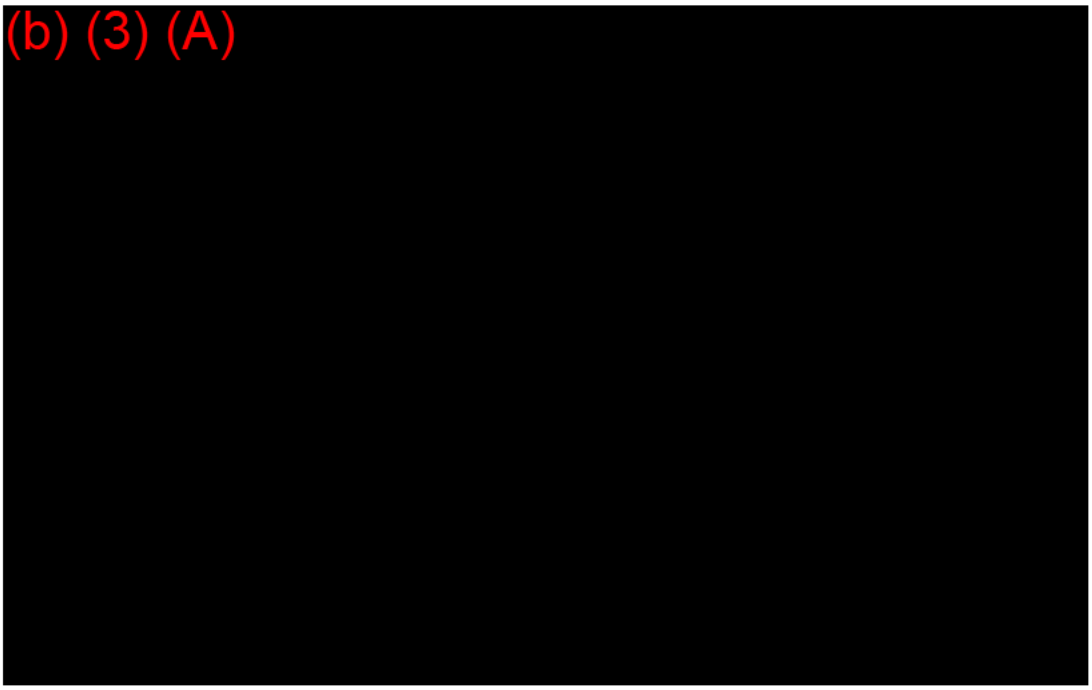
Naval Facilities Engineering Systems Command
EXWC Engineering & Expeditionary Warfare Center

OCTOBER 2021

RED HILL BULK FUEL STORAGE FACILITY JP-5 PIPING MITIGATIONS REPORT

(b) (3) (A)



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EXECUTIVE SUMMARY

The "Root Cause Analysis of the JP-5 Pipeline Damage Report" dated 7 Sep 2021 (RCA Report) provided an engineering-based examination of the Red Hill pipeline failure incident on 6 May 2021. This Mitigation Report analyzes the RCA Report findings, and provides clarification which translates both causes and contributing factors of the pipeline failure into actions. This report will recommend actions to reduce or mitigate the likelihood and/or severity of recurrence by improving system resiliency and safety.

Actions taken under the Technical Authority of Naval Facilities Engineering Systems Command (NAVFAC) for POL Facilities Engineering will be coordinated with Naval Supply Systems Command (NAVSUP) and Defense Logistics Agency (DLA). Recommendations for actions which lie outside of NAVFAC technical authority, (e.g., Naval Network Warfare Command, (NETWARCOM) for Automated Fuel Handling Equipment (AFHE) modification), will be provided to NAVSUP and DLA. As the decision to implement action lies in part outside of NAVFAC, this report is intended for internal DoD or contractor use only. NAVFAC will provide facilities-related support necessary to implement any actions.

This report categorizes the findings of the RCA Report as either causes or contributing factors. Causes include "root" (ultimate event or condition that if not present, the pipeline failure would not have occurred), "proximate" (event or condition that occurred or existed before the pipeline failure, directly resulted in its occurrence, and if eliminated or modified would have prevented the pipeline failure) and "direct" (event or condition which is closest to, or immediately responsible for causing the pipeline failure). Contributing factors include any condition that increases the likelihood and/or severity of the pipeline failure; eliminating a contributing factor will not eliminate the pipeline failure.

