Contract N62742-14-D-1884, Delivery Order 0028

NAVFAC
Naval Facilities Engineering Command
NAVFAC HAWAII

# Section 8.2: Risk/Vulnerability Assessment Scope of Work

April 13, 2017

## Red Hill Bulk Fuel Storage Facility
## NAVSUP FLC Pearl Harbor, HI (PRL)
## Joint Base Pearl Harbor-Hickam

## Administrative Order on Consent
## In the matter of Red Hill Bulk Fuel Storage Facility
## EPA Docket No. RCRA 7003-R9-2015-01
## DOH Docket No. 15-UST-EA-01

**Contract Agency:**

NAVFAC Pacific
258 Makalapa Drive, Suite 100
JBPHH Hawaii 96860-3134

Prepared by:
Mr. Mark Manfredi
Mr. John F. Montgomery II

# QRVA Scope of Work Executive Summary

The Quantitative Risk and Vulnerability Assessment (QRVA) will assess the level of risk the Red Hill Bulk Fuel Storage Facility (RHBFSF) may pose to the surrounding groundwater to inform the Government in subsequent development of best available practicable technology (BAPT) decisions.

During the scoping discussions for Section 8 of the Administaravtive Order on Consent Statement of Work (AOC SOW) all Parties agreed that a qualitative risk vulnerability assessment had limited value to support prudent decision making. A Quantitative Risk and Vulnerability Assessment was selected for providing a more rigorus and repeatable approach to evaluating risk. A normal baseline QRVA for a large, complex facility requires 5 to 7 years to complete and is normally broken into phases. This specific baseline QRVA will be broken into four distinct phases: internal events (excluding internal fire and flooding), internal/external fire and flooding, seismic events, and other external events.

The first phase of the baseline QRVA, and this scope of work, is designed to focus on internal events (not including fire or flood). This includes, but is not limited to equipment or structural failures in both frontline and support systems, human errors, etc. The report from the first phase will be submitted 18 months from the approval of this scope of work, in compliance with the RHBFSF AOC SOW Section 8.3. The remaining three phases will be performed sequentially and overlapped where technically feasible to better support scheduling for the AOC.

As other sections of the AOC are completed and new information becomes available, future revised assessments could be done in comparison to the baseline. Sections 5 and 6 of this scope of work explain this in further detail.

## Table of Contents — Page



## List of Tables



## List of Figures

## List of Appendices

# 1 – Introduction

The purpose of this scope of work is to define the processes and methodology necessary to complete phase one of the baseline Quantitative Risk and Vulnerability Assessment (QRVA) for the Red Hill Bulk Fuel Storage Facility (RHBFSF) in compliance with the RHBFSF Administrative Order on Consent – Statement of Work (AOC-SOW) Section 8.2. The phase one QRVA baseline report will be due 18 months from the approval date of this scope of work. It will be designed to serve as a tool to help facilitate decision making that will mitigate risk and improve safety.

## 1.1 – Background

The RHBFSF site is located approximately 2.5 miles northeast of Pearl Harbor on the island of Oahu in Hawaii. The facility lies along the western edge of the Koolau Range and is situated on a topographic ridge that divides the Halawa Valley and the Moanalua Valley. The site is bordered to the south by the Salt Lake volcanic crater and occupies approximately 144 acres of land. The surface topography varies from approximately 200ft to 500ft above mean sea level.

The facility consists of twenty 12.5-million-gallon, field constructed, underground storage tanks (UST) constructed in the early 1940s. The tanks are 250ft tall and 100ft in diameter, with a domed top and base. The facility currently stores Jet Propulsion Fuel No. 5 (JP-5), Jet Propulsion Fuel No. 8 (JP-8), and marine diesel (F-76). Historic fuel storage has included diesel oil, Navy Special Fuel Oil, Navy distillate (ND), F-76, aviation gas, motor gas, JP-5, and JP-8.

In January 2014, up to 27,000 gallons of JP-8 was released from Tank 5, which was being returned to service after having undergone inspections, repair, and maintenance. As a result of the fuel release from Tank 5, the U.S. Environmental Protection Agency (EPA) and the Hawaii Department of Health (DOH) brought an enforcement action against the Navy and the Defense Logistics Agency (DLA) to address the fuel release and minimize the likelihood and impact of future releases. Regulatory experience has shown that a negotiated agreement, such as an administrative order on consent, is the appropriate enforcement tool to address such a unique facility and solve complex environmental problems since it allows for flexible, collaborative, and innovative solutions. The AOC-SOW is a proactive approach that goes beyond the normal scope of merely complying with current regulations.

# 2 – Risk Levels, Scope of Hazards, and Boundary Assessments

Prior to initiating technical work on a facility QRVA, it is necessary to clearly establish the desired risk level, scope phase, and boundary assessments.

## 2.1 – Risk Assessment Levels

“Levels” of risk assessment are frequently defined to focus the evaluations such that the associated results can efficiently and effectively support risk management. These levels of risk assessment can be defined, as desired, by the risk analyst, but the objective of defining these levels is to support an understanding of risk, which ultimately can facilitate the development and implementation of effective risk management actions or options. The "level" of a QRVA is often best described by characterizing the key figure(s) of merit desired to be developed and quantified via the QRVA. For example, any or all of the following levels of QRVA could be pursued for a RHBFSF QRVA:

- Level 1 – Frequency (and Annual Probability) of Loss of Fuel Inventory Control (by Volume Range) within the RHBFSF Property Boundaries

- Level 2 – Frequency (and Annual Probability) of Uncontrolled Release of Fuel Inventory (by Volume Range) Outside the RHBFSF Property Boundaries that Could Impact Red Hill Groundwater Shaft Water Quality

- Level 3 – Frequency (and Annual Probability) of Exceeding Public Water Supply Quality Levels or Limits (e.g., within the Red Hill groundwater shaft) Directly Associated with Uncontrolled Release of Fuel Inventory outside the RHBFSF Property Boundaries

- Level 4 – Frequency (and Annual Probability) of Public Deaths (or Injuries or Illnesses) Directly Associated with Uncontrolled Release of Fuel Inventory outside the RHBFSF Property Boundaries

Experience has shown that Levels 1 and/or 2 above are often adequate to facilitate effective risk management decision-making for the facility owner/operator. The QRVA described in this SOW focuses on a Level 2 risk assessment, as defined above. The result of this risk assessment can provide evaluation information and metrics to support work being executed under the AOC-SOW Sections 6 and 7 which can support expansion of the risk assessment to a Level 3 assessment for the Red Hill groundwater shaft, as desired and directed by the Navy. Other QRVA levels can, of course, be defined through modification or supplementation of the risk metrics outlined above.

