Surface Mooring Gas Mitigation Test Plan

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Table of Contents

1 Introduction 1
1.1 Scope 1
1.2 Gas Mitigation Test Purpose 2
1.3 Surface Mooring Environmental Monitoring, Gas Venting, and Power Generation Test Plan Overview 2
1.4 Roles and Responsibilities 2
1.5 Reference Documents 2
1.6 Definitions & Acronyms 2
2 Test Strategy 2
2.1 Test Objectives 2
2.2 Test Configurations 3
3 Planned Tests 3
3.1 Test Scenario 1: Venting 3
3.1.1 Test Activity 3
3.2 Test Scenario 2: Gas Detection 4
3.2.1 Test Activity 4
3.3 Test Scenario 3: Battery Charging 5
3.3.1 Test Activity 5
3.4 Test Group 4: 6
3.4.1 Test Case 1: Purge Procedure Effectiveness 6
4 Data Collection and Analysis Plan 6
5 Environmental, Health, and Safety Requirements 6
6 Test Team Organization and Responsibilities 6
7 Test Schedule 7
8 Requirements Traceability 7
9 Records 7
APPENDIX A : List of Test Procedures 1

List of Figures

Figure 1	Calculated Hydrogen generation due to battery terminal voltage

List of Tables

N/A

1 Introduction

1.1 Scope

CP01CNSM, a medium power OOI surface mooring, stopped all data transmission on 17 Feb. 2014. Two, self-contained emergency beacons continued to transmit location as normal. The buoy remained within its expected watch circle. The failure of all buoy telemetry systems simultaneously was considered an anomaly due to the redundant and parallel telemetry system architecture. Upon initial recovery, it was reported that there are clear signs of an explosion in the buoy instrument well. Further analysis on shore determined the root cause of the explosion to be a lack of venting in the instrument well, allowing an explosive concentration of Hydrogen gas, created during battery charge cycles, to accumulate inside the well. This mixture reached the Lower Explosive Limit (LEL), and was then ignited by an electrical arc from a power relay in the mooring power management system.

Figure 1 below demonstrates the calculated accumulation of Hydrogen gas (in red) inside the instrument well with respect battery voltage (in blue) over the time of the mooring deployment. The instrument well is approximately 1600 Liters. Therefore, the volume of Hydrogen required to reach the 4% LEL is approximately 64 Liters.