This report categorizes action types for all causes and factors as "corrective" (action taken to stop a recurrence of the pipeline failure), "remedial" (action taken to remove a nonconformity, without addressing the root cause), and "preventive" (action taken to stop the potential for conditions that could create a pipeline failure).

Report findings, actions and action agency for each cause and factor are summarized in the table below.

Finding	Description	Category	Action
Transient surge pressure of fuel	Near-instantaneous hydraulic collapse of a pocket of low-pressure in piping near Tanks 18 and 20 produced a transient pressure which damaged piping	Direct Cause	Remedial: Follow operations orders. [OPR: NAVSUP].
Improper valve sequencing	There was a disregard of proper valve sequencing dictated in the specific operations orders which caused the transient surge pressure	Root Cause	Corrective: Follow operations orders; improve training. [OPR: NAVSUP].
Lack of sufficient piping restraint	The (b) (3) (A) JP-5 mainline piping near Tank 20 was displaced laterally and separated pipe couplings	Proximate Cause	Corrective: Provide means of restraint for piping. [OPR: NAVFAC]. Note 1: This action will not prevent all damage caused by a severe pressure transient. Note 2: This action is already included in the pipeline repair contract.
Lack of alarms	Out-of-balance alarm insensitive to event; low-pressure reading did not actuate an alarm.	Contributing Factor	Preventive: Implement out-of-balance and low-pressure alarms; consider installing additional Pressure Indicating Transmitters. [OPR: NAVWARCOM; OCR: NAVFAC].
Leaking butterfly valve	Butterfly valves (BFV), designed to throttle flow not isolate, leak when exposed to high differential pressure. Failure to follow the operations orders resulted in the isolation valves between the RHTF storage tanks and the Surge Tank 2 being open while the butterfly valve was closed and leaking.	Contributing Factor	Corrective: Always operate the system so that the butterfly valves are never relied upon to isolate. [OPR: NAVSUP] Preventive: Inspect and maintain BFVs in adherence with UFC 3-460-03 to minimize but not eliminate leakage. [OPR: NAVSUP]

ACRONYMS AND ABBREVIATIONS

AFHE	Automated Fuel Handling Equipment
ATG	Automatic Tank Gauge
DOD	Department of Defense
DOE	Department of Energy
DLA	Defense Logistics Agency
EXWC	Engineering and Expeditionary Warfare Center
FLC	Fleet Logistics Center
FLCPH	Fleet Logistics Center Pearl Harbor
JP-5	Jet Propellant 5 Aviation Turbine Fuel
MOV	Motor Operated Valve
NAVFAC	Naval Facilities Engineering Systems Command
NAVSUP	Naval Supply Systems Command
NIWC	Naval Information Warfare Center
OCR	Office of Coordinating Responsibility
OPR	Office of Primary Responsibility
PIT	Pressure Indicating Transmitter
POL	Petroleum Oil and Lubricants
PS	Pipe Support
RCA	Root Cause Analysis
UFC	Unified Facilities Criteria
RHBFSF	Red Hill Bulk Fuel Storage Facility
UFGS	Unified Facilities Guide Specifications

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1.0 INTRODUCTION

1.1 Purpose

In response to a 10 May 2021 request by the Fleet Logistics Center Pearl Harbor to investigate damage to JP-5 piping at the Red Hill Bulk Fuel Storage Facility (RHBFSF), Naval Facilities Engineering and Expeditionary Warfare Center Code SH25 (NAVFAC EXWC) conducted a damage assessment, procured an independent engineered investigation of the root cause of the damage, developed measures to mitigate a recurrence of the event, and awarded a contract to repair the damage.

This Mitigations Report analyzes and amplifies the independent root cause investigation report, identifies actions to prevent a recurrence of the event, and recommends measures to increase the resilience of the system. Each finding in this report is categorized as either a cause or a contributing factor. Each finding has an action and an action agency.

