Framework for Underground Research for Generic Repository Investigations in Salt

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
David C. Sassani, Kristopher L. Kuhlman
(Sandia National Laboratories)
Bruce A. Robinson, Douglas J. Weaver
(Los Alamos National Laboratory)
Jens Birkholzer
(Lawrence Berkeley National Laboratory)
National Laboratory

September 18, 2014
FCRD-UFD-2014-000620
SAND2014-17828 R

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Prepared by:
Sandia National Laboratories
Albuquerque, New Mexico 87185

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Revision 2
12/20/2012

APPENDIX E
FCT DOCUMENT COVER SHEET [1]

Name/Title of Deliverable/Milestone/Revision No.	Framework for Underground Research for Generic Repository Investigations in Salt / M4FT-14SN0818054 / DRAFT rev
Work Package Title and Number	Salt R&D to Support Field Studies – SNL (FT-14SN081805)
Work Package WBS Number	1.02.08.18
Responsible Work Package Manager	Kris Kuhlman (Name/Signature)
Date Submitted	

Quality Rigor Level for Deliverable/Milestone[2]	☒ QRL-3	☐ QRL-2	☐ QRL-1 Nuclear Data	☐ Lab/Participant QA Program (no additional FCT QA requirements)

This deliverable was prepared in accordance with Sandia National Laboratories
(Participant/National Laboratory Name)

QA program which meets the requirements of

☒ DOE Order 414.1 ☐ NQA-1-2000 ☐ Other

This Deliverable was subjected to:

☒ Technical Review ☐ Peer Review

Technical Review (TR)
Review Documentation Provided

☐ Signed TR Report or,
☐ Signed TR Concurrence Sheet or,
☒ Signature of TR Reviewer(s) below

Peer Review (PR)
Review Documentation Provided

☐ Signed PR Report or,
☐ Signed PR Concurrence Sheet or,
☐ Signature of PR Reviewer(s) below

Name and Signature of Reviewers
Frank Hansen

NOTE 1: *Appendix E should be filled out and submitted with the deliverable. Or, if the PICS:NE system permits, completely enter all applicable information in the PICS:NE Deliverable Form. The requirement is to ensure that all applicable information is entered either in the PICS:NE system or by using the FCT Document Cover Sheet.*

NOTE 2: *In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity, along with the Document Cover Sheet, is sufficient to demonstrate achieving the milestone. If QRL 1, 2, or 3 is not assigned, then the Lab / Participant QA Program (no additional FCT QA requirements) box must be checked, and the work is understood to be performed and any deliverable developed in conformance with the respective National Laboratory / Participant, DOE or NNSA-approved QA Program.*

AKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy (DOE) Office of Nuclear Energy (NE), through the Office of Used Nuclear Fuel Disposition Research and Development within the Office of Fuel Cycle Technologies.

The authors acknowledge our gratitude to Prasad Nair (DOE NE-53), William Spezialetti (US DOE NE-53), Timothy Gunter (DOE NE-53), and Frank Hansen (SNL) and Robert MacKinnon (SNL) for their helpful discussions, oversight, and guidance on topics covered in this report, and to Nancy Buschman (DOE EM) and Roger Nelson (DOE EM) for helpful discussions on radioactive waste disposal in salt repository systems.

The complete draft report benefitted from internal technical review by Frank Hansen (Sandia National Laboratories).

CONTENTS

FIGURES

ACRONYMS

DOE	Department of Energy
DOE-NE	Department of Energy Office of Nuclear Energy
FEPs	Features, Events, and Processes
HLW	High-Level Waste
LANL	Los Alamos National Laboratory
QA	Quality Assurance
R&D	Research and Development
SNL	Sandia National Laboratories
TPD	Test Proposal Document
UFD	Used Fuel Disposition
URL	Underground Research Laboratory
US	United States
WP	Work Package

USED FUEL DISPOSITION CAMPAIGN/DISPOSAL RESEARCH: SALT RESEARCH AND DEVELOPMENT

1. INTRODUCTION

Consistent with the generic disposal strategy being implemented by the United States Department of Energy Office of Nuclear Energy (DOE-NE) Used Fuel Disposition (UFD) Campaign, the purposes of doing field testing in a generic salt Underground Research Laboratory (URL) are: to support/confirm the bases of a safety case for a generic (non-site specific) geologic repository in salt host rock; to facilitate resolution of identified uncertainties/issues; to increase confidence in the technical bases for safe disposal of high-heat generating waste in a generic salt repository (the ultimate long-term goal); and to develop science and engineering tools and capabilities that will facilitate future site-specific work. Note that the UFD Campaign focus is on generic disposal of commercial used (or spent) nuclear fuel (SNF; generally at the high end of heat generating waste forms), but encompasses disposal considerations for high-level waste (HLW) and DOE-managed SNF also.

