with Scenario One, after the fuel has reached the drinking water aquifer beneath Red Hill, it should not migrate very far since the aquifer is bounded on three sides by groundwater barriers (Wentworth 1951). Valley fill in Moanalua and Halawa Valleys and the caprock on the makai side of Red Hill will probably contain the fuel in the area beneath Red Hill. It is unlikely that the fuel will flow mauka or upgradient since the regional groundwater flow is towards Pearl Harbor. If the groundwater pumps were in operation, the fuel would most likely flow towards the pumps. The fuels stored at Red Hill are less dense than water and would thus float on the groundwater surface; therefore, the release will not impact the deeper portions of the aquifer.

Potential Contamination of Ecologically Important Groundwater Systems

In Scenario Two the fuel does not flood the tunnels or spill out of Critical Infrastructure The potential for contamination of the upper unconfined aquifer (near-surface groundwater) below the Critical Infrastructure is eliminated.

5.5.3.3 Scenario Two: Potential Surface Water Contamination

Scenario Two eliminates the potential for surface water contamination.

5.5.3.4 Scenario Two: Potential Human Exposure

In Scenario Two the majority of the fuel is contained by a new door Critical Infrastructure This limits human exposure considerably, except for workers in the tank and tunnel area.

Exposure to Contaminated Drinking Water

As discussed in Section 5.5.3.2, fuel will likely leach to ground water. The potential human consumption of contaminated drinking water would provide the worst-case health risk for human exposure. Dermal contact with contaminated drinking water and inhalation of water vapor would also provide a health risk. In the event of a spill, the PWC pump station should be shut down immediately.

Exposure to Contaminated Soil

Human exposure to contaminated soil will be eliminated in Scenario Two.

Direct Contact with Fuel

Workers inside the Red Hill storage facility or tunnels at the time of the release could be severely impacted by the flowing fuel.

5.5.3.5 Scenario Two: Potential Impact to Flora and Fauna

Scenario Two would eliminate any impact on flora and fauna.

5.5.4 Evaluation of Potential for Earthquake Damage

The seismic zone for Oahu is 2A, according to the Uniform Building Code. For the maximum 475-year return period, the peak effective ground acceleration is 0.150 g.

Oahu has experienced a number of earthquakes in recent recorded times, although most that are felt on Oahu are centered near the island of Hawaii and cause no damage on Oahu. In the spring of 1948, an earthquake of 4.8 magnitude, centered slightly off the coast of Oahu, resulted in broken windows in downtown Honolulu (Macdonald et al., 1983). The 1948 earthquake had a seismic intensity of VI on the Modified-Mercalli Scale, and caused little other damage in Honolulu (Furamoto, 1990). In 1978 an earthquake of 4.2 magnitude was centered on the north shore of Oahu, again causing little or no damage on Oahu.

Earthquake damage to the interior of tunnels is rarely significant or irreparable, except in places which do not have good natural ground or are subject to eccentric loads (Okamoto, 1973). Damage may take the form of failure of portal sections, transverse and longitudinal cracking of the linings, spallings and deformation. Tunnels in hard rock will undergo significantly less earthquake damage than tunnels through soft rock. Liner thickness may have some effect on the magnitude of damage; where liner thicknesses vary in a tunnel, damage is often greater in sectors with thick lining (Okamoto, 1973).

In the early 1950's an investigation was conducted by C.K. Wentworth concerning cracks in the lining of the Red Hill Tunnel system (Wentworth, 1954). He investigated conditions back of the gunite arch in some areas and found that the wood framing had rotted and was incapable of supporting any load. Wentworth found no evidence of crushing or of pressure or load from the rock above, which appeared to be holding its natural arch, despite an earthquake of considerable intensity in 1948.

Wentworth attributed the cracks in the gunite roof to tension cracks, due to the slumping of the gunite shell, which resulted from rotting wood supports. He suggests that this slumping may have been aggravated by earthquake disturbance, but it was his view that the tunnel cracks were cosmetic problem only and that there was no threat to the continued stability of the rock tunnel itself. Wentworth recommended patching the gunite but considered it not necessary to rebuild the tunnel lining with reference to supporting the overlying rock structure.

MFA believes that the potential for earthquake damage to the Red Hill tunnel is low, given the quality of the rock through which the tunnel passes. In the Red Hill end of the tunnel, the tunnel and tanks are constructed in primary basalt, and the likelihood of earthquake damage of the tunnel rock structure is very low. The tuff formations seaward of Red Hill consist of well-cemented basalt and calcareous ejecta, and, while not as hard as primary basalt, appear to be structurally competent. Sections of the tunnel may pass through an approximately 5-foot strata of weathered rock that forms the contact between the Alimanu and Salt Lake tuff deposits. Wentworth alluded to this weathered rock overlying the tunnel in the location of the cracks he investigated, but he also describes the apparent integrity of the rock arch in this area, despite the occurrence of a sizable earthquake since construction of the tunnel.

Piping in the tunnel is supported by anchors as shown in Figures 5-5 and 5-6 and by steel and concrete supports shown in Figure 5-7. The large Critical Infrastructure DFM line is close to the floor and is supported vertically and laterally by concrete supports. The Critical Infrastructure JP-5 line Critical Infrastructure framed in by the steel double angle support and the tunnel shell. The Critical Infrastructure DFM line Critical Infrastructure is the most vulnerable to an earthquake,especially in areas midway between the anchors since the only form of retention on the support is the 3-inch x 3-inch x ¼-inch angle clip welded to the end of the horizontal steel angle supports. Restraining the movement of this line to prevent it jumping off the support or being pushed off the support by collapsing rock and tunnel lining during an earthquake would provide a low cost form of insurance. Restraint every 100 feet would prevent the line leaving the support, but installing restraints every other or every third support would lessen the load at any given support.

5.6 Conclusions and Recommendations

5.6.1 Conclusions

In conclusion, an uncontrolled massive fuel release from the Red Hill tanks or LAT would cause irreparable damage to the drinking water source below the site. The cost of clean up would be prohibitive, long term, and may not be completely successful. The benefits of preventive measures to avoid a catastrophe, far outweigh the cost and environmental effect of a massive or even short term fuel release.