## 2.2 – Scope of Hazards

Next, the scope of hazards to be addressed within the QRVA must be specified. Industry experience, supplemented by industry standards for risk assessment, has established that a comprehensive QRVA should generally consider risks from the hazard sources below. They are grouped into phases, which are recommended to efficiently characterize the scope of hazards to be addressed in the RHBFSF QRVA:

- Phase 1 – Internal Events (not including fire or flood)
  - Equipment or structural failures in both frontline and support systems, human errors, etc.

- Phase 2 – Internal and External Fire and Flood Events
  - Internal flooding
  - Internal fires
  - Internal sabotage (not included within the scope of this analysis for security reasons)
  - External flooding, tsunami, and heavy precipitation
  - External fires

- Phase 3 – Seismic Events
  - Earthquakes

- Phase 4 – Additional External Events
  - High Winds
  - Storms (tornados, hurricanes, etc.)
  - Landslides (or mud slides)
  - Proximity Transportation Accidents
  - Aircraft Crashes
  - External Hazardous Material or Chemical Spills or Releases
  - Extreme Weather (e.g., high temperature, etc.)
  - Terrorist Acts (not included within the scope of this analysis for security reasons)
  - Other Facility-Specific Hazards (often location-dependent hazards that can be special cases of other general hazard sources)

As part of this scope of work, Phase 1 scope of hazards will be assessed in the QRVA SOW and delivered to the regulating agencies 18 months from the approval of this scope of work, in accordance with the AOC. The remaining phases will be assessed in the normal linear progression of a QRVA outside of this scope of work (see Section 4).

## 2.3 – Boundaries of Assessment

The scope of a QRVA is defined via clear and comprehensive characterization of assessment boundaries. First, the functional and physical boundaries of the facility to be assessed must be clearly defined. The functional boundaries are facility-specific, depending upon the processes performed by or at the facility. The physical boundaries are generally defined by specifying the target property lines, structures, systems, and components (SSC) considered to be within the facility functional boundaries. Functional and physical boundaries are generally those supported by existing as-built, as-operated design basis documentation (DBD). DBD includes currently-effective documentation and schematic drawing information associated with the as-built, as-operated facility. DBD includes all effective documentation associated with facility design, operation, maintenance, and testing; e.g., documentation associated with the initial information item request presented in Section 2.4.1 of this SOW.

Closely related to analysis boundaries is the issue of the physical and functional basis or starting point for the QRVA. An effective design freeze date must be established to ensure a stable design basis for the QRVA. Regarding determination of the RHBFSF design basis for the QRVA, the following design basis has been selected by the Navy:

> Freeze the facility design as of the date of approval of this scope of work. The design basis will be the as-built, as-operated facility as of the scope of work approval date, to include design, operation, maintenance, and testing changes that have been approved and funded as of that date, but with no additional modification options.

## 2.4 – Procedural Approach

The overall process flow for the RHBFSF baseline QRVA is summarized in Figure 2-1.

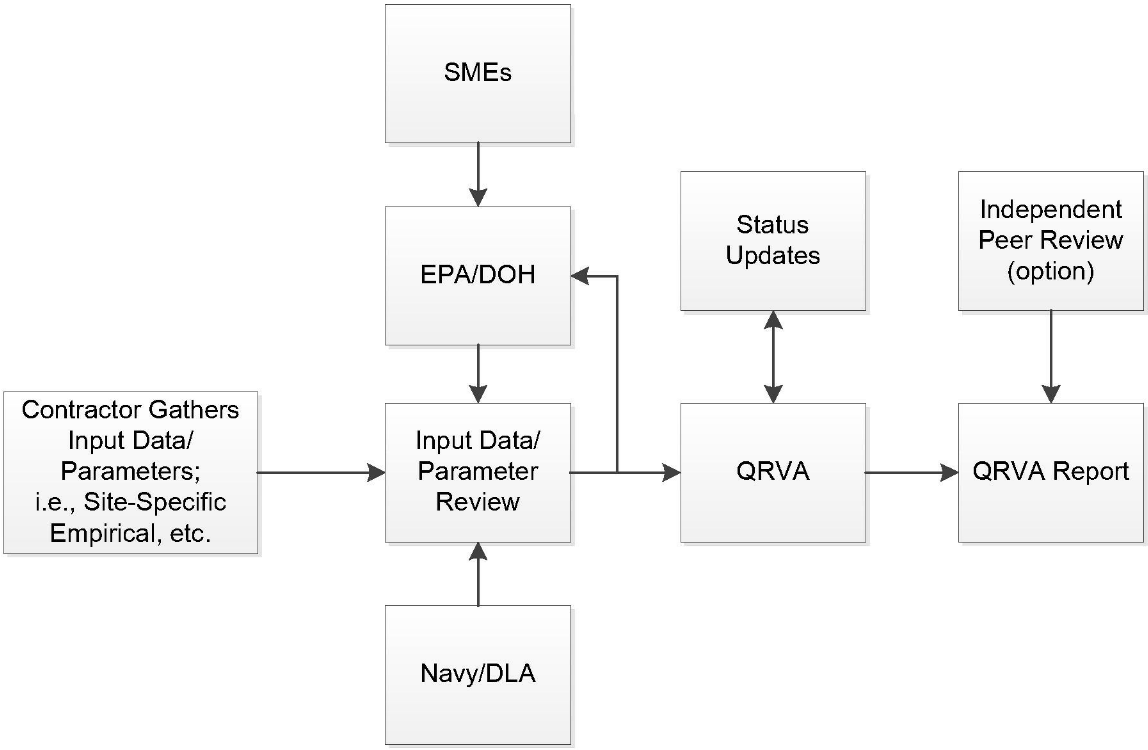


**Figure 2-1. QRVA Process Overview**

The lines of communication for the QRVA process is summarized in Figure 2-2.