Field testing within a URL in salt is being evaluated as part of the larger disposal research and development (R&D) activities in the UFD Campaign because carefully designed science and engineering field studies have the potential to reinforce the current strong technical basis for geologic disposal in salt. Generic URL/field testing will focus on addressing issues likely to contribute additional confidence in the safety of disposing heat-generating waste in a generic salt repository. Emphasis on this central purpose for generic field-based testing facilitates using resources efficiently because such large-scale testing tends to be personnel intensive, multi-year in nature, and relatively expensive. The cost of large-scale field studies in salt could represent a substantial portion of current UFD Disposal R&D program resources. A clearly defined rationale with specific objectives delineated within the context of the safety case for a generic salt repository includes transparent justification and thorough planning to enable decision making within this undertaking.

Many international disposal programs have, or have had, operating URLs in clay/shale, granite/crystalline, and salt lithologies, in which relevant field experiments are being (or have been) conducted. Such testing conducted in representative rock formations at scales comparable to actual emplacement designs is considered by the international community to be a strong element in a safety case for geologic disposal of radioactive waste (see Section 3). Although the UFD Campaign has no operating URL for *in situ* science in generic host rock options such as clay/shale, granite/crystalline, and salt, consideration of field testing in a generic salt environment has led to the development of this framework for implementing and managing field activities in an underground laboratory in salt. The principles of this framework are delineated below for a field tests in a generic salt system, but are flexible enough to be used as a template for developing/ managing field testing in URL in clay/shale or granite/crystalline systems.

This document describes a framework for managing and implementing a generic field-testing research program from initial proposed testing through incorporation of results into a safety case for disposal in a salt repository. The framework includes protocols for reviewing, selecting and planning URL testing activities in a transparent objective forum to refine testing priorities and

ensure rigorous science as the basis for the selected investigations. Detailed test planning will establish a robust rationale to achieve testing objectives, to avoid test-to-test interference and interference between testing and other URL activities, and to meet infrastructure requirements.

This report describes the process of technical and peer review of proposed testing activities and the requirements for planning/coordinating field tests and in situ activities, including the expectation of Quality Assurance required for Test Plans. Test Plans are the primary implementing documents for URL testing and will be in accord with provisions equivalent to those of QA Procedure 20-1 (SNL, 2014). Draft test plans will be reviewed by an external panel of experts to provide objective oversight of the testing activities proposed for a URL as input to the UFD Campaign decision process. This report completes milestone M4FT-14SN0818054 from UFD work package (WP) FT-14SN081805 and milestone M4FT-14LA0818066 from UFD WP FT-14LA081806, and constitutes a portion of milestone M4FT-14LB0818076 from UFD WP FT-14LB081807.

1.1 Framework Purpose and Objectives

The framework purpose is to facilitate objective, rigorous, and transparent science and engineering testing in a salt URL. With strategic planning, investigations conducted in the underground can address a number of salt-based disposal issues that would further strengthen the safety case for disposal in a salt repository. This framework is described for field testing in a generic salt URL anywhere in the world, but if a salt URL were established in the US, then future operation of a salt URL in the US could be expanded to include an international mission for salt repository research. Involvement of the international community performing investigations within a US salt URL would add to its scientific credibility and further strengthen stakeholder confidence in a salt repository safety case.

Central to achieving the above goals, this framework includes establishing a review procedure using an independent expert panel as an integral part of the decision process for URL testing activities. This process will help ensure a comprehensive approach to deciding upon the prioritization of proposed URL tests, the nature of the URL (generic or site-specific), and the activities to be conducted in the URL. The independent panel would evaluate (a) the suite of proposed URL testing to provide input to prioritizing the proposed testing, and (b) the draft Test Plans for those highest priority tests (selected by the UFD Campaign) focusing on objectives, strategy, metrics, and requirements at an early stage of development to assess the merit and likelihood of success of the planned activity. After receiving the expert panel input on draft Test Plans, final Test Plans will include full layout of instrumentation and data collection processes for test implementation. At each stage, the panel's conclusions and recommendations would be considered by the UFD Campaign to guide decision making on the testing program within the available research and development funding. Temporal sequencing (both near-term and long-term) and spatial arrangement of tests in the URL will also be considered within the UFD Campaign to address testing coordination issues that go beyond evaluation of the merits of any individual test.