In Scenario One, drinking water is significantly impacted since fuel flows into the PWC pump station and all along the LAT and upper portion of the Harbor Tunnel. Surface water and surface soils are significantly impacted by releases from Critical Infrastructure These areas of release also result in more human and environmental (flora and fauna) exposure. Since the Scenario One release is spread over such a large area and many media are effected (i.e., groundwater, surface water, and soil), the required cleanup effort and cost would be tremendous.

By comparison, in Scenario Two the release of fuel is contained in the tank area. No surface spill would occur and the potential for human contact with contaminated soil and surface water, as well as impact to flora and fauna would be eliminated or reduced. In addition, immediate action to remove the fuel from the LAT will reduce the potential of drinking water contamination substantially.

5.6.2 Recommendations

It is our recommendation that precautions be taken to protect the drinking water below the site. If a release of fuel was to occur it would be best to contain it before it flows down the LAT. If containment did not occur at the end of the tanks additional precautions should be taken to protect the PWC pump station. Water tight doors should be repaired, designed, and maintained, especially near the PWC pump station, to divert the fuel away from the water pumping station down the tunnel and into Critical Infrastructure Critical Infrastructure and into Pearl Harbor. A surface spill in Pearl Harbor would be easier to clean up than a release into the subsurface and drinking water aquifer at Red Hill.

If a major spill occurs and is contained behind water-tight doors, provisions must be made to remove this fuel quickly. A pipe through the bulkhead that is valved on the downstream side of the door and can be tied into existing piping will allow drainage of the fuel into the existing fuel piping so pumps at the receiving pumphouse can pump this fuel into another Red Hill tank or transfer the fuel to the Upper Tank Farm or other storage. Critical Infrastructure

Additional recommendations include:

- Seal the manhole cover of the well in the PWC pump station and install water tight doors before (upgradient) of the pump station.
- Install doors or thrust block to prevent a release from reaching the PWC pump station.
- Install U-clamps and Critical Infrastructure in tunnel to restrain movement of this line in case of earthquake, per Figure 5-7.
- Install a tank level monitoring system.
- Make hourly visual checks of the tanks, tunnels, and pipelines.
- Repair and routinely test the water-tight doors.
- Repair cracks and open holes in the tunnel.
- Seal off the two former drainage tunnels to Halawa Stream.
- Seal off the doorway to Critical Infrastructure
- Install secondary confinement thrust block below Critical Infrastructure

- Repair and clean out french drain in Harbor Tunnel.
- Clean out and test product in open trench near sump for tanks.
- Clean out drains beneath Harbor Tunnel.
- Seal the water riser shaft at Critical Infrastructure o prevent a release from reaching the surface.
- Emergency evacuation procedures for workers Critical Infrastructure and workers at Red Hill.
- Floor drains in the Harbor Tunnel and Pump House should be periodically cleaned out to ensure they are working properly.
- The tunnel floor has many holes, some of which were formed by water damage and others man made. Efforts to seal the holes in the floor and walls should be undertaken as precautionary measures, but the possibility of sealing all holes in the floor and walls of the tunnel seems unlikely.

Exhibit 5-1

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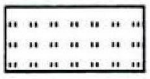
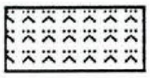
Critical Infrastructure

Critical Infrastructure

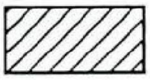
LEGEND for Figure 5-2



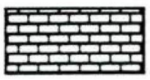
Honolulu Volcanic Series. Consolidated gray, lavender, and brown bedded, only slightly permeable deposits of basic vitric-crystal-lithic tuff composed of angular fragments of Koolau and post Koolau basalt, limestone, and other ejecta in a matrix of plagonite and glass, commonly cemented by calcite, forming cones near the vents but thin elsewere and caused by phreatomagmatic explosions.



Koolau Volcanic Series. Gray, blue, red, and black jointed dense to very vesicular, aphanitic and porphyritic permeable effusive basalts. The basalt was poured out of fissure and vents in rapid succession as short and long pahoehoe and aa flows 10 to 80 feet thick; the pahoehoe flows occur chiefly near the crest of the Koolau Range; aa flows, some platy, with their clincker beds make up about 60% of the range; the basalt is deeply weathered except where it forms cliffs; in the lower flanks of the range it is covered with a deep red lateritic soil, but in the higher areas, where rain is abundant, the soil is brown or black. The basalt exceeds 3,500 feet in thickness and individual beds have dips as steep as 15 degrees; it is the great aquifer of Oahu and yields water copiously to wells, tunnels, and springs.



Consolidated noncalcareous deposits. Chiefly older alluvium, generally consisting of mottled brown to red-brown, deeply weathered, poorly assorted, and nearly impermeable friable conglomerates, in places cemented with limonite or hematite and usually forming conspicuous terraces along the principal streams. Near the mouths of the valleys and especially around Pearl Harbor the older alluvium grades into partly consolidated sands and silts that are emerged delta deposits. The degree of consolidation is largely dependent upon the amount of rainfall, for in dry regions the material is much better cemented. Near the heads of valleys the older alluvium grades into coarse angular talus and landslide deposits which, in places, carry considerable water.



Consolidated calcareous marine sediments. Chiefly emerged coral reefs but in places, especially near Pearl Harbor, finely laminated lagoon limestone. Beach deposits resembling the various types of present calcareous beaches in lithified form. Extremely permeable because of primary and secondary cavities and yields water copiously, but the water is apt to be brackish.

From: Stearns, H.T., Geologic Map and Guide of the Island of Oahu, Hawaii
U.S. Geological Survey, August 1939.