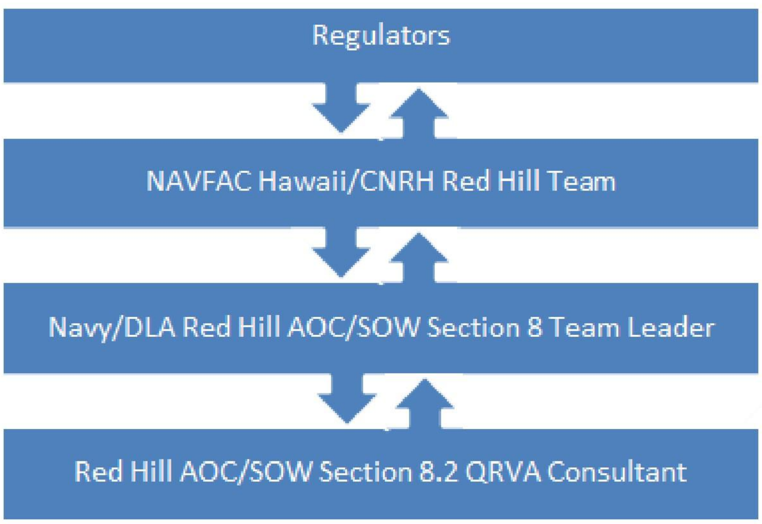


**Figure 2-2. QRVA Lines of Communication**

### 2.4.1 – Contractor Gathers Input Data/Parameters

An initial data request will include, but not be limited to:

1. RHBFSF general site and facility layout and arrangement drawings.
2. A comprehensive set of RHBFSF P&IDs or equivalent flow and/or logic diagrams.
3. Tank and piping isometric drawings or similar layout diagrams.
4. System description documentation.
5. A comprehensive electronic list of all SSCs included within the scope of the QRVA, including alpha-numeric component ID numbers, system designators, specific component service descriptions, component types, component locations, and reference(s) to SSC design documentation. This list should include all tanks, piping, pumps, valves, electric power, and associated instrumentation and controls equipment required to operate the facility.
6. SSC design documentation, preferably in electronic format, including design or building code information; e.g., American Petroleum Institute (API) and/or American Society of Mechanical Engineers (ASME) code information for tanks.
7. Structure and component seismic design criteria.
8. RHBFSF site location scheme; e.g., areas, zones, rooms, or compartments with associated location (e.g., 3D coordinate system) information. If fire zones have been designated for this facility based on fire area and barrier criteria, this information is preferred.
9. All facility operating and maintenance procedures, including normal and emergency (incident response) operating procedures and policies.
10. Facility operating logs, preferably for the entire history of the facility, but for at least the last 5 years (e.g., 2012 to present) of facility operation.
11. A list of all historical incidents involving hydrocarbon or other fuel or material release from facility tanks and systems, to include not only tank or piping rupture events, but also releases associated with human errors; e.g., during fuel or other fluid tank fill, tank emptying, or other transfer, maintenance, or testing operations. This includes all Unplanned Fuel Movement (UFM) reports and associated corrective action taken.
12. Loss of fuel inventory incident reports over the entire history of the facility.
13. Either the record of all fuel movements over the past 5 years or an expected realistic facility operating profile to be used in the QRVA; i.e., average demand loading for all RHBFSF equipment over the long term. This includes estimates for run time and demand cycle numbers for all RHBFSF equipment per year over the long term (e.g., pump on/off cycles and run time, valve open/closure cycles, tank fill/offload

cycles and timing, piping segment active flow time and standby/rest time, equipment sensor cycles and monitoring time, instrumentation and control equipment actuation cycles and monitoring time, and power source energize/de-energize cycles and power provision time over the long term).

14. The full text of any previous facility risk and vulnerability assessments and other risk assessment reports performed for the RHBFSF, along with all associated appendices, models, and databases.

15. Other documentation deemed pertinent to RHBFSF QRVA, as determined by DOD.

Information collection, review, and data management will be performed in accordance with standard quality assurance/quality control practices defined in Section 3.7 of this document.

Data applied in the QRVA are generally documented and applied within relational databases embedded within the QRVA software applied for event sequence quantification, RISKMAN™, in this project. Typical quantitative parameters required for a QRVA include:

- Initiating Event Frequency Values
- Scenario-Related Failure Exposure Parameters
  - Calendar Time Exposure
  - Mission Time or Operating Time Exposure
  - Mission Demand Exposure

  - Basic Event Probability Values Developed Using the Exposure Parameters above with:

  - Component Failure Rates (time-based and demand-based)
  - Human Failure Event Human Error Probability Values

  - Common Cause Failure Parameter Values Based on Common Cause Failure Group Size (e.g., α, β, γ, and δ values)

  - System or Component Alignment Fractions

The general process for developing and managing these data is as follows:

  - Identify the data parameters necessary to support the QRVA.

  - Obtain industry generic data for these parameters via industry data sources.

  - Obtain data for SSCs similar to those in operation at the QRVA target facility (the RHBFSF in this case).

  - Obtain facility-specific data, from the owner/operator of the target facility, the Navy in this case, primarily from the RHBFSF operator, the Joint Base Pearl Harbor Fuels Department.

- Combine these data mathematically to formulate appropriate parameter entries for QRVA event sequence quantification, primarily via application of Bayesian update techniques (see Appendix A for details).

Generic data applied in the QRVA will be taken from reputable documented references. Most current references for generic data, such as NUREG/CR-6928, apply Gamma functions to characterize time-based initiating event frequency values and equipment failure rates, and they apply Beta functions for demand-based failure rates. That practice will be followed for this QRVA. In general, Poisson distributions, sometimes used as examples in this SOW, will not be applied in the actual QRVA, and Beta function distributions will be applied instead, in accordance with current standard data analysis practices (see NUREG/CR-6928).

Any documented component-specific degradation model information provided by the Navy or AOC stakeholders via the communication channel presented in Figure 2-2 will be evaluated and considered for application in the QRVA. While the data parameters will reside in the applied QRVA software, RISKMAN, in this project, these parameters will be extracted into common tabular format; e.g., via Microsoft (MS) Excel or MS Access tables, for technical review and verification. Each data parameter applied in the RHBFSF QRVA will have a pedigree documented within the QRVA report, including the information sources applied in the development of the parameter. In some cases, engineering judgment may be applied to estimate some QRVA input parameters. When engineering judgment is so applied, the QRVA report will provide documentation of the bases and assumptions supporting development of each of these input data parameters.

All data applied in the QRVA will not only have a documented pedigree, but will also have a documented preparer, reviewer, and approver within the Contractor.

### 2.4.2 – Input Data/Parameter Review

Upon completion of the QRVA data analysis task, the QRVA data will be made available for review by the Navy, Regulators, and SMEs; e.g., the EPA, DOH, DLNR, USGS, BWS, etc. This review is scheduled to be conducted over a 2-week time period. The documented review comments on this data review will be evaluated and resolved by the Contractor via written response approximately 2 weeks after receipt of all review comments

### 2.4.3 – Technical Work

Technical work on the RHBFSF QRVA will be conducted applying the methodology, guidelines, and procedures outlined in the QRVA Methodology presented in Appendix A of this SOW. Primary guidance information sources include the following:

- American Nuclear Society (ANS) and Institute of Electrical and Electronic Engineers, “PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants,” sponsored by the U.S. Nuclear Regulatory Commission and the Electric Power Research Institute, NUREG/CR-2300, April 1983 (Reference 3).