1.2 Objectives of URL Testing

Creation of new underground space for *in situ* salt science could provide an exceptional opportunity to further advance the scientific basis for disposal of heat-generating waste in salt. In

addition, a state-of-the-art research facility would allow participation by the next generation of students and nuclear waste management scientists through provision of a unique laboratory for basic and applied model development, laboratory testing, and field investigations. Underground research laboratories are also ideal places for international collaboration, as examples from other countries have shown.

Recognizing that mined space is an expensive and limited resource, and that large-scale field testing can be expensive and require long-term program commitment of resources, executing URL operations comes with a significant responsibility to use the physical space resource and the program R&D resources as strategically and cost-effectively as possible. Activities within the underground will be highly visible so the tests executed within a URL R&D program have an obligation to first serve the needs of the UFD Campaign generic repository program, with a secondary goal of addressing international scientific interests. Proposed uses for the URL must address issues that are relevant to the safety case for disposing of heat-generating waste in deep salt formations, as well as operational issues related to repository construction and emplacement of waste. Research will be planned in the context of the existing body of salt science.

Within a larger program that includes model development and laboratory testing, carefully considered *in situ* science and engineering studies in a URL could further bolster the strong position for salt disposal. For example, URL research activities that address either representative subsurface conditions and/or large-scale tests that include potential repository layout and emplacement configurations could be used to assess/validate models and address scaling issues related to using laboratory data for processes in the field. Prerequisites to a successful testing program for a salt URL are informed by the experience and lessons learned in the design and management of previous underground investigations programs in the US and internationally, in salt and other geologic media. This experience provides further insights into the proper design and operation of URL research programs for maximum utility. For example, Test Plans are required to ensure that infrastructure requirements are adequately established and to avoid test interferences (from other tests or other underground activities). These and other formalities for developing a URL strategy are described herein, to ensure that principles of procedural integrity and scientific rigor are the framework bases to develop and integrate a URL testing program dedicated to long-term salt research into the larger UFD Campaign program of disposal research.

Scientific, technical, and programmatic objectives of activities within a URL can be justified in several ways, such as:

1. Addressing FEPs: Confirm our understanding and ability to model features, events and processes (FEPs) that affect the performance of a deep geologic repository for heat generating radioactive waste in salt.

2. Building Confidence: Through *in situ* testing, build confidence that the safety functions of a deep geologic repository in salt are understood and can be forecast over regulatory-relevant time periods.

3. Fostering international collaboration: Enhance technical credibility through engagement of the international community.

4. Testing Concepts: Evaluate designs, such as in-drift or borehole emplacement concepts, and operational practices, such as remote emplacement of waste canisters and application of backfill.

5. Validating Models: Predict and confirm evolution of coupled thermal, mechanical, chemical, and hydrologic processes at full-scale in an environment representative of a salt repository.

2. FRAMEWORK FOR URL STUDIES

There are many potential uses of a URL. Therefore, a first step is to establish a robust and well-vetted research strategy at the outset of URL test planning. This begins with an initial set of proposed testing activities to evaluate aspects such as prioritization, possible dual-purpose synergy, potential test-to-test interferences, data acquisition, among other considerations. Concepts for use of the URL would need to be developed sufficiently to permit detailed review by an expert panel. Although testing in a URL would focus on issues related to disposal of heat-generating waste, the overall testing portfolio may address repository design and operation issues that are separated from heat, such as engineered barrier construction.

2.1 Research Strategy

The development of proposed testing activities will benefit considerably by incorporating a risk-informed, systems-level, structured decision making process that includes scientific objectives, such as uncertainty reduction, to support the development of a safety case. For scientific objectives, the Performance Assessment methodology can be deployed, using a hierarchy of upper tier requirements (and evaluation of FEPs) that drives delineation and prioritization of issues to be addressed. This structured framework can help to communicate transparently the up-to-date understanding of the repository safety case, including an assessment of the nature and potential impact of remaining uncertainties and how proposed testing would address those. In addition, consideration of cost-benefit analysis, risk management, and operational processes would be taken into account.