Critical Infrastructure

Critical Infrastructure

LEGEND for Figure 5-4

AQUIFER CLASSIFICATION EXPLANATION

AQUIFER AND STATUS CODES*

Aquifer Code	=	Island
	+	Aquifer Sector
	+	Aquifer System
	+	Aquifer Type
Thus, 30104111	=	Aquifer Code
where 3	=	Oahu
01	=	Honolulu
04	=	Moanalua
1	=	basal
1	=	unconfined
1	=	flank
and		
(11111)	=	Status Code
where 1	=	currently used
1	=	drinking
1	=	fresh, <250 mg/l Cl⁻
1	=	irreplaceable
1	=	high vulnerability to contamination

IS.	AQUIFER SECTOR	AQUIFER SYSTEM
3	01 Honolulu	01 Palolo
		02 Nuuanu
		03 Kalihi
		04 Moanalua
		05 Waialae
	02 Pearl Harbor	01 Waimalu
		02 Waiawa
		03 Waipahu
		04 Ewa
		05 Kunia
	03 Waianae	01 Nanakuli
		02 Lualualei
		03 Waianae
		04 Makaha
		05 Keaau
	04 North	01 Mokuleia
		02 Waialua
		03 Kawailoa
	05 Central	01 Wahiawa
		02 Koolau
	06 Windward	01 Koolauloa
		02 Kahana
		03 Koolaupoko
		04 Waimanalo

*Where sedimentary caprock aquifers rest on primary basalt aquifers, two Aquifer and Status Codes separated by a slash indicate numerator code is upper aquifer and denominator is lower aquifer.

AQUIFER TYPE:		Hydrology†
1	Basal	Fresh water in contact with seawater
2	High Level	Fresh water not in contact with seawater
1	Unconfined	Where water table is upper surface of saturated aquifer
2	Confined	Aquifer bounded by impermeable or poorly permeable formations, and top of saturated aquifer is below groundwater surface
3	Confined or Unconfined	Where actual condition is uncertain

AQUIFER TYPE:		Geology‡
1	Flank	Horizontally extensive lavas
2	Dike	Aquifers in dike compartments
3	Flank/Dike	Indistinguishable
4	Perched	Aquifer on an impermeable layer
5	Dike/Perched	Indistinguishable
6	Sedimentary	Nonvolcanic lithology

†1st two digits from hydrologic descriptors (pos. 1, 2).
‡Last digit from geologic descriptor.

STATUS CODE (GROUNDWATER)

Development Stage
1 Currently used
2 Potential use
3 No potential use

Utility
1 Drinking
2 Ecologically important
3 Neither

Salinity (mg/l Cl⁻)
1 Fresh (<250)
2 Low (250-1000)
3 Moderate (1000-5000)
4 High (5000-15,000)
5 Seawater (>15,000)

Uniqueness
1 Irreplaceable
2 Replaceable

Vulnerability to Contamination
1 High
2 Moderate
3 Low
4 None

Rev. Feb. 1990

From: Mink and Lau, Aquifer Identification and Classification for Oahu: Groundwater Protection Strategy for Hawaii, February 1990.

PIPELINE ANCHORS

Critical Infrastructure

Figure 5-5
Red Hill Complex
Tunnel Piping Anchors

Critical Infrastructure

Critical Infrastructure

SECTION 6

POTENTIAL CATASTROPHIC FAILURE RISK ASSESSMENT AND STRUCTURAL ANALYSIS

6.1 General

This section evaluates the potential catastrophic failure of the tanks, valves and/or pipelines which comprise the Critical Infrastructure capacity Red Hill Complex which includes Critical Infrastructure and pipelines to Pearl Harbor. Three scenarios are presented and secondary containment measures are recommended to reduce the impact of both large and small failures.

Existing oil-tight doors/bulkheads were cored, and the concrete from these cores was tested for compressive strength. Volume calculations were conducted for all areas where leaked fuel would be trapped, and this established the pressures that would bear on the oil-tight door/bulkhead. Then a structural analysis was conducted on the concrete bulkhead, the door beams and the door plates. This analysis with volume calculation is contained in Appendix D, Volume 2 of this report and the results are synopsized in this section.

6.2 Scope

The project scope is provided in Section 2. Pertinent parts of the scope which will be addressed in this sectionÿare quoted as follows:

Scope of Work - General Requirements

The A-E shall conduct a comprehensive study of the Red Hill Fuel Tunnel Complex and provide a fire, life safety, and environmental risk assessment/analysis. The study shall include preliminary construction cost estimates for recommendations and alternatives and economic analysis for major alternatives. The scope of work for this study shall be the entire Red Hill Fuel Tank/Tunnel Complex, including the Critical Infrastructure Critical Infrastructure The primary objective of this study is to assess existing safety and fire protection conditions and systems and provide recommendations and alternatives for improvement and correction of deficiencies. Potential environmental impacts shall also be investigated and evaluated.

In addition to the General Requirements, the A-E shall include an assessment of the following elements:

(1) Potential catastrophic failure of:

- Fuel tanks

- Pipeline, valves and associated pipeline components
- Other facility equipment

(2) Relocation of existing tunnel fuel piping underground to reduce fire hazards.

- Ecological evaluation of:
- Adequacy of existing tunnel walls, floor and doors to contain a massive fuel spill.

(3) Compartmentalization of tunnel for fire and safety separations:

- Existing tunnel doors
- Existing french drains system in floor (to be discussed in more detail in Amendment 2 which calls for conducting 3 excavations and 20 cores)
- Alternatives to existing systems"

6.3 Description of Facilities

The fuel storage facility at Red Hill consists of Critical Infrastructure constructed in subterranean vaults hollowed out of rock. Each vault has the form of a vertical cylinder closed top and bottom by hemispherical domes. The diameter of each tank is Critical Infrastructure and the overall height from bottom to top is Critical Infrastructure The capacity of each tank is approximately Critical Infrastructure of either JP-5 jet fuel or diesel fuel marine.