- U.S. Nuclear Regulatory Commission, “PSA Procedures Guide,” NUREG/CR-2815, 1985 (Reference 4).

- American Institute of Chemical Engineers Center for Chemical Process Safety, “Guidelines for Chemical Process Quantitative Risk Analysis,” 2nd Edition, October 1999 (Reference 5).

Additional guidance for special QRVA topics and tasks is provided via the references cited in Section 7, Appendix A, and via the information sources included in the bibliography of this SOW.

# 3 – Quantitative Risk and Vulnerability Assessment

## 3.1 – Definitions of Key Terms

The definitions of some key terms applied in QRVA are presented in this section. A comprehensive list of QRVA terms and definitions is presented in Appendix E. Some definitions of fundamental QRVA terms are presented as follows:

**Risk:** The combined answer to three questions that consider (1) what can go wrong?, (2) how likely is it?, and (3) what are the potential consequences? More sophisticated definitions of risk include a fourth question: (4) what is our level of uncertainty (or confidence) associated with the answers to the first three questions?

**Hazard:** Anything that has the potential to initiate or cause an undesired sequence of events and/or conditions to occur that leads to an undesired consequence. Examples of QRVA hazards are facility equipment failures, human errors, fires, floods, earthquakes, adverse weather, etc.

**Vulnerability:** Weakness in the design or operation of a system, component, or structure that could increase the probability of disabling its function and, thus, contribute, in a potentially significant way, to overall facility risk.

**Initiating Event:** An event that perturbs the steady state operation of the facility and could lead to an undesired facility condition. This is an event that can start or precipitate a sequence of additional events or conditions that ultimately result in an undesired consequence.

**Basic Event:** An element of the QRVA model for which no further decomposition is performed because it is at the limit of resolution consistent with available data.

**Probability:** The likelihood that an event will occur as expressed by the ratio of the number of actual occurrences to the total number of possible occurrences.

**Frequency:** The actual (historical) or expected (future) number of occurrences of an event or accident condition expressed per unit of time.

**Boolean Logic:** A branch of algebra in which all operations are either true or false; i.e., yes or no, and all relationships between the operations can be expressed with logical operators such as AND, OR, or NOT. Invented by English mathematician George Boole.

## 3.2 – Description of QRVA Methodology

The details of the QRVA methodology to be applied on this project are presented in Appendix A of this SOW. A conceptual overview of general QRVA activities is presented as follows:

- Facility Familiarization and QRVA Scope Determination
- Initiating Event Analysis
- Event Sequence (Event Tree) Analysis
- System (Failure Modes and Effects Analysis [FMEA] and Fault Tree) Analysis
- Data Analysis (including Dependent Events Analysis)
- Human Reliability Analysis
- Event Sequence Quantification (including Uncertainty Analysis)
- Risk Results Compilation (e.g., Detailed Risk Matrix)
- Risk Decomposition and Vulnerability Assessment
- QRVA Documentation and Communication (Presentation)

The Contractor must first review and evaluate facility information, such as that identified in the initial information request items presented in Section 2.4, to become thoroughly familiar with facility SSCs and the operational profile of the facility. This includes review of facility operating, maintenance, and testing procedures for both normal and emergency operating conditions.

The team then conducts an analysis of potential event sequence initiating events, specifically initiating event frequencies, which may be precipitated via the hazards considered within the scope of the QRVA. For this QRVA, these hazards are those identified in Section 2.2 of this SOW.

The team then develops qualitative event sequences that could lead to undesired consequences contributing to risk. For this QRVA, the primary undesired consequence is the uncontrolled release of fuel from the RHBFSF.

The event sequence analysis is conducted via event tree analysis. The team conducts facility system FMEA and fault tree analysis to characterize event tree top events and split fractions. To support quantification of QRVA event sequences, data analysis must be performed to support quantification of event tree split fractions. Quantification of event tree split fractions is supported primarily via fault tree quantification. The data analysis is performed to quantify initiating event frequencies and conditional probability of individual event tree split fractions for event sequence quantification. The event tree split fraction conditional probability values are derived primarily via fault tree quantification. The data analysis includes derivation of fault tree basic event probability values. In developing event sequences and fault trees for a facility QRVA, it is necessary to identify human actions (e.g., facility operator actions) that may contribute to facility event sequences. Human reliability analysis (HRA) is performed to identify and characterize these actions in terms of human failure events (HFE) for the fault trees and event trees. HRA also includes evaluation of HFE human error probability (HEP) values for application within the event sequence quantification.

When the fault tree models are completed and quantified, and the split fraction data is entered into the event trees, the event sequences can then be quantified, and baseline risk can be determined. Fault tree analysis and quantification and event tree analysis and quantification are accomplished via state-of-the-art QRVA software packages, such as RISKMAN, to be applied on this project. The data for fault tree and event tree quantification are entered as probability distributions in the QRVA software. Uncertainty analysis is performed by propagating the input data probability distributions through the fault tree and event tree quantifications processes applying either a Monte Carlo or a Latin-Hypercube process in RISKMAN, resulting in a probability distribution for the baseline risk. Baseline risk results are compiled and expressed via a table of results sometimes called a risk matrix.

After the baseline risk results have been determined, the vulnerability assessment is performed by decomposing the risk into its component parts in a number of ways. We apply what are known as risk importance measures to decompose the total baseline risk into fractional risk contributors by event sequence, initiating event group, etc. We also calculate risk importance measures down to the basic component failure mode and human failure event levels of risk contributors to develop ranked lists of these risk model elements. These ranked lists of contributors by initiating event group, event sequence, and individual basic events or fundamental elements of risk contribution provide valuable insight into the vulnerability of the facility to risk. Finally, the baseline risk results and the vulnerability assessment are documented in a report in terms that can support prudent decision-making for the facility.

## 3.3 – Assumptions and Level of Uncertainty

The bases and assumptions associated with the QRVA will be clearly documented in the QRVA report. In QRVA, every effort is made to develop and apply realistic "best estimate" models and data. In some cases, simplifying assumptions may be applied to simplify overall risk modeling and quantification. In cases, where simplifying assumptions are made in the QRVA, these assumptions will be documented in the QRVA report.

Uncertainty is considered in rigorous high-quality QRVA. The RHBFSF Contractor will apply probability distributions for applicable input data in the risk quantification performed via the selected QRVA software, RISKMAN, for this QRVA. The source of input data probability distributions will be documented in the QRVA report. The uncertainty represented by these input data probability distributions will be propagated through the risk model quantifications of the QRVA via the RISKMAN software using either Monte Carlo simulation techniques or Latin-Hypercube simulation techniques. The more common of these two methods of uncertainty propagation is the Monte Carlo simulation technique. Propagation of input data uncertainty through the risk model enables the analysts to express overall baseline risk results in terms of probability distributions, which express our uncertainty in the baseline risk results.