The resulting proposed research strategy and associated scientific portfolio then needs to be reviewed and assessed by an independent expert review panel. This deliberate step is indispensable to the credibility and ultimate success of the URL. Not only does this step help maximize utility of very precious underground testing space, but it conveys clearly the intended generic application and transferability of experimental results from the work to be conducted. The mission of the independent review panel is to critically evaluate the overall mission and proposed research strategy for the URL and make recommendations to the UFD Campaign regarding the test portfolio prioritization and proposed testing merits. Review of the suite of proposed URL testing by an expert panel would provide input to UFD Campaign decisions for prioritizing and selecting the activities and would work to ensure that the views of potential stakeholders and decision makers are appropriately considered in the development of test plans in this high-profile area of research. This expert panel would also conduct periodic reviews of technical progress and future proposed testing activities. In response to the initial external review, the research strategy will be refined, leading to a road map for optimal usage of the underground research space.

2.2 Functional and Operational Requirements

Subsequent to rigorous review and finalization of a research strategy, functional and operational requirements of field test implementation must be carefully and transparently reviewed to: (a) sequence the selected activities; (b) promote open and objective concurrence on implementation (including with the site owner/operator); (c) ensure proper forward planning to maximize return on investment; and (d) coordinate infrastructure needs for a safely operated and an agile URL testing program. Development of the functional and operational requirements should address test features such as the size, shape and arrangement of openings, analysis of possible test-to-test interferences, sequencing and duration, power requirements, ventilation systems, data acquisition, synergistic goals and possibilities, quality assurance, records management, and most importantly, safety in the underground. In addition to these requirements, the organization hosting the URL will likely have site-specific requirements that must be addressed, integrated, and implemented as well.

2.3 Test Plans

Previous underground testing associated with site characterization in US repository investigation programs (e.g., the Waste Isolation Pilot Plant) provides guidelines for an extensive and well documented science program. Quality Assurance (QA) procedures governing preparation of Test Plans have been used on these programs for extensive URL testing (e.g., SNL Nuclear Waste Management Test Plan Procedure NP 20-1 for field and laboratory testing and LANL test plan procedure SDI-SP-002). A similarly rigorous approach to test planning would be used in salt URL investigations (see Attachment A for Test Plan outline). Test Plans would be reviewed and approved prior to initiation of work and describe the scientific activity in sufficient detail to allow action to be taken.

A Test Plan will include test objectives, questions to be addressed by the test, and describe parameters to be measured, such as deformation, temperature and stress; or processes to be observed, such as viscoplastic flow, brine migration, and mineral evolution; or operations to be demonstrated, such as the emplacement of backfill. Data quality objectives for measurement of fundamental parameters can be derived from numerical models of the detailed coupled processes under investigation. In turn, the instrumentation and its layout, cabling, time sequencing, power, and data channels all can be developed based on detailed numerical simulations of the test together with expert experience of Principal Investigators for the field test. A Test Plan will also provide a set of post-test evaluation criteria to determine how the results of a completed test might be used to inform future testing.

3. IMPLEMENTATION

This document has described a framework by which an underground experimental testing program may be developed and managed within the larger R&D repository program of the UFD Campaign. Figure 3-1 provides an overview of the process for identifying proposed tests (described in test proposals), reviewing, prioritizing, and selecting tests to develop, and developing rigorous test plans (via QA procedures) that have input from the expert panel in terms of technical merit and rigor. The path to rigorous, objective, and transparent science and engineering begins with development of test proposals for URL testing activities. The suite of test proposals would be reviewed by an independent panel of experts (review board) to provide

objective input on the merit and prioritization of proposed testing to the US DOE UFD Campaign.

The Review Board's findings and recommendations will be used by the UFD Campaign to refine the URL testing strategy to make decisions about allocation of resources and scheduling for proposed testing activities. From this objective basis, individual Test Plans would be developed that are consistent for the selected activities. The expert panel would also review each draft Test Plan, focusing on test objectives, strategy, metrics, and requirements to assess the merit of the test and likelihood of success of the planned activity (note these draft Test Plans would include all aspects short of detailed field locations of instrumentation). After receiving the expert panel input on draft Test Plans, final Test Plans will include full layout of instrumentation and data collection processes for test implementation. Test Plans are the primary implementing documents for URL testing and will be in accord with provisions equivalent to those of QA Procedure NP 20-1 (SNL, 2008; or e.g., LANL, 2012). At each stage, the panel's conclusions and recommendations would be considered by the UFD Campaign to guide decision making on the testing program within the available research and development funding. As test planning progresses, a systems engineering approach would then be used as a collaborative effort to develop the Functional and Operational Requirements that support the strategy and planned testing.