The Critical Infrastructure at Red Hill are located Critical Infrastructure Critical Infrastructure with the Critical Infrastructure Critical Infrastructure There are Critical Infrastructure The upper tunnel is near the dome area of each tank and the lower tunnel has its floor about Critical Infrastructure below the tank bottoms. Both the upper and lower tunnel have short spur tunnels, which in the case of the lower tunnel branch to a Critical Infrastructure

The upper tunnel extends from Critical Infrastructure approximately Critical Infrastructure There is a Critical Infrastructure to the Critical Infrastructure A bulkhead separates Critical Infrastructure from the remainder of tanks. This bulkhead has a mandoor for egress from one area to the other. There are Critical Infrastructure Critical Infrastructure which travels from the upper tunnel level to the lower tunnel level. These Critical Infrastructure must be used to get from the lower tunnel on one side of the bulkhead to the lower tunnel on the other side. The more Critical Infrastructure has explosion-proof equipment and machinery, and has a vestibule at each tunnel level for the protection of workers while waiting Critical Infrastructure in case of fire or other emergency.

Approximately Critical Infrastructure from the upper tunnel level, there is a tunnel providing primary access to the area containing Critical Infrastructure this tunnel leads to Critical Infrastructure The Critical Infrastructure in this section of tanks provides the only egress from the Critical Infrastructure

At the upper access tunnel level, there is a Critical Infrastructure Critical Infrastructure On top of each tank there is an opening through a steel cover manhole in which there is a smaller hole for tank gauging.

The lower tunnel extends from the tanks approximately Critical Infrastructure to the Receiving Pumphouse. There are Critical Infrastructure n the lower access tunnel: Critical Infrastructure carrying diesel fuel marine; Critical Infrastructure Critical Infrastructure carrying JP-5 jet fuel; Critical Infrastructure carrying diesel fuel marine.

About Critical Infrastructure which branches from the main tunnel and provides a shorter approach from a portal in the Critical Infrastructure of the ridge. At the junction of the main tunnel and the lower access tunnel, there is a pumping plant operated by Public Works (PWC). This pumping plant, with deep wells in the lava rock, provides a part of the fresh water reserve supply for the Naval Base. At this location there is also a ventilating shaft extending to the surface. Within the vent shaft there is a 6-inch water line providing fire protection water to the upper and lower access tunnels. A 500,000-gallon, aboveground, concrete water tank provides the water supply.

At the PWC water pump station the lower access tunnel branches in a Critical Infrastructure o form the Harbor Tunnel. The Harbor Tunnel is approximately Critical Infrastructure and terminates at the Receiving Pumphouse. Critical Infrastructure s the entrance tunnel to the Receiving Pumphouse. There Critical Infrastructure to the Harbor Tunnel through Critical Infrastructure which intersects at Critical Infrastructure

In the early 1960s Critical Infrastructure at the Red Hill Complex were converted for the storage of AVGAS. As such, all equipment in this area was converted to explosion-proof, Class I, Division 1 rating. Also a 22-ton Cardox low pressure, carbon dioxide system was installed to provide total flooding fire protection for this area.

In the 1980s, due to concern for personnel as well as system leaks and inadvertent discharges, the CO_2 system was emptied and taken out of service. The only remaining fire protection for the storage tank area consists of portable fire extinguishers and hydrants (valve outlets) from the installed water line for manual firefighting.

In July 1983 Bill Garrison, M & M Protection Consultants, conducted a risk analysis for fire protection in the underground pumphouse, Building 59. As a result of this study, an extensive list of recommendations was developed requiring fixed fire suppression for this facility. In 1987 a project was initiated to implement most of these recommendations by installing a fixed aqueous film forming foam (AFFF) system throughout the pumphouse, thermal and ultraviolet (UV) detection systems for actuation of the foam system, and a Halon 1301 system for protection of the control room, calibration room, and transformer room.

Figure 3-3 indicates the Critical Infrastructure cored and evaluated by WEI. They are designated Critical Infrastructure for purposes of discussion in this report. Critical Infrastructure is the location of a proposed bulkhead and door to provide improved secondary containment.

6.4 Potential Catastrophic Failure and Current Conditions

6.4.1 General

The potential for catastrophic failure of a steel lined Red Hill tank encased in concrete and rock is extremely remote. Any potential failure would more likely occur in the piping or valves serving these tanks. These lines are located in the lower tunnel and valve galleries at the bottom of the tanks. Lines or valves could be broken by an earthquake or fire could damage pipe supports holding the Critical Infrastructure Critical Infrastructure which would cause a large bending stress on the tank skin valves sufficient to break these valves. Improved maintenance of facilities, where piping and supports are not allowed to be weakened by corrosion and fuel is not allowed to accumulate on floors and in gutters where it can contribute, spread and exacerbate any fire, are ways to prevent a small failure from becoming catastrophic. Secondary containment is just what the term implies; secondary. Emphasis should be placed on primary containment as the first line of defense to prevent spills. This includes inspection and upkeep of the steel tank lining and its coating, repair/replacement of valves, upkeep of pipe supports and piping, maintaining a fully operational and accurate gauging system and providing adequate fire protection.

6.4.2 Current Conditions

None of the oil-tight doors are currently operational. Trip mechanisms are broken and the doors are tied off with ropes to prevent accidental closure when a train is passing through the door opening. The flat door seals are old and not resilient and some have been painted. They appear to be conveyer belting material. Some warpage of the door at Critical Infrastructure was noted during the closure test, preventing complete closure without undue pressure. Flapper valves in the drop track areas are broken and not operational. These valves and the 4" piping are to allow surface water to flow under the door and down the tunnel during non-emergency, but wet conditions. Under closure conditions, these inoperative valves would let fuel pass under the door at high velocity and in sufficient volume to be undesirable. These existing flapper valves are primitive and should be replaced, preferably with a more positive and dependable closure. The general maintenance of pipelines, pipeline supports, tunnel arch supports and electrical conduits in the tunnels is sub-standard. See Photos RH3-35, 36. Oil-soaked muck is contained in the drain gutter and oil from leaking valve stems puddles on the concrete floor. The tunnel also has numerous penetrations near the ceiling that need to be plugged. See Photo RH3-34, 37. Gunite at the tunnel wall to floor joint has many areas that are deteriorated, with welded wire fabric and wood construction timbers showing. Fuel could easily escape the confines of the tunnel. See Photos RH3-38, 39, 40. In general, the concrete tunnel floors are in good condition except for one longitudinal crack noted and some "pukas" (small holes) in the concrete over the ends of the rotted ties.