By expressing our level of uncertainty in the QRVA, we greatly improve the ability of decision-makers to apply QRVA results in support of making prudent decisions. Guidelines for addressing uncertainty in QRVA are provided in Appendix A of this SOW and in NUREG-1855, which will be applied as a guide supporting the uncertainty analysis performed for this QRVA.

## 3.4 – Evaluating and Prioritizing Events

In this QRVA, event sequences and individual events will be evaluated and prioritized based on their contribution to overall facility baseline risk, primarily via the vulnerability assessment portion of the QRVA. In some areas of the QRVA, simplifying assumptions may be applied, which may be slightly conservative “locally” at the individual event or event sequence level of indenture in the risk model, but which “globally” have no significant effect on the overall quantification of facility baseline risk. In cases where simplifying assumptions are applied, they will be documented in the QRVA report.

Screening analyses may also be applied in this QRVA to effectively simplify the risk quantification by eliminating insignificant contributors to risk. Any such screening analyses or evaluations applied in this QRVA will be based on criteria for acceptable threshold of risk provided by the regulator; e.g., the EPA in this case. If the regulator does not or cannot provide quantitative acceptable risk thresholds for this QRVA, these risk thresholds will be developed by the RHBFSF Contractor, and the bases behind these risk thresholds will be documented in the QRVA report for Navy and regulator review.

## 3.5 – Content and Format of Deliverables

The primary deliverable of the QRVA for this project will be the QRVA report, which clearly documents the bases, assumptions, methodology, databases, calculations, and results of the RHBFSF baseline risk assessment. This report content will be developed generally corresponding to the tasks identified in the project work breakdown structure (WBS) presented in Section 4 of this SOW. The report will be generated applying standard software tools, such as Microsoft Word, and will be communicated via Adobe Acrobat PDF file format. Supporting databases and computer calculation files will also be transmitted to the Navy to archive as part of the overall QRVA deliverable.

As of the writing of this SOW, the Navy anticipates that portions of the QRVA may be required to be treated as Department of Defense Classified information. The exact classification level has not yet been determined by the Navy, but may at a minimum be be at the Confidential or Secret level of security classification. This means that portions of the QRVA report will not be able to be released to the general public or those without the proper security clearance. A redacted version, in full compliance with the Freedom of Information Act will be made available.

## 3.6 – Coordination with Other AOC/SOW Sections

The Contractor will accomodate open communication and cooperation with work being performed under other sections of the RHBFSF AOC. Meetings and conference calls will be arranged, directed, and facilitated by the Navy to support work coordination, communication, and cooperation among AOC technical teams.

## 3.7 – Quality Control/Assurance Process

This section describes the recommended quality assurance (QA) and quality controls practices to be applied to the QRVA project.

### 3.7.1 – ISO 9001 Quality Assurance

Work on this project will be conducted following the standard ISO 9001 Quality Management System. Experience has shown that this approach provides sufficient quality controls and assurance of product quality for high-quality analyses and evaluations, while also providing a significant basis for cost savings.

The QRVA project will commit to operate consistent with applicable environmental legislation and regulations and to provide services consistent with international standards developed to avoid, reduce, or control pollution to the environment.

The QRVA project will monitor performance as an ongoing activity, to strive for continual improvement, and to provide a framework for establishing and reviewing quality and environmental objectives and targets.

### 3.7.2 – ASME/ANS Standard RA-S-2008 (with current addenda) Capability Categories

It is recommended that the QRVA project be designed to achieve and clearly document general compliance with Capability Category II high level and supporting level requirements stipulated in ASME/ANS Standard RA-S-2008 with updated addenda through RA-Sb-2013, appropriately adapted for application to a fuel storage facility like the RHBFSF.

## 4 – Project Milestones, In-Progress Reviews, and Schedule

A preliminary work breakdown structure for the project is presented in Table 4-1. The overall QRVA project will be divided into four phases, the first of which is being executed by this scope of work in compliance with Section 8.3 of the AOC-SOW. The four phases are as follows:

- Phase 1 – Levels 1 and 2 QRVA for Internal Events (not including fire or flood)
- Phase 2 – Levels 1 and 2 QRVA for Internal and External Flooding and Fire
- Phase 3 – Levels 1 and 2 QRVA for Seismic Events
- Phase 4 – Levels 1 and 2 QRVA for Other External Events (see Section 2.2)