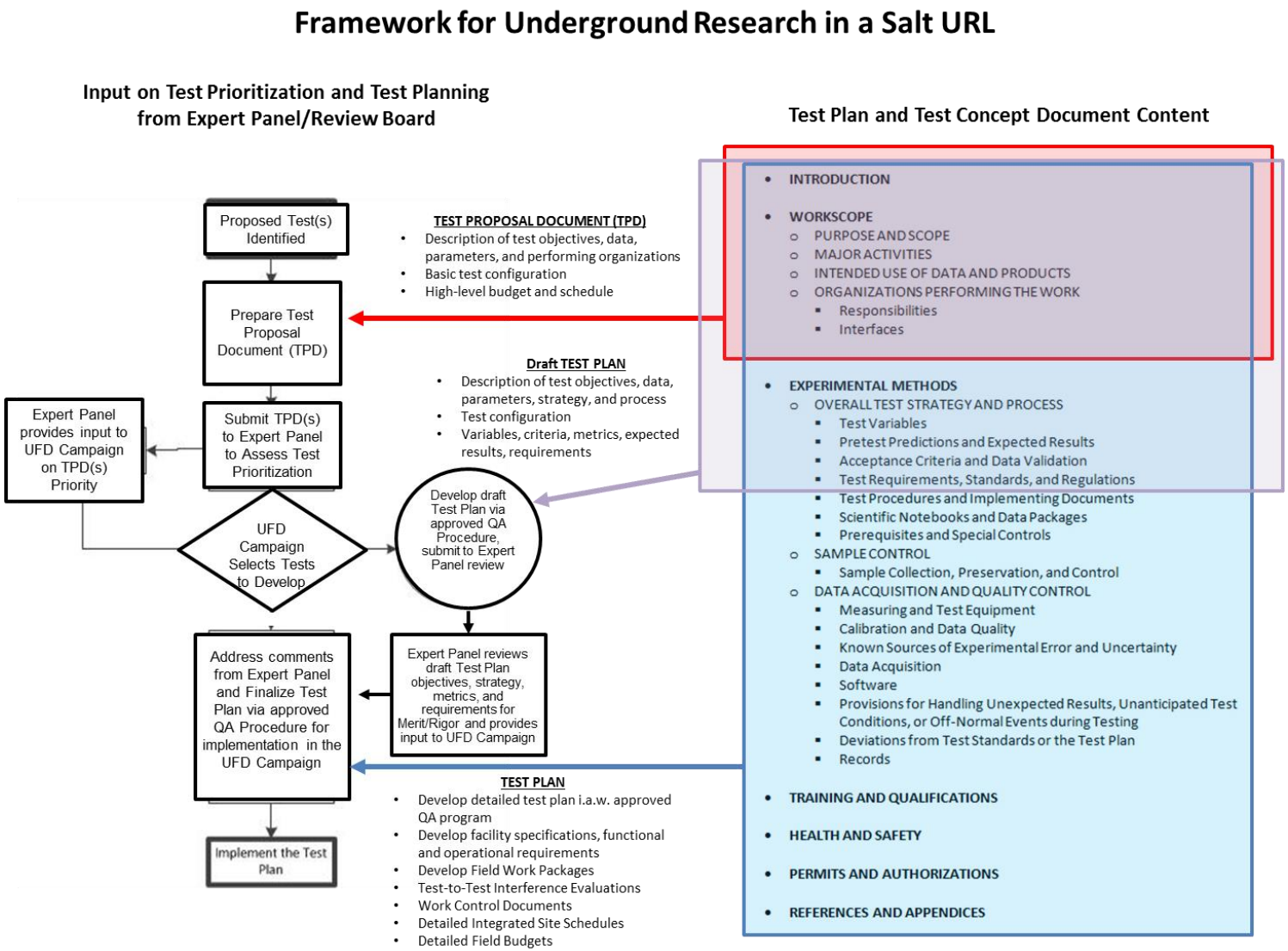

Figure 3-1. Flow diagram of the process for identifying, prioritizing, selecting, and developing tests for a Salt URL.