6.5 Evaluation of Secondary Containment

6.5.1 Scenarios Selected

Since there are any number of incidents that could occur and it would be impractical to evaluate all of them, Willbros Engineers established two primary scenarios for FSC, MFA and WEI to consider in this study.

Scenario One:

a. Critical Infrastructure is full and discharge begins through a Critical Infrastructure diameter nozzle at an average rate of Critical Infrastructure Critical Infrastructure

b. All doors are open. Critical Infrastructure is closed before fuel reaches it.

c. All doors are open. Critical Infrastructure is closed before fuel reaches it.

Scenario Two:

a. Critical Infrastructure is full and discharge begins through a Critical Infrastructure diameter nozzle at an average rate of Critical Infrastructure Critical Infrastructure

b. A new door has been installed in the tunnel near Critical Infrastructure and this door is closed before fuel reaches it.

Critical Infrastructure are at the highest elevation of all the tanks, but were not selected for a potential discharge in this scenario since they are separated from the other Critical Infrastructure n the lower tunnel by a solid concrete wall. This left Critical Infrastructure as the tanks with highest elevation which would therefore cause the greatest head or pressure on doors/walls and would provide the greatest potential for possible escape of fuel through openings, vent shafts, adits, etc. A Critical Infrastructure Critical Infrastructure was used as the discharge opening since it is the size of the skin valves at each tank.

6.5.2 Scenario One - Evaluation of Tunnel Doors, Walls and Floors

To evaluate tunnel doors and walls, three oil-tight doors and concrete bulkheads selected by FISC were cored during the site investigation by Critical Infrastructure under the direction of Willbros Engineers. The location of these doors is shown on Figures 3-1, 3-3 as doors Critical Infrastructure Photos RH3-3 thru 20 refer.

Cores from these locations were tested by Critical Infrastructure for their compressive strength. Diagonal cores were taken at the wall-to-tunnel joint to determine whether the walls were keyed into the surrounding rock. A description of the cores and test results are contained in Section 1 of Appendix D (Volume 2 of this report).

To determine the pressures that these doors would have to withstand, the volumes of the tunnels from Pumphouse 59 up through the Harbor Tunnel, and including the Lower Access Tunnel (LAT), the upper tunnel Critical Infrastructure were all calculated and are tabulated in Section 3 of Appendix D.

6.5.2.1 Critical Infrastructure

Secondary containment for a large fuel spill at Red Hill was included in the original design. The first such containment which would be reached by a fuel spill was installed as an oil-tight concrete bulkhead and steel door at Critical Infrastructure in the LAT as shown on Figure 3-3, as Critical Infrastructure and in Photos RH3-13, 20. This location is just upgrade, or in case of a leak, upstream from the PWC Pump Station. Calculations indicate with a Critical Infrastructure failure as described in Scenario One, the oil would fill the tunnel between Critical Infrastructure Critical Infrastructure until the lost fuel reached an equilibrium with oil in the tank. The level would create a hydrostatic head at Critical Infrastructure when a 1.1 impact factor is added.

The bulkhead at Critical Infrastructure gunite and has an opening of Critical Infrastructure for passage of the train. It is also penetrated by single Critical Infrastructure pipelines. There are no 5' thick concrete pipe anchors at this bulkhead, contrary to what is shown on construction drawings. Corings indicate the bulkhead is adequately keyed into the surrounding rock. Section 2 of Appendix D indicates how the bulkhead and door were analyzed and the results of this analysis. The analysis of the bulkhead showed that the 1" square reinforcing steel bars were adequate to resist the bending forces but the allowable shear stresses of Critical Infrastructure were exceeded with stresses of up to Critical Infrastructure at 12 elements out of 133.

The oil-tight doors were designed to be fabricated from 3/8" thick steel plate stiffened with wide flange beams as shown on photos RH3-16, 17. Two vertical beams located at the 1/3 points of the door's width and two horizontal beams located at the 1/3 points of the vertical dimension of the door form the bracing of the plate. Critical Infrastructure was designed for 8" beams, but 6" beams were installed.

It was found that stresses in the steel door exceed the AISC allowable in shear and bending. The allowable bending stresses in the plate are also exceeded by a factor of 2.5.

In summary, the bulkhead would probably withstand the pressures, but the steel door would fail.

6.5.2.2 Critical Infrastructure

Critical Infrastructure is located at about Critical Infrastructure in the LAT on the Critical Infrastructure as shown on Figures 3-1 and 3-3 and as pictured on Photos RH3-3, 4 5, 6, 8. This door is not an oil-tight door and has no drop track arrangement for the railroad so that an adequate seal can be obtained on the bottom edge of the door. The bulkhead is only 1' thick and the door is steel, using vertical wide flange beams sandwiched between two relatively thin plates. It is referred to as a fire door on the original construction drawings.

No stress analysis was done on this door since it is not oil-tight and would obviously not hold the pressures from a catastrophic failure.

6.5.2.3 Critical Infrastructure

Critical Infrastructure is installed at Critical Infrastructure in the Critical Infrastructure as shown on Figures 3-1 and 3-3 and as pictured on Photos RH3-3, 4, 5, 6, 8. As indicated on the photos, this bulkhead is integral with the pipeline anchors, giving it a thickness of 60 inches except at the top which is 18 inches thick.

Volume calculations indicate a failure of Critical Infrastructure as set forth in Scenario 1 would result in a maximum head of Critical Infrastructure of liquid or Critical Infrastructure no impact factor). This lower pressure is due to a large volume of the liquid which would end up in the Harbor Tunnel.

No analysis was conducted of the bulkhead in view of the 5' anchors, lower pressures at this location and in view of the fact that the bulkhead at Critical Infrastructure was marginally satisfactory with Critical Infrastructure additional pressure.