1.2 Background

1.2.1 Definitions

For purposes of this Mitigations Report, the following terms are defined below.

1.2.1.1 Contributing Factor

Any condition that increases the likelihood and/or severity of the pipeline failure; eliminating a contributing factor will not eliminate the pipeline failure.

1.2.1.2 Corrective Action

Action taken to stop a recurrence of the pipeline failure.

1.2.1.3 Direct Cause

Event or condition which is closest to, or immediately responsible for causing the pipeline failure.

1.2.1.4 Preventive Action

Action taken to stop the potential for conditions that could create a pipeline failure.

1.2.1.5 Proximate Cause

Event or condition that occurred or existed before the pipeline failure, directly resulted in its occurrence, and if eliminated or modified would have prevented the pipeline failure.

1.2.1.6 Remedial Action

Action taken to remove a nonconformity, without addressing the root cause.

1.2.1.7 Root Cause

Ultimate event or condition that if not present, the pipeline failure would not have occurred.

1.2.2 Root Cause Analysis

Root Cause Analysis (RCA) is a forensic engineering process designed to investigate and determine the underlying cause of an event. RCA is a tool used to identify the "what", "how", and "why." That identification is essential to implement corrective action necessary to mitigate recurrence of an event.

1.2.3 Event

On 06 May 2021, a damaging event occurred in JP-5 piping at the RHBFSF onboard Joint Base Pearl Harbor Hickam, Pearl Harbor, Hawaii. As a result of the event, fuel was spilled to the ground near Tank 20. On an emergent basis, NAVFAC EXWC engaged AE contractor Austin Brockenbrough & Associates (AB&A) to provide an unbiased determination of the cause of the event, and mobilized Code SH25 personnel to evaluate the damage. Due to the significance of the DOD mission provided by the RHBFSF piping and the need to rapidly identify the root cause, substantial compression of preparatory, investigative, and reporting activities was necessary. For purposes of this Mitigations Report, the event is defined as the piping failure which took place on 06 May 2021.

On 07 Sep 2021, AB&A provided a report entitled *Root Cause Analysis of the JP-5 Pipeline Damage* (RCA Report). The RCA Report determined the root cause and contributing factors which are paraphrased and summarized in Table 1.

Table 1 RCA Report Root Cause and Contributing Factors

Root Cause	
1	Personnel failed to adhere to two operations orders.
Contributing Factors	
1	Inappropriate use of butterfly valves for leak tight service
2	The lack of an out-of-balance alarm prior to the event
3	The lack of a low-pressure alarm for (b) (3) prior to the event
4	Lack of mainline piping restraint

1.2.4 Damage from Event

NAVFAC EXWC assessed the damage to the JP-5 system piping in May 2021. As a result of the event, damage to pipe couplings were found at Tanks (b) (3) (A). Several bent pipe stands, a slight shift in the longitudinal position of the mainline, several pipe dents, and damage to several support saddles and frames were identified. Damage was found in the vicinity of Tanks 17 through 20. Coating and insulation was removed as necessary to conduct the assessment. Visual and nondestructive means were used. A repair list was generated and programmed into a repair contract.

1.3 Intent

The intent of mitigation measures in this report is to address findings in order to reduce the likelihood of another event. Repair work, inspection of repairs, and testing will be conducted in accordance with current criteria. It is not the intent of this report to address all risks or mitigate risk to zero.

2.0 DIRECT CAUSE

2.1 Analysis

The RCA Report identified that a liquid column separation and substantial pressure transient took place in the JP-5 piping prior to the event. The RCA Report discussed and modeled the fluid mechanics of the pressure transient. At the time the Tank 12 isolation valve was opened, a pocket of low pressure existed in the piping. A near-instantaneous hydraulic collapse of the pocket of low pressure in piping near Tanks 18 and 20 produced a transient pressure which damaged piping.

The phenomenon of column separation is well documented in engineering literature. It can occur within a piping system when boundary conditions are such that pressure is reduced near the upper end of a pipe. In unsteady flow situations, a rapid disturbance of pressure can result when an inrush of high pressure liquid encounters a region of low pressure (Wylie & Streeter, 1983).