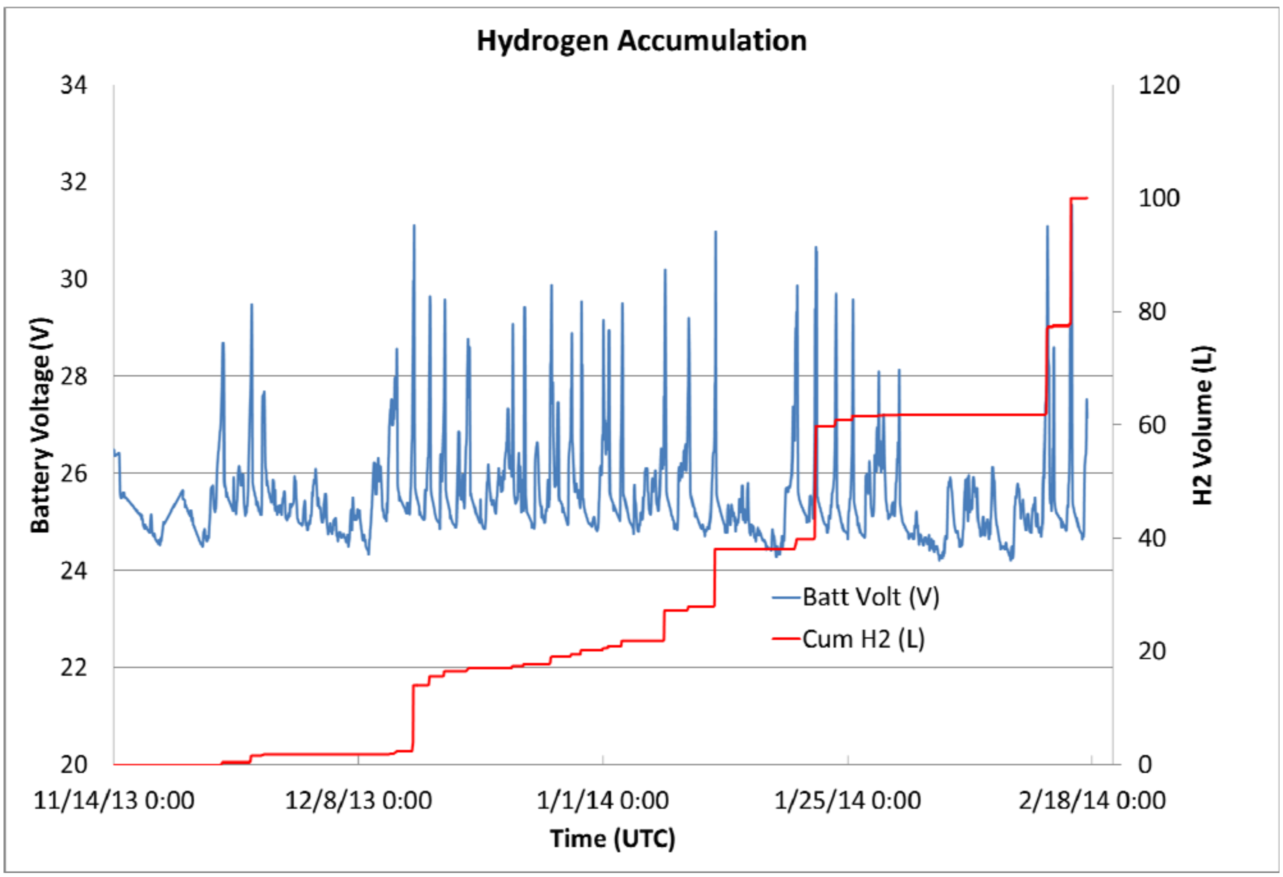

Figure 1: Calculated Hydrogen generation due to battery terminal voltage.

This document is designed to capture the design process and the test procedures that quantify that will mitigate the risk of future explosions.

Reduce the risk of mooring explosion through:

- Venting of volatile gases
- Monitor gas production
- Reduce gas generation
- Handling and recovery procedures

1.2 Gas Mitigation Test Purpose

Verify the effectiveness of venting and reduction of combustible gas in the surface mooring instrument well. Monitor in real time the concentration of Hydrogen gas in the instrument well. Develop a recovery procedure in the case of an unknown Hydrogen concentration and/or a mooring in an unknown state.

1.3 Surface Mooring Environmental Monitoring, Gas Venting, and Power Generation Test Plan Overview

Instrument Well: Adequate venting of potential gas, monitor Hydrogen concentration.
Power Generation: Reduce the production of gas generation
Handling and Recovery: Reduce risk of personal harm

1.4 Roles and Responsibilities

Matthew Palanza:	Technical Lead
Jeremy Paulus:	Mechanical Engineer, venting system
Steve Lerner:	Software Engineer, Control and data collection
Bob Pettit	Electrical Engineer, Power System
Mark D'Angelo:	Firmware development, Wiring Diagrams, configuration management
Jeff Pietro:	Handling and recovery procedures

1.5 Reference Documents

- FAR-00008-CP01CNSM Failure Analysis
- BuoySafety_2009
- FOASsafetyalert GMO v4.doc
- H.12.001 Hazardous Atmosphere Testing of 3-Meter Buoys--D

1.6 Definitions & Acronyms

PSC: Power System Controller (Mooring battery/charge management system)
CPM: Control & Power Manager (Mooring platform controller)
DCL: Data Concentrator Logger (Mooring sensor interface and data logger)
H2: Hydrogen gas
LEL: Lower Explosive Limit

2 Test Strategy

There are four major disciplines required for resolving the gas mitigation issue; Mechanical Engineering for the venting scheme, Software/Firmware engineering for the monitoring of Hydrogen concentration, battery charging algorithms, and remote intervention, Electrical Engineering for battery system, and Operations for handling and recovery procedures. Each of these four disciplines can work on specific tests, and the combination can be implemented on the buoy system.