The steel door was fabricated with 6" wide flange beams and 3/8" plates similar to Critical Infrastructure except there is only one vertical beam located on the centerline of the door. In this case, the beams used are within the allowable AISC stresses in bending and shear, but the 3/8" plate is inadequate. See Section 8 of Appendix D for calculations.

In summary, the concrete bulkhead at Critical Infrastructure is satisfactory, but the steel door would require redesign and replacement to withstand the pressures used in this scenario.

6.5.3 Scenario Two

6.5.3.1 General

Scenario One utilizes existing bulkheads to contain fuel spills at a considerable distance from the source of the discharge. Critical Infrastructure is approximately Critical Infrastructure from Red Hill and Critical Infrastructure is approximately Critical Infrastructure While this scenario has the advantage of reducing the head that has to be contained, it has the serious disadvantage of spreading the leaked fuel over a Critical Infrastructure distance in tunnels that are not leak-proof and cannot be made leak-proof for the pressures encountered. For example, Critical Infrastructure results in a Critical Infrastructure on the gunited walls and floors. This would surely cause outward collapsing or serious cracking of sections of the tunnel ceiling or shell where hollow areas are known to exist, thus allowing fuel to get into the surrounding rock/soil. The extent of the failures would be dependent on the area of the hollow locations back of the gunite. Containment at Critical Infrastructure would place a large volume of fuel directly over the PWC aquifer and would cause flooding of the PWC pumphouse and could cause direct flow of fuel into the existing well unless this area was protected. Even blockage at Critical Infrastructure would place fuel with Critical Infrastructure dangerously close to the aquifer since the water development tunnel passes under the LAT twice in this area. (See Paragraph 5.4.4 and 5.5.2.3 of Environmental Section 5.)

In view of the major disadvantages and potential problems with Scenario One, an alternative solution is proposed as Scenario Two.

6.5.3.2 Description of Scenario Two

Scenario Two would provide secondary containment by providing an oil-tight door Critical Infrastructure and bulkhead and blockage of the tunnel at the pipe anchor located Critical Infrastructure as shown on Figure 3-3 and on Photo RH3-29. The tunnel transitions from a wide tunnel at the sump to a narrow tunnel from this anchor onward. See Photos RH3-24, 25, 26, 27, 28. This area was chosen since it has the least area to close off and only one set of rails exist at this point, while two sets exist in the sump area. This description varies slightly from the original scenario since Critical Infrastructure is a more favorable location than Critical Infrastructure for the reasons given above. The head would be lowered approximately [illegible] from the original since fuel would be allowed to go Critical Infrastructure the tunnel from Critical Infrastructure Critical Infrastructure

The scenario would confine all the leaked fuel to the tank area and reduce the spreading of fuel to a practical minimum. This would reduce the potential for potable water contamination, groundwater pollution and other environmental contamination. It would also greatly reduce the clean-up problem which would be horrendous if fuel were allowed to go down the Harbor Tunnel in any volume. The danger of fuel ignition in areas such as the PWC pumphouse would also be reduced by confining the fuel in the tank area. Naturally, the new door and bulkheads should be designed to the latest standards, using fail-safe technology in lieu of the schemes used on existing doors. With Scenario Two, fuel would reach equilibrium at Critical Infrastructure With a tunnel elevation of Critical Infrastructure the head of liquid would Critical Infrastructure

6.5.3.3 Scenario Two Assessment

A good, fail-safe, operable closure at Critical Infrastructure would eliminate the need for large spill containment at Critical Infrastructure These doors could be upgraded with new seals, trip mechanisms, etc. and serve as containment for pipeline spills in the tunnel only. This could be accomplished at a minimum of cost. Since the potential for large volumes of fuel to come down the tunnels has been eliminated by Critical Infrastructure it is unnecessary to seal off the PWC pump station with oil-tight bulkheads and doors. A simple walkover wall 18" high at the pedestrian entrance would preclude small tunnel pipeline leaks from entering this area, but this would be a low priority project. Tunnel repairs and plugging for out leaks would also be low priority, except at floor holes and deteriorated floor-to-wall joints which could be concrete coved like those observed in the Critical Infrastructure The door to the Critical Infrastructure Critical Infrastructure will not be of concern since they will not be subjected to fuel which will be stopped at Critical Infrastructure

6.6 Other Potential Scenarios

6.6.1 Discharge from Critical Infrastructure

6.6.1.1 General

Just as Scenario One and Two discussed a failure of a tank in the Critical Infrastructure it is necessary to consider what would happen if a similar event occurred in the Critical Infrastructure With the solid concrete bulkhead installed in the lower tunnel just downgrade from Critical Infrastructure no spilled fuel can travel down the lower tunnel beyond this wall. To evaluate a scenario for this area Critical Infrastructure the tank with the highest elevation will be chosen as potentially the worst case.

6.6.1.2 Discussion

Critical Infrastructure has a bottom elevation of Critical Infrastructure and a top elevation of Critical Infrastructure As in Scenario One and Two, the assumed discharge would be from a Critical Infrastructure orifice. The discharge would fill the Critical Infrastructure in the Critical Infrastructure Critical Infrastructure being blocked from going down the tunnel beyond Critical Infrastructure by the concrete bulkhead installed there in the 1960s. The fuel would next flow into the newer Critical Infrastructure and begin rising to the Critical Infrastructure Critical Infrastructure Fuel would then flow out Critical Infrastructure and rise no further. Since this would not be tolerable, it can be assumed Critical Infrastructure will be blocked by installing a proper bulkhead. Then the fuel would rise and begin to fill the upper tunnel in the Critical Infrastructure Doors leading to tanks downgrade of Critical Infrastructure in the upper tunnel will have to be made liquid-tight. The following volumes have been calculated to arrive at the eventual liquid level which would be reached. Assume tank is filled to Elevation Critical Infrastructure which is equivalent to Critical Infrastructure

	Cavity Location	Vol. Ft.^{3}	Vol. BBLs	Tank Fill Height	Tank Level at Equilibrium	Surface Level of Fuel in Upper Tunnel
1	Critical Infrastructure					
2						
3						
4						
5						