Table 4-1. Preliminary WBS

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 1 | 1 | Internal Events | Not Applicable | Information Collection |
| 1 | 2 | Internal Events | Not Applicable | Facility Familiarization and Information Review |
| 1 | 3 | Internal Events | Not Applicable | Definition of Safety and Fuel Release Protective Functions |
| 1 | 4 | Internal Events | Not Applicable | Development and Documentation of QRVA Bases and Assumptions |
| 1 | 5 | Internal Events | Not Applicable | Initiating Events Analysis |
| 1 | 6 | Internal Events | Not Applicable | Event Sequence Analysis |
| 1 | 7 | Internal Events | Not Applicable | Systems Analysis |
| 1 | 8 | Internal Events | Not Applicable | Human Reliability Analysis |
| 1 | 9 | Internal Events | Not Applicable | Data Analysis |
| 1 | 10 | Internal Events | Not Applicable | Event Sequence Quantification |
| 1 | 11 | Internal Events | Not Applicable | Unplanned Fuel Movement Report Data Analysis |
| 1 | 12 | Internal Events | Not Applicable | Acute Release from Accident Sequences Analysis |
| 1 | 13 | Internal Events | Not Applicable | Risk Results Presentation and Interpretation |
| 1 | 14 | Internal Events | Not Applicable | Risk Vulnerability Assessment |
| 1 | 15 | Internal Events | Not Applicable | QRVA Documentation |
| 1 | 16 | All Stage 1 | Not Applicable | QRVA Peer Review Support |
| 1 | 17 | All Stage 1 | Not Applicable | QRVA Peer Review Finding and Observation Resolution Support |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 1 | 18 | All Stage 1 | Not Applicable | Project Management, Overview, and Quality Control |
| 2 | 19 | Internal Flood | Not Applicable | Events Scope Determination |
| 2 | 20 | Internal Flood | Not Applicable | Facility Partitioning |
| 2 | 21 | Internal Flood | Not Applicable | Flood Source Identification and Characterization |
| 2 | 22 | Internal Flood | Not Applicable | Flood-Induced Initiating Event Analysis |
| 2 | 23 | Internal Flood | Not Applicable | Scenario Development |
| 2 | 24 | Internal Flood | Not Applicable | Human Reliability Analysis |
| 2 | 25 | Internal Flood | Not Applicable | Accident Sequence Analysis |
| 2 | 26 | Internal Flood | Not Applicable | Data Analysis |
| 2 | 27 | Internal Flood | Not Applicable | Risk Quantification |
| 2 | 28 | Internal Flood | Not Applicable | Risk Uncertainty Analysis |
| 2 | 29 | Internal Flood | Not Applicable | Risk Results Presentation and Interpretation |
| 2 | 30 | Internal Flood | Not Applicable | Risk Vulnerability Assessment |
| 2 | 31 | Internal Flood | Not Applicable | QRVA Documentation |
| 2 | 32 | External Flood | Not Applicable | Events Scope Determination |
| 2 | 33 | External Flood | Not Applicable | Facility Partitioning |
| 2 | 34 | External Flood | Not Applicable | Flood Source Identification and Characterization |
| 2 | 35 | External Flood | Not Applicable | Flood-Induced Initiating Event Analysis |
| 2 | 36 | External Flood | Not Applicable | Scenario Development |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 2 | 37 | External Flood | Not Applicable | Human Reliability Analysis |
| 2 | 38 | External Flood | Not Applicable | Accident Sequence Analysis |
| 2 | 39 | External Flood | Not Applicable | Data Analysis |
| 2 | 40 | External Flood | Not Applicable | Risk Quantification |
| 2 | 41 | External Flood | Not Applicable | Risk Uncertainty Analysis |
| 2 | 42 | External Flood | Not Applicable | Risk Results Presentation and Interpretation |
| 2 | 43 | External Flood | Not Applicable | Risk Vulnerability Assessment |
| 2 | 44 | External Flood | Not Applicable | QRVA Documentation |
| 2 | 45 | Internal Fire | Not Applicable | Facility Walkdowns |
| 2 | 46 | Internal Fire | Not Applicable | QRVA Database Development |
| 2 | 47 | Internal Fire | Not Applicable | Facility Boundary and Partitioning Definition |
| 2 | 48 | Internal Fire | Not Applicable | QRVA Component Selection |
| 2 | 49 | Internal Fire | Not Applicable | QRVA Cable Selection |
| 2 | 50 | Internal Fire | Not Applicable | Qualitative Screening |
| 2 | 51 | Internal Fire | Not Applicable | Fire-Induced Risk Model Development |
| 2 | 52 | Internal Fire | Not Applicable | Fire Ignition Frequencies Development |
| 2 | 53 | Internal Fire | Not Applicable | Post-Fire HRA Screening Assessment |
| 2 | 54 | Internal Fire | Not Applicable | Quantitative Screening Phase 1 |
| 2 | 55 | Internal Fire | Not Applicable | Scoping Fire Modeling |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 2 | 56 | Internal Fire | Not Applicable | Quantitative Screening Phase 2 |
| 2 | 57 | Internal Fire | Not Applicable | Detailed Circuit Failure Analysis |
| 2 | 58 | Internal Fire | Not Applicable | Circuit Failure Mode and Likelihood Analysis |
| 2 | 59 | Internal Fire | Not Applicable | Detailed Fire Modeling |
| 2 | 60 | Internal Fire | Not Applicable | Post-Fire HRA Detailed and Recovery Assessment |
| 2 | 61 | Internal Fire | Not Applicable | Seismic-Fire Interactions Assessment |
| 2 | 62 | Internal Fire | Not Applicable | Fire Risk Quantification |
| 2 | 63 | Internal Fire | Not Applicable | Uncertainty and Sensitivity Analyses |
| 2 | 64 | Internal Fire | Not Applicable | QRVA Documentation |
| 2 | 65 | External Fire | Not Applicable | Facility Walkdowns |
| 2 | 66 | External Fire | Not Applicable | QRVA Database Development |
| 2 | 67 | External Fire | Not Applicable | Facility Boundary and Partitioning Definition |
| 2 | 68 | External Fire | Not Applicable | QRVA Component Selection |
| 2 | 69 | External Fire | Not Applicable | QRVA Cable Selection |
| 2 | 70 | External Fire | Not Applicable | Qualitative Screening |
| 2 | 71 | External Fire | Not Applicable | Fire-Induced Risk Model Development |
| 2 | 72 | External Fire | Not Applicable | Fire Ignition Frequencies Development |
| 2 | 73 | External Fire | Not Applicable | Post-Fire HRA Screening Assessment |
| 2 | 74 | External Fire | Not Applicable | Quantitative Screening Phase 1 |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 2 | 75 | External Fire | Not Applicable | Scoping Fire Modeling |
| 2 | 76 | External Fire | Not Applicable | Quantitative Screening Phase 2 |
| 2 | 77 | External Fire | Not Applicable | Detailed Circuit Failure Analysis |
| 2 | 78 | External Fire | Not Applicable | Circuit Failure Mode and Likelihood Analysis |
| 2 | 79 | External Fire | Not Applicable | Detailed Fire Modeling |
| 2 | 80 | External Fire | Not Applicable | Post-Fire HRA Detailed and Recovery Assessment |
| 2 | 81 | External Fire | Not Applicable | Seismic-Fire Interactions Assessment |
| 2 | 82 | External Fire | Not Applicable | Fire Risk Quantification |
| 2 | 83 | External Fire | Not Applicable | Uncertainty and Sensitivity Analyses |
| 2 | 84 | External Fire | Not Applicable | QRVA Documentation |
| 2 | 85 | All Stage 2 | Not Applicable | QRVA Peer Review Support |
| 2 | 86 | All Stage 2 | Not Applicable | QRVA Peer Review Finding and Observation Resolution Support |
| 2 | 87 | All Stage 2 | Not Applicable | Project Management, Overview, and Quality Control |
| 3 | 88 | Seismic Events | Not Applicable | Develop Facility-Specific Risk Hazard Curves |
| 3 | 89 | Seismic Events | Not Applicable | Perform Initial Modification to Internal Events Systems Models |
| 3 | 90 | Seismic Events | Not Applicable | Develop Seismic Equipment List (SEL) |
| 3 | 91 | Seismic Events | Not Applicable | Conduct Soil Failures Evaluation |
| 3 | 92 | Seismic Events | Not Applicable | Perform Seismic Response Analysis |
| 3 | 93 | Seismic Events | Not Applicable | Perform Facility Walkdowns |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 3 | 94 | Seismic Events | Not Applicable | Screen Components from SEL |
| 3 | 95 | Seismic Events | Not Applicable | Perform Relay Chatter Evaluation |
| 3 | 96 | Seismic Events | Not Applicable | Develop Seismic Fragility Parameters |
| 3 | 97 | Seismic Events | Not Applicable | Modify Internal Events QRVA Boolean Logic Models |
| 3 | 98 | Seismic Events | Not Applicable | Human Reliability Analysis |
| 3 | 99 | Seismic Events | Not Applicable | Accident Sequence Analysis |
| 3 | 100 | Seismic Events | Not Applicable | Data Analysis |
| 3 | 101 | Seismic Events | Not Applicable | Risk Quantification |
| 3 | 102 | Seismic Events | Not Applicable | Risk Uncertainty Analysis |
| 3 | 103 | Seismic Events | Not Applicable | Risk Results Presentation and Interpretation |
| 3 | 104 | Seismic Events | Not Applicable | Risk Vulnerability Assessment |
| 3 | 105 | Seismic Events | Not Applicable | QRVA Documentation |
| 3 | 106 | All Stage 3 | Not Applicable | QRVA Peer Review Support |
| 3 | 107 | All Stage 3 | Not Applicable | QRVA Peer Review Finding and Observation Resolution Support |
| 3 | 108 | All Stage 3 | Not Applicable | Project Management, Overview, and Quality Control |
| 4 | 109 | Other External Events | High Winds and Storms | Initiating Events Analysis |
| 4 | 110 | Other External Events | High Winds and Storms | Event Sequence Analysis |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 4 | 111 | Other External Events | High Winds and Storms | Systems Analysis |
| 4 | 112 | Other External Events | High Winds and Storms | Human Reliability Analysis |
| 4 | 113 | Other External Events | High Winds and Storms | Data Analysis |
| 4 | 114 | Other External Events | High Winds and Storms | Event Sequence Quantification |
| 4 | 115 | Other External Events | High Winds and Storms | Acute Release from Accident Sequences Analysis |
| 4 | 116 | Other External Events | High Winds and Storms | Risk Results Presentation and Interpretation |
| 4 | 117 | Other External Events | High Winds and Storms | Risk Vulnerability Assessment |
| 4 | 118 | Other External Events | High Winds and Storms | QRVA Documentation |
| 4 | 119 | Other External Events | Landslides | Initiating Events Analysis |
| 4 | 120 | Other External Events | Landslides | Event Sequence Analysis |
| 4 | 121 | Other External Events | Landslides | Systems Analysis |
| 4 | 122 | Other External Events | Landslides | Human Reliability Analysis |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 4 | 123 | Other External Events | Landslides | Data Analysis |
| 4 | 124 | Other External Events | Landslides | Event Sequence Quantification |
| 4 | 125 | Other External Events | Landslides | Acute Release from Accident Sequences Analysis |
| 4 | 126 | Other External Events | Landslides | Risk Results Presentation and Interpretation |
| 4 | 127 | Other External Events | Landslides | Risk Vulnerability Assessment |
| 4 | 128 | Other External Events | Landslides | QRVA Documentation |
| 4 | 129 | Other External Events | Proximity Transportation Accidents | Initiating Events Analysis |
| 4 | 130 | Other External Events | Proximity Transportation Accidents | Event Sequence Analysis |
| 4 | 131 | Other External Events | Proximity Transportation Accidents | Systems Analysis |
| 4 | 132 | Other External Events | Proximity Transportation Accidents | Human Reliability Analysis |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 4 | 133 | Other External Events | Proximity Transportation Accidents | Data Analysis |
| 4 | 134 | Other External Events | Proximity Transportation Accidents | Event Sequence Quantification |
| 4 | 135 | Other External Events | Proximity Transportation Accidents | Acute Release from Accident Sequences Analysis |
| 4 | 136 | Other External Events | Proximity Transportation Accidents | Risk Results Presentation and Interpretation |
| 4 | 137 | Other External Events | Proximity Transportation Accidents | Risk Vulnerability Assessment |
| 4 | 138 | Other External Events | Proximity Transportation Accidents | QRVA Documentation |
| 4 | 139 | Other External Events | Extreme Weather | Initiating Events Analysis |
| 4 | 140 | Other External Events | Extreme Weather | Event Sequence Analysis |
| 4 | 141 | Other External Events | Extreme Weather | Systems Analysis |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 4 | 142 | Other External Events | Extreme Weather | Human Reliability Analysis |
| 4 | 143 | Other External Events | Extreme Weather | Data Analysis |
| 4 | 144 | Other External Events | Extreme Weather | Event Sequence Quantification |
| 4 | 145 | Other External Events | Extreme Weather | Acute Release from Accident Sequences Analysis |
| 4 | 146 | Other External Events | Extreme Weather | Risk Results Presentation and Interpretation |
| 4 | 147 | Other External Events | Extreme Weather | Risk Vulnerability Assessment |
| 4 | 148 | Other External Events | Extreme Weather | QRVA Documentation |
| 4 | 149 | Other External Events | Other Facility-Specific Hazards | Initiating Events Analysis |
| 4 | 150 | Other External Events | Other Facility-Specific Hazards | Event Sequence Analysis |
| 4 | 151 | Other External Events | Other Facility-Specific Hazards | Systems Analysis |
| 4 | 152 | Other External Events | Other Facility-Specific Hazards | Human Reliability Analysis |
| 4 | 153 | Other External Events | Other Facility-Specific Hazards | Data Analysis |