2.2 Finding

The direct cause of the event was the transient surge pressure of fuel.

2.3 Action

Technical authority over system operations lies with NAVSUP. Recommended remedial action is listed below.

2.3.1 Follow operations orders

3.0 ROOT CAUSE

3.1 Analysis

AB&A determined the root cause was categorically a procedural error, and specifically was the failure of operator personnel to adhere to the valve lineup prescribed in two written operations orders. The orders prescribed valve alignment and sequencing for two fuel movement evolutions, with Evolution 3 required to be completed before initiating Evolution 4. The RCA Report identifies specific parts of the orders which were not followed and resulted in valve misalignments. At the conclusion of Evolution 3, (b) (3) (A) which are normally closed valves, were left in the open position during a period of time when the operations order prescribed them to be closed. (b) (3) (A) were later closed as part of Evolution 3, but Valve (b) (3) (A) remained open. When Evolution 4 was initiated, Valve (b) (3) (A) was still open, despite the operations order which prescribed it to be closed.

AB&A further determined and documented in the RCA Report the existence of a liquid column separation. Its relevance to the event and how the pressure transient took place was explained. Hydraulic modeling and stress analysis were conducted independent of each other, and their relevance to the event was established. The fact that adherence to the operations orders would have precluded the event from occurring was demonstrated. The root cause as reported by AB&A is supported by the facts, the simulations, and the empirical data. There was a disregard of proper valve sequencing dictated in the specific operations orders which caused the transient surge pressure.

3.2 Finding

The root cause of the event was improper valve sequencing.

3.3 Action

Technical authority over system operations lies with NAVSUP. Recommended corrective actions are listed below. It is not recommended to change the AFHE system to remove operator control and automate actuation of valves.

3.3.1 Follow valve sequencing in operations orders

3.3.2 Improve operator training.

4.0 PROXIMATE CAUSE

4.1 Analysis

The RCA Report cites lack of JP-5 mainline restraint as a contributing factor. Couplings which are present in the crosstunnel piping rely on minimal displacement (restraint) of the mainline in order to function within manufacturer requirements. During the event, the (b) (3) JP-5 mainline piping near Tank 20 was displaced laterally and separated pipe couplings.

4.2 Finding

The proximate cause of the event was the lack of sufficient piping restraint.

4.3 Action

Recommendations for measures to provide system restraint (along with repairs due to damage) were made in Sep 2021 by NAVFAC EXWC and received concurrence from Fleet Logistics Center Pearl Harbor, Naval Petroleum Office, and the Defense Logistics Agency. The approximate cost for engineering design, repairs to the system, and piping restraint is (b) . NAVFAC EXWC awarded a contract to execute work in Sep 2021. This action will not prevent all damage caused by a severe pressure transient.

Technical authority over work to repair the piping system lies with NAVFAC. Recommended corrective action is listed below. This action is already included in the piping repair contract.

4.3.1 Provide means of restraint for piping.

5.0 CONTRIBUTING FACTOR 1

5.1 Analysis

The RCA Report cited the lack of an out of balance alarm prior to the event as a contributing factor. It was demonstrated by the AFHE system operator during the investigation that sufficient data are collected to trigger an alarm for an out of balance condition. However, the AFHE out of balance alarm setting was insensitive to the volume moved prior to the event and did not trigger an alarm for FLC fuels operator awareness. During the period of improper valve sequencing prior to the event, an out of balance alarm could have notified the operator of anomalous conditions. The out-of-balance alarm was insensitive to the event.

5.2 Finding

A contributing factor to the event was the lack of out of balance alarm.

5.3 Action

Technical authority over work to change the AFHE system software and settings lies with NAVWARCOM. Recommended preventative actions are listed below.

5.3.1 Modify the AFHE system software to detect and actuate an audible or visual alarm on gains and losses in tanks involved in an evolution when isolation valves are closed and fuel should not be moving.