4. References

Sandia National Laboratories (SNL) 2008, Nuclear Waste Management Procedure NP 20-1 Test Plans, Revision 5, 6 p.

Los Alamos National Laboratory (LANL) Salt Disposal Investigation Standard Procedure SDI-SP-002, Revision 0, Test Plans, 16 p.

A-1. Appendix A – Test Plan Outline from WIPP SNL NP 20-1

Test Plan Content

Test Plans (TPs) shall include the following, unless the nature of the work does not involve the item or concept:

• **Title and Header Information -** See format in Section 2.2.

• **Reviews and Approvals** - Provide the name, title, and dated signatures of persons approving the TP, including the author and reviewers i.e. technical, QA and management.

• **Table of Contents** - Provide an outline of the TP contents and the corresponding pages at which the sections start.

• **Revision History** - Describe the purpose and content of the current revision made.

• **Purpose and Scope** – Describe the purpose and scope of the scientific activity (hypothesis or hypotheses to be tested), and the intended use of the data.

• **Experimental Process Description** – Describe the primary tasks and the conduct of the scientific investigation activity, addressing the following (note: if specifics are not known, describe how they will be documented during the scientific investigation activity):

⇒Planning Overall Strategy and Process

- Critical variables to be measured and controlled including the acceptance criteria for data quality evaluation to ensure the data are valid and satisfy the purpose and scope of the test plan
- Coordination with organizations providing inputs or using the results
- Procedures to be used/developed
- Identification of prerequisites, special controls (including controls to prevent tampering of data during acquisition and analysis), specific environmental conditions, processes, or skills.
- Known sources of error and uncertainty including any uncertainty about the quality of input data
- Compatibility of data processing with any conceptual/mathematical models used at each applicable stage
- Specify documents to be maintained as QA records (e.g., scientific notebooks)

⇒Sample Control

- Sample labeling/identification method to be used (e.g., as described/recorded in scientific notebook)
- Sample handling/nonconforming requirements - reference NP 13-1 (Control of Samples and Standards)
- Sample storage and/or environmental controls - Sample disposal and/or disposition

⇒Data Quality Control

- Measuring and Test Equipment (M&TE) - reference NP 12-1 (Control of Measuring and Test Equipment)
  - ▪ calibration requirements and acceptance/tolerance limits to meet the purpose and scope of the test plan
  - ▪ use of M&TE, standards, and other tools - Data Acquisition System (DAS)

▪ for the intended use, identify required periodic in-use manual or automatic self-check routines (e.g., visual data inspection, established alarm interval limits, calibrated source)

▪ for commercial software not modified, document the name, version and the hardware for which it is used

▪ for developed or modified stand-alone software (i.e., software which can be operated and verified independent of the hardware system), refer to NP 19-1 (Software Requirements) for qualification

- Methods for justification, evaluation, approval, and documentation of any deviations from test standards or of establishment of specially prepared test procedures (e.g., when no nationally recognized test standards exist)

- Controls/reference sample use (e.g., use of replicates, spikes, split samples, control charts, blanks, reagent checks)

- Test media (e.g., fluids) when used, shall be characterized and controlled in accordance with test procedures.

⇒Data Identification and Use - Method(s) of recording data (e.g., scientific notebook, log books, data sheets) to clearly identify and trace to the source from which the data was generated

- Data control to ensure that data integrity and security are maintained. Controls shall prescribe how data will be stored to protect from damage and destruction during their prescribed lifetime.

- Data transfer and reduction controls to ensure data transfer is error free and that input is completely recoverable

- Control of erroneous or inadequate data (includes identification, segregation, and disposition)

- Data conversion controls

• **Training** –Identify special qualification and training requirements, if applicable (reference NP 2-1, Qualification and Training).

• **Health and Safety** – Describe any unique health and safety hazards associated with this work, and describe specific requirements and procedures to mitigate impact.

• **Permitting/Licensing** – Discuss special permitting or licensing requirements which may be required to conduct the scientific activity (e.g., state permit to drill wells).

• **References** – List documents referenced in the TP in sufficient detail (e.g., author, journal name, publish date) to allow copies to be obtained by the reader.