* Critical Infrastructure

6.6.1.3 Conclusions

To provide secondary containment for Critical Infrastructure it is apparent that Critical Infrastructure provides the most serious discharge point for a large spill from a full tank. An oil-tight bulkhead and door is needed at Critical Infrastructure to ensure against this type discharge. Using the entire Critical Infrastructure would store over Critical Infrastructure of fuel which is equivalent to Critical Infrastructure of fuel in a tank. This lessens the amount of fuel that would end up in the upper tunnel and, therefore, it is recommended any blockage of the Critical Infrastructure be at the Critical Infrastructure end of the tunnel versus the Critical Infrastructure end of the tunnel. The doors and bulkhead installed in the upper tunnel during the 1960s need to be oil-tight. One alternative solution would be to lower the operational fill height of the uppermost tanks by Critical Infrastructure barrels to an elevation of Critical Infrastructure which is equivalent to a fill height of Critical Infrastructure Critical Infrastructure and a capacity of Critical Infrastructure Another alternative would be to provide an opening and oil-tight door in the bulkhead which now separates tanks Critical Infrastructure from the remainder of the Red Hill tanks. A fuel bypass could be constructed to allow release of fuel retained by Critical Infrastructure into pipelines downgrade of Critical Infrastructure Critical Infrastructure thereby eliminating upper tunnel containments such as that proposed for Critical Infrastructure

6.6.2 Tank Overfilling And Upper Level Leakage

So far, this report has addressed secondary containment for Critical Infrastructure pipelines in the LAT and Harbor Tunnels Critical Infrastructure Other ways fuel could escape would be by overfilling a tank which could push fuel out of a vent or failure of a Critical Infrastructure flange or access tube and manhole at the Critical Infrastructure tank level. The former problem is best prevented by having operational remote gauging, dependable valving, written operations procedures, and most of all, trained operators.

Failure of the second type would appear very remote and the quantities of fuel would be greatly reduced from that of a full tank. Fuel discharged into the upper tunnel could leave via Critical Infrastructure An oil-tight door and bulkhead could be installed at Critical Infrastructure for secondary containment. Similarly, an oil-tight closure could be installed in Critical Infrastructure however, since the upper tunnel slopes toward Critical Infrastructure a Critical Infrastructure high diversionary walkover type wall at the Critical Infrastructure tie-in point may be as effective and far less expensive than an oil-tight enclosure since it would keep fuel in the upper tunnel from running out Critical Infrastructure and force it to flow toward Critical Infrastructure In addition, if the level of fuel rose much above the Critical Infrastructure tunnel tie-in, invert fuel would begin to flow down the original Critical Infrastructure Only Critical Infrastructure are located above the Critical Infrastructure These containments would all be considered lower priority than Scenario Two improvement, Critical Infrastructure containment and modifying existing pipeline containment in the tunnels.

6.6.3 Lower Red Hill Tank Tunnel Fire

All scenarios discussed so far in this Report have assumed failure of one tank. A fire in the Lower Tunnel could spread throughout the Critical Infrastructure using the drain gutter which has oil and oil-soaked muck as an avenue. If such a fire was fed by even a small leak from an overheated draw-off valve or sample valve, sufficient heat might be generated to weaken steel pipe supports. If these supports failed in sufficient numbers, the elevated pipes to each tank would drop [redacted] to the floor. With a Critical Infrastructure ever arm from the center of the main tunnel to the concrete wall at the tank "face", the Critical Infrastructure lines full of fuel would exert a sufficient momentum on the [redacted] valves and pipe at the tank face to cause a break. If this occurred at the tank face wall, there would be no shut-off valve to stop the flow of fuel. This event could occur to one tank or several tanks, but probably not all tanks since the volume of fuel would probably snuff out the fire in the region of the piping and valve galleries.

It may be argued that this will not occur once AFFF is installed in the Lower Tunnel, and this is good justification for installing fire protection in this area.

This Scenario could also be prevented or its potential greatly reduced by application of a fireproofing material to the strucutral steel pipe support to provide a minimum of the fire resistance rating.

Consideration should be given to providing this relatively low cost backup protection in any case. An analagous situation exists in high rise buildings where all structural steel is fire protected whether the building has an automatic sprinkler system or not.

6.6.4 Miscellaneous

With the installation of Critical Infrastructure the importance of sealing the upper areas of the LAT and Harbor Tunnels downgrade of the door is diminished since these areas will not be subjected to pressure. Coving of floor-to-wall joints that are defective and repair of floor holes is recommended to retain any pipeline leaks that might occur. Photos RH3-38, 39 and 40 refer. Upgrade of Critical Infrastructure here are some large penetrations of the tunnel ceiling in the area of the sump that should be sealed. Photos RH3-41 and 42 refer.

Critical Infrastructure was looked at as a possible discharge point for a fuel leak. The original design of this adit provides an entrance which is about Critical Infrastructure the tunnel floor. This would act as a dam for any liquid in the tunnel. The elevation of this entrance is Critical Infrastructure which is high enough above the PWC pump station wye elevation of Critical Infrastructure to cause any liquid in the tunnel to go down the Harbor Tunnel instead of leaving out the Critical Infrastructure entrance.

With any scenario where Secondary Containment is installed to control a massive discharge of fuel it is important to inspect each tank face in the lower tunnel to ensure there are no open drain pipes, sample pipes or other penetrations where fuel underpressure in the lower tunnel could reach the outside of the tank liner. Fuel under pressure from a full tank discharge could enter these avenues during filling of the lower tunnel and cause collapse of the steel liner of an empty or partially filled tank.

While more will be learned about existing floor drains in the subsequent rail study it was observed the drain entering the pumphouse was 5/8 full of coarse sand/soil and needs to be cleaned. Clean outs should be installed at 300' intervals to keep these lines clear.

Gutters in the lower tunnel at the tanks contain fuel and muck which provides an ideal way to spread fire throughout the Critical Infrastructure Grating over portions of this gutter are deteriorated and are a personnel safety hazard. See Photo RH3-52.