5.3.2 Increase the fidelity of the system to detect smaller out of balance situations.

5.3.3 Update Operations Orders to require monitoring of out of balance readings and to address alarm response.

6.0 CONTRIBUTING FACTOR 2

6.1 Analysis

The RCA Report cited the lack of a low-pressure alarm prior to the event as a contributing factor. It was demonstrated by the AFHE system operator during the investigation that sufficient data are collected to trigger an alarm for a low-pressure condition. However, the low-pressure reading did not actuate an alarm. During the period of improper valve sequencing prior to the event, a low-pressure alarm could have notified the FLC operator of anomalous conditions.

6.2 Finding

A contributing factor to the event was the lack of low-pressure alarm.

6.3 Action

Technical authority over work to change the AFHE system software and settings lies with NAVWARCOM. Recommended preventative actions are listed below.

6.3.1 Modify the AFHE system software to detect and actuate an audible or visual alarm on pressure drops at (b) (3) (A) during an evolution when isolation valves are closed and fuel should not be moving.

6.3.2 Consider installing additional PITs on both sides of (b) (3) (A) for system redundancy.

6.3.3 Update Operations Orders to require monitoring of pressure readings and to address alarm response.

7.0 CONTRIBUTING FACTOR 3

7.1 Analysis

Butterfly valves (BFV) are commonly used to control liquid flow. Unless specifically configured, BFVs are not expected to be leak tight. As used in the Red Hill JP-5 piping system, the BFVs are intended to control bi-directional flow. The operations orders in use on 06 May 2021 were consistent in that leak-tight performance was not required for the valves to perform satisfactorily. The relevant inspection and maintenance criteria of BFVs is UFC 3-460-03 *Petroleum Fuel Systems Maintenance* (Deparment of Defense, 2021).

Butterfly valves, designed to throttle flow not isolate, leak when exposed to high differential pressure. Failure to follow the operations orders resulted in the isolation valves between the RHTF storage tanks and the Surge Tank (b) being open while the butterfly valve was closed and leaking.

7.2 Findings

A contributing factor to the event was a leaking butterfly valve.

7.3 Action

Technical authority over system operations lies with NAVSUP. Recommended corrective and preventive actions are listed below.

7.3.1 Corrective: Always operate the system so that the butterfly valves are never relied upon to isolate.

7.3.2 Preventive: Inspect and maintain BFVs in adherence with UFC 3-460-03 *Petroleum Fuel Systems Maintenance* (Deparment of Defense, 2021) to minimize but not eliminate leakage.

8.0 SYSTEM RESILIENCE

NAVFAC EXWC identified items of mechanical work which will improve and make the piping system more resilient. These items are not the direct result of the event. Recommendations for these preventive measures were made in Sep 2021 by NAVFAC EXWC and received concurrence from Fleet Logistics Center Pearl Harbor, Naval Petroleum Office, and the Defense Logistics Agency. The approximate cost for engineering design and work to increase system resilience is (b) (5). Table 2 contains a list of recommendations and preventive actions programmed into a construction contract awarded by EXWC in Sep 2021.

Table 2 System Resilience Recommendations and Actions

Recommendation*	Preventive Action†
(b) (3) (A) [redacted]	Install permanent means of restraint
(b) (3) (A) [redacted]	Install upgraded and insulated pipe couplings
(b) (3) (A) [redacted]	Install new pipe supports
(b) (3) (A) [redacted]	Shorten deadleg
Mainline alignment change spool pitted	Replace with new flanged spool
Obsolete pipe joint design	Replace with new butt-welded pipe joints
Nonstandard small bore fittings	Replace with welded and standard components
Crosstunnel fitting pitted	Install replacement fitting
Mainline segment pitted	Replace with new piping segment
Several mainline support saddles misaligned	Reset saddles to bear on piping
* (b) (3) system unless stated otherwise	
† Design and construct	

9.0 CONCLUSIONS

Table 3 summarizes findings, actions and action agency for each cause and factor.

Table 3. Summary of Findings and Actions

Finding	Description	Category	Action
Transient surge pressure of fuel	Near-instantaneous hydraulic collapse of a pocket of low-pressure in piping near Tanks 18 and 20 produced a transient pressure which damaged piping	Direct Cause	Remedial: Follow operations orders. [OPR: NAVSUP].
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