2.1 Test Objectives

- Verify effectiveness of new venting system

- Verify sensor detection capability
- Verify SW/HW updates to limit H2 gas production
- Verify ability to purge buoy well to ensure safe handling and recovery procedures

2.2 Test Configurations

Each of the four specific tests types will be conducted with a separate configuration specific to their respective test requirements:

> Vent characterization will initially be conducted using a physical mock-up of the vent design, and continue through gas level monitoring of the completed instrument well.
>
> Gas monitoring will be conducted using the surface mooring battery strings. During initial testing the battery strings will be outside of the instrument well to allow for instrumentation. A test will be conducted prior to sealing the batteries in the instrument well. And final testing will occur in the sealed instrument well.
>
> The battery charge test configuration is to increase the logging rate of PSC data. The primary requirement is to increase the resolution of battery terminal voltage measurement.
>
> Recovery procedure testing will use the surface mooring instrument well itself.

3 Planned Tests

There are four major test scenarios:

1. Venting of any gas produced
2. Monitoring, detection, and intervention
3. Battery charging inputs
4. Procedures for handling and recovery

3.1 Test Scenario 1: Venting

Quantify the expected flow rate of the improved venting scheme due to the buoyancy of Hydrogen.

3.1.1 Test Activity

Build a mock-up of the vent system. Attach the vent system to a small, sealed enclosure that emulates a scaled down version of surface mooring instrument well. The enclosed space can then be flooded with Helium. Helium will be used as a Hydrogen substitute due to its buoyant, but inert nature. Use gas sensing instrumentation to measure the ventilation rate of a buoyant gas escaping after it is introduced into a closed system.

3.1.1.1 Requirements Addressed

Do not allow the accumulation of volatile gas by installing a passive ventilation system. An initial vent rate has been calculated at 34 mL/min. This is based on venting capability at the calculated H2 off-gas rate multiplied by a safety factor of 4.

Calculated off-gas rate: 0.0083 L/min: based on empirical charge data
Vent rate: 0.0083 L/min * a safety factor of 4 = 34 mL/min

3.1.1.2 Pre-conditions

Empirical data is to be collected based on a physical model of the vented instrument well.

3.1.1.3 Hardware Preparation

The vent outlet points will be monitored by an operator using a handheld instrumentation. Flow rate through the ventilation system will be determined by timing the reduction of concentration of the Helium gas.

3.1.1.4 Software Preparation

N/A

3.1.1.5 Test Inputs

The scale model enclosure must be fully flooded by the release of helium gas into the sealed enclosure.

3.1.1.6 Expected Results

The buoyant force of Helium should lead the migration of gas out of the enclosure, and create a convection air flow through the ventilation system.

3.1.1.7 Criteria for Evaluating Results

Determine a baseline flow rate for the venting system, by measuring the time it takes for the Helium to ventilate out of the enclosure. Calculate an expected flow rate for Hydrogen due to the increased buoyancy. This flow rate should meet or exceed the potential rate of Hydrogen generation.

3.2 Test Scenario 2: Gas Detection

Determine requirements for a suitable sensor to be installed inside the instrument well.

3.2.1 Test Activity

Monitor environment in the instrument well during a variety of operational cycles.

3.2.1.1 Requirements Addressed

Monitor the production of Hydrogen gas, detect and measure the concentration of Hydrogen gas, and intervene in order to reduce the production by removing charge sources.

Minimum concentration detection capability: 1% (10,000 ppm) H_2 concentration.

3.2.1.2 Pre-conditions

Appropriate requirements for H_2 sensor(s) must be developed. Acquire the H_2 sensor(s) and integrate into the current test environment.

- H_2 Sensor Selection: Establish requirements:
    - Interface (serial or Ethernet)
    - Power / Voltage (12-24 Volts)
    - Sensitivity (H_2 level)
    - Selectivity (H_2 specific)
    - Duty Cycle (Detection synchronous with charge cycle?)

3.2.1.3 Hardware Preparation

The final selection of H_2 sensor(s) must be integrated into the mooring data collection system.

- H_2 Sensor Hardware Interface:
    - Communication Protocol
    - Power Requirement
    - Duty Cycle

3.2.1.4 Software Preparation

Specific software implementation will be based on final hardware architecture. Final configuration will be designed based on if hardware interfaces to CPM, DCL or PSC.