Other oil-tight doors were inspected in the Pumphouse 59 area. Other than maintaining and upgrading the existing doors and seals and ensuring that the doors are not bypassed by new wall penetrations, no further recommendations are offered in this area.

6.6.5 Scope Item b(2), "Relocation of Existing Tunnel Fuel Piping Underground to Reduce Fire Hazards"

It is understood this proposal would replace the Harbor Tunnel Critical Infrastructure pipelines with new underground lines that would exit at Critical Infrastructure and then proceed underground to Pearl Harbor, possibly following, in part, the route of the existing Critical Infrastructure which connects Red Hill to Pearl City.

The Harbor Tunnel and LAT have served as a conduit for the Critical Infrastructure lines connecting Red Hill to Pearl Harbor for over 50 years. The purpose of the tunnels was probably to provide bomb-proof and sabotage-proof protection for these vital pipelines. The tunnels have done an outstanding job of protecting the pipelines from corrosion as evidenced by only 2 minor leaks having occurred during this period, according to reports. The lines installed in the tunnel allow visual and ultrasonic inspection and, therefore, have some of the advantages of aboveground pipelines. The lines remain in excellent condition except for some specific problem areas where water has been allowed to drip on the lines. In addition, the lines have required little painting, no cathodic protection, no cathodic surveys and have never had to be moved for freeways or other developments. If the lines had been installed underground, many relocations would have occurred as they have occurred on the Critical Infrastructure lines to Critical Infrastructure

As this report is being written, the local news has reported an LPG line, which was punctured by construction equipment, caught fire and burned several days and destroyed nearby houses. In Panama, the government owned Transisthmian line carrying a "safe" JP-5 fuel under pressure was punctured by the draw bar pin of a bulldozer, spraying fuel on the tractor and severely burning the tractor and operator. Government lines between San Pedro and Norwalk pumped 2,400 BBLs of JP-4 fuel onto the streets of Wilmington, California due to a rupture in an underground line. Utility companies tried augering through the Navy's San Diego to Miramar pipeline but were not successful. The Critical Infrastructure in the Harbor Tunnel have not been subjected to the ravages of earth-moving contractors, and they have been immune from relocation for 50 years.

Although war conditions are now remote, unfortunately, terrorism is not dead. The Critical Infrastructure lines are far better protected from terrorism in the tunnels than if they were installed near and under public roads enroute to Pearl Harbor.

The relocation would cause a certain amount of environmental disruption in an environmentally sensitive area and, of course, would require an environmental impact assessment/study.

In addition to the many disadvantages of relocating the line underground, the greatest deterrent would be the cost of accomplishment.

Willbros Engineers believes the hazards of leaks and fire would be increased considerably by replacing the tunnel pipelines with underground lines and strongly recommends the lines remain in tunnels and be properly maintained.

6.7. Conclusions and Recommendations

6.7.1 Conclusions

The on-site investigation revealed there is no secondary containment that would function if a large catastrophic failure occurred at the Red Hill complex. Containment installed during original construction is no longer operational and even if operational would not provide the optimum type protection of the environment, especially of the water supply. Installation of a new oil-tight Critical Infrastructure just below the tank area will preclude fuel in any large quantity from going down the LAT and Harbor Tunnels. It is, therefore, unnecessary to protect other critical areas such as the PWC pumphouse, Critical Infrastructure Critical Infrastructure and real and suspected cross tunnels from large volumes of discharged fuel. Tunnel repairs from a containment standpoint (excluding structural and in leakage problems) would only have to be concerned with pipeline spills which have limited volume and generally would have a slow leakage rate. Alternatives to existing systems have been presented and the alternative of relocating the lines has been discussed in detail.

6.7.2 Recommendations

1. Construct a new oil-tight bulkhead and door at Critical Infrastructure ust below tanks lands in the narrow portion of the tunnel to confine any catastrophic failures to the Critical Infrastructure

   Estimated cost from Appendix C is $ 100,720

2. Refurbish existing drop track Critical Infrastructure o act as containment for tunnel pipelines leaks This will adequately protect Critical Infrastructure as well as the pumphouse, from the fuel leaks in the tunnel pipelines.

   Estimated cost from Appendix C is $ 17,152

3. Provide oil-tight door/bulkhead in Critical Infrastructure to provide secondary containment for Critical Infrastructure

   Estimated cost from Appendix C is $ 42,251

4. Install secondary containment at Critical Infrastructure and a 3' high diversionary wall at Critical Infrastructure Both these projects are considered low priority to be done only after all above work is accomplished.

   Estimated cost from Appendix C is $ 44,551

5. Construct 18" high diversionary wall at PWC pump station entrance to prevent relatively small pipeline leaks from entering the pump station.

   Estimated cost of wall from Appendix C is $ 2,800

6. Inspect/seal all penetrations/pipes in the lower tunnel valve galleries to prevent a massive fuel spill from migrating to the area outside the steel liner and thereby collapsing the liner.

   Estimated cost of tunnel repairs from Appendix C is $ 2,240

7. If secondary containment in the upper tunnel between Critical Infrastructure is not capable of retaining fuel, consider reducing the filling height in Critical Infrastructure This is equivalent to the Critical Infrastructure and will prevent fuel from entering the upper tunnel in case of a catastrophic leak in any of Critical Infrastructure

   Estimated cost No Direct Cost

8. Strongly recommend that pipelines not be relocated out of the tunnel to an underground right-of-way but FISC should maintain existing pipelines, pipeline supports, valves and tunnel structure, drains and drain gutters in a good state of repair and cleanliness.

Estimated cost from Appendix C for repairing defective areas of tunnel gunite, plugging tunnel openings, replacing corroded arches and unsafe gratings, installing clean outs on existing drain lines and cleaning drains and gutters.	$ 60,470

Projects for maintaining pipeline supports, and prevention of water in-leakage from contacting pipes and steel supports have been recommended in previous reports and therefore are not repeated in this report.