Table 4-1. Preliminary WBS (Continued)

| Phase Number | Task Number | QRVA Hazard Category | QRVA Hazard Sub-Category | Task Title |
|---|---|---|---|---|
| 4 | 154 | Other External Events | Other Facility-Specific Hazards | Event Sequence Quantification |
| 4 | 155 | Other External Events | Other Facility-Specific Hazards | Acute Release from Accident Sequences Analysis |
| 4 | 156 | Other External Events | Other Facility-Specific Hazards | Risk Results Presentation and Interpretation |
| 4 | 157 | Other External Events | Other Facility-Specific Hazards | Risk Vulnerability Assessment |
| 4 | 158 | Other External Events | Other Facility-Specific Hazards | QRVA Documentation |
| 4 | 159 | All | Not Applicable | Total Aggregate Risk Consolidation |
| 4 | 160 | All | Not Applicable | Risk Results Presentation and Interpretation |
| 4 | 161 | All | Not Applicable | Risk Vulnerability Assessment |
| 4 | 162 | All | Not Applicable | QRVA Documentation |
| 4 | 163 | All Stage 4 | Not Applicable | QRVA Peer Review Support |
| 4 | 164 | All Stage 4 | Not Applicable | QRVA Peer Review Finding and Observation Resolution Support |
| 4 | 165 | All Stage 4 | Not Applicable | Project Management, Overview, and Quality Control |

A Gantt chart of the project schedule will be generated by the contractor and capture all of the Tasks listed in Table 4-1. Phase 1 of the baseline QRVA report will be completed within 18 months of approval of this scope of work. Normally, from the perspective of best technical approach, the four Phases of the QRVA are performed sequentially; however, as schedule is important in this project, the four stages of the QRVA can be overlapped to compress the overall schedule to approximately 4 years total. This timeline is achievable, while maintaining acceptably high standards for the full-scope assessment.