- H2 Sensor Software Interface:
    - PSC: Hardware and firmware development, add data to PSC status output
    - CPM: Serial interface, add data to CPM status string
    - DCL: Create an instrument driver, log similar to science instrumentation.

3.2.1.5 Test Inputs

There are a series of tests starting with characterization of Hydrogen generation during all phases of operation. Here, a Hydrogen sensor can be mounted on a battery vent and data can be logged continuously.

3.2.1.6 Expected Results

It is expected to measure the production of Hydrogen gas from the battery system during all phases of operation; idle, charge and discharge cycles.

3.2.1.7 Criteria for Evaluating Results

Determine if there are other modes of operation that may generate Hydrogen, and apply

3.3 Test Scenario 3: Battery Charging

Investigate control methods and/or hardware to minimize excessive voltage on the battery bus. Verify the effect of mitigating voltage levels on the battery terminals/bus. Predict an expected amount of H2 gas production.

3.3.1 Test Activity

Use H2 sensors to monitor H2 gas generation during the expected variety of charging scenarios, including simulated wind turbine, and PV outputs.

3.3.1.1 Requirements Addressed

Reduce gas generation due to overvoltage on the battery terminals.

3.3.1.2 Pre-conditions

- Data analysis: clearly establish the conditions that led to the generation of excessive amounts of H2 gas.

3.3.1.3 Hardware Preparation

- Surface mooring battery system
- External power supply: programmable, capable of emulating wind turbines, PV panels, and fuel cell outputs
- H2 sensors installed (electrical interface implemented)

3.3.1.4 Software Preparation

Create a driver and/or data logging system for logging H2 sensor data. Increase current scan resolution.

3.3.1.5 Test Inputs

Use standard PSC string including timestamp, battery terminal temperature, and bus voltage.

3.3.1.6 Expected Results

It is expected to verify the reduction of Hydrogen generation, by reducing the battery terminal voltage during a charge cycle.

3.3.1.7 Criteria for Evaluating Results

Plot gas generation with respect to battery terminal voltage, compare expected output and evaluate with respect to measured ventilation capability.

3.4 Test Group 4:

Determine safe handling and recovery procedures. Test the effectiveness of the Hydrogen purging procedure.

3.4.1 Test Case 1: Purge Procedure Effectiveness

Validate the effectiveness of evacuating volatile gases out of an instrument well.

3.4.1.1 Requirements Addressed

Develop a safe and effective recovery procedure in the event of a mooring with an explosive concentration of Hydrogen in the instrument well.

3.4.1.2 Pre-conditions

A complete instrument well with ventilation hardware and purge valve installed.

3.4.1.3 Hardware Preparation

Calculate the requirement for a suitable sized Nitrogen tank. Investigate and acquire handheld gas sensing instrumentation.

3.4.1.4 Software Preparation

N/A

3.4.1.5 Test Inputs

Flood the instrument well with Helium. For safety reasons, Helium is used as a buoyant, yet inert substitute for Hydrogen.

3.4.1.6 Expected Results

The instrument well should be purged of Helium to less that 1% concentration (10,000 ppm).

3.4.1.7 Criteria for Evaluating Results

An acceptable result is to reduce the concentration of Helium to 1% (10,000 ppm). This concentration value is to be verified using the instrumentation selected for the recovery kit.

4 Data Collection and Analysis Plan

Individual test results are to be collated to form a comprehensive, multi-disciplinary solution scheme.

5 Environmental, Health, and Safety Requirements

TBD: Pending detailed test procedures.

6 Test Team Organization and Responsibilities

Matthew Palanza:	Technical Lead
Jeremy Paulus:	Mechanical Engineer, venting system
Steve Lerner:	Software Engineer, Control and data collection
Bob Pettit	Electrical Engineer, Power System
Mark D’Angelo:	Firmware development, wiring diagrams, configuration management
Jeff Pietro:	Handling and recovery procedures

7 Test Schedule

TBD: Pending CDR

8 Requirements Traceability

TBD: New requirements are being evaluated

9 Records

Each of the four test events will require completion of:

A Quick-Look Test Report: Template-3101-00065
A Detailed Test Plan and Procedure: Template-3101-00041

A final test report summary evaluating the effectiveness of the above stated approach will be completed.

APPENDIX A: List of Test Procedures

Test Case ID	Test Case Name	Procedure Document Number