While frequent review of interim work products will be performed by the Navy, only one formal in-progress review (IPR) is scheduled for Phase 1 of the project. The IPR, upon Navy approval, will include review by Regulators and external SMEs. This IPR will be performed immediately following completion of the data analysis task. The focus of this IPR is limited to QRVA data analysis. The IPR will be conducted over a 2-week period and culminate with submittal of written review comments to the Contractor. It is the intent of the team to resolve these IPR review comments in writing within 2 weeks from receipt of the complete set of all consolidated review comments, depending upon the volume and complexity of the comments.

# 5 – Interpretation of Results and Consideration of QRVA in Decision Making

As the RHBFSF QRVA is a Level 2 QRVA, the overall baseline risk results will be presented in terms of frequency and annual probability of uncontrolled release of fuel from the facility. As shown in Appendix A, the risk of releases will be broken down by fuel type and by volume range. It is conceivable that, via careful review of baseline risk values and probability distributions, the Navy and other stakeholders could determine that the risk of fuel release from the RHBFSF is acceptably low for the current design and operation of the facility, to include currently-authorized and funded facility modifications. In such cases, the QRVA is applied over the remaining life cycle of the facility to help optimize safety management through the end of the facility life. In cases where the baseline risk is determined to be unacceptably high, the QRVA vulnerability assessment can be applied to support development, evaluation, and prioritization of risk-reducing improvements to the facility.

In the vulnerability assessment, the consolidated baseline risk is decomposed into elements contributing to risk in a number of ways to help facilitate prudent decision-making concerning potential risk reduction alternatives for the facility. Key elements of the QRVA Vulnerability Assessment are presentations of the risk element risk importance measures and associated sensitivity case studies in the form of tabular results and via presentation of risk element "tornado charts". In effect, tornado charts are bar charts of risk element importance measure or sensitivity case study results rotated by 90 degrees and rank ordering the bars from high to low moving downward on the chart, creating, in effect, a tornado-shaped chart of results with the most important elements at the top and the least important elements at the bottom. Experience has shown that there can be significant pitfalls in attempting to interpret risk importance measure and sensitivity case study results directly from tables and charts.

By reviewing all the ranked lists of importance measure results along with the sensitivity case study tornado charts, we can obtain an understanding of facility-specific risk-dominating vulnerabilities. Examples of facility risk importance measures are fractional importance, risk achievement worth, risk reduction worth, Fussell-Vesely importance, and Birnbaum importance. Please refer to Appendix A for additional details on risk importance measures.

It is also instructive to compare facility-specific component failure rates (i.e., the Bayesian-updated failure rates) and HFE HEP values with their associated generic data values. Those facility-specific values that are significantly greater than (e.g., more than 50% relative difference) their associated generic values can point to potential facility-specific risk vulnerabilities.

These results will be presented in the QRVA report with an accompanying discussion developed by analysts experienced with the RHBFSF risk model designed to facilitate meaningful interpretation of vulnerability assessment results.

Using QRVA results to support decision-making is relatively straightforward. For example, as stated above, the baseline QRVA results can be applied to determine whether or not we have adequate confidence that the facility presents acceptable or unacceptable risk. If we determine that predicted risk is too high for the facility, we can use the results of the vulnerability assessment to help identify potential facility improvement options that can effectively reduce risk. For example, if the QRVA results show that risk is being dominated by seismic events (earthquakes), and the scenarios dominating that risk are associated with failure of a certain section of piping in the facility, then a potential improvement option may be to replace that piping with piping having a higher resistance to seismic damage (lower fragility to seismic damage), or it may be that replacing or strengthening the support brackets for the identified piping segment(s) could be effective in reducing risk from that particular facility vulnerability.

The QRVA can be applied to investigate and evaluate the potential cost-benefit-risk impacts associated with proposed improvement options at the facility. This is generally accomplished via development and evaluation of risk improvement option case studies. This is also know as “alternatives analysis” in many technical circles. In general, the QRVA can be applied to predict the potential benefit (risk reduction) associated with a proposed improvement option and, by linking that to the implementation cost associated with the improvement option, evaluate improvement option cost-benefit. In that way, proposed improvement options can be prioritized based on the quantitative value of the ratio of risk reduction per dollar invested.

## 6 – Future Case Studies Consideration

As described in Section 5, the QRVA can be applied to investigate and evaluate the potential cost-benefit-risk impacts associated with proposed improvement options at the facility. This is generally accomplished via development and evaluation of risk improvement option, or more aptly named risk reduction option, case studies. In general, the QRVA can be applied to predict the potential benefit (risk reduction) associated with a proposed improvement option and linking that to the implementation cost associated with the improvement option. In that way, proposed improvement options can be prioritized based on the quantitative value of the ratio of risk reduction per dollar invested. For example, the QRVA could be applied to evaluate potential risk reduction associated with AOC-SOW Section 3 tank upgrade alternatives and, using the case study results and the ratio of risk reduction to alternative cost, prioritize the tank upgrade alternatives by predicted risk reduction per dollar invested, by alternative case.

While no such case studies are included in the baseline QRVA included within this SOW, the application of a mature QRVA could be applied to support case study evaluation of risk reduction alternatives in the future, and throughout the remaining life of the facility.

# 7. References


1. United States Navy Contract N62742-14-D-1884, Task Order 0028, February 8, 2017.
2. Administrative Order on Consent for the Red Hill Bulk Fuel Storage Facility, U.S. Environmental Protection Agency, 2015 (https://www.epa.gov/red-hill/red-hill-administrative-order-consent).
3. American Nuclear Society (ANS) and Institute of Electrical and Electronic Engineers, "PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants," sponsored by the U.S. Nuclear Regulatory Commission and the Electric Power Research Institute, NUREG/CR-2300, April 1983.
4. U.S. Nuclear Regulatory Commission, "PSA Procedures Guide," NUREG/CR-2815, 1985.
5. American Institute of Chemical Engineers Center for Chemical Process Safety, "Guidelines for Chemical Process Quantitative Risk Analysis," 2nd Edition, October 1999.