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Idaho National Laboratory
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Nuclear Operations: Readiness Assessments Supporting a Nuclear-enabled NASA Mission

Kelly L. Lively\textsuperscript{1a} and Drake C. Kirkham\textsuperscript{1b}

\textsuperscript{1a}Radioisotope Power Systems Department Manager and \textsuperscript{1b}Quality Assurance Department Manager, Idaho National Laboratory, Idaho Falls, ID 83415-6122
(208)533-7388; Kelly.Lively@inl.gov

Abstract. The Radioisotope Power Systems (RPS) Program, located at Idaho National Laboratory (INL), is responsible for assembling, testing, and delivering plutonium oxide-fueled RPSs for use in powering missions in remote, harsh environments such as deep space. An informative presentation will be given discussing the readiness assessments involved in performing nuclear operations to support providing these systems to end users for the Department of Energy (DOE). Readiness for start-up is determined through independent assessment against established acceptance criteria to ensure activities can be performed safely and within a well-defined nuclear safety envelope. There is also an RPS Program approval element for product quality requiring additional readiness review before nuclear operations can begin. Typically, the assessments/review criteria requires, at a minimum, review of operating instructions to ensure technical safety requirements are adequately identified, review of training records to ensure personnel are adequately trained to perform the specified work scope, personnel are interviewed to determine adequacy of level of knowledge for work scope, and a high-fidelity performance of the operation to ensure the operating instructions and conduct of operations are adequate to perform the work scope. As each assessment/review is conducted, a formal report delineating any issues in the form of findings, observations, and noteworthy practices will be issued. Before start-up approval is obtained, all issues must be resolved to the satisfaction of the individual teams. Approval for start-up is formally communicated by memorandum from DOE. Programmatic approval is also formally communicated where vested Program representatives in the RPS community (to include DOE Nuclear Energy (DOE NE) and DOE Idaho Operations Office (DOE ID) representatives) ensure personnel, documentation, and materials are in place to perform the activity. RPS assembly and testing operations to support the Mars 2020 Mission, the next planned space mission using a nuclear power system, will require about a year of assessments/reviews before the nuclear operations are performed. From a regulatory perspective, Title 10 of the Code of Federal Regulations (CFR), Part 830\cite{1} governs DOE and its contractors conducting activities that affect, or may affect, the safety of DOE Nuclear Facilities. Further, DOE Order 425.1\cite{2} and 414.1\cite{3} establish requirements to verify readiness for startup or re-start of Hazard Category 1, 2, and 3 nuclear-facility activities and to ensure products and services meet or exceed customer’s requirements and expectations, respectively.

Keywords: INL, Operations, Assessments, DOE, Quality Assurance, QA.
RADIOISOTOPE POWER SYSTEMS

A Radioisotope Power System (RPS) such as the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) (ref. Figure 1) is an electrical generator that converts the heat generated by decay of iridium clad, $^{238}\text{PuO}_2$ fuel pellets into electricity. RPSs are used as power sources for use in remote, harsh environments such as space. The Department of Energy’s (DOE) Idaho National Laboratory (INL) is the only national facility capable of performing nuclear activities to safely fuel, test, store, transport, and perform end-user handling for mission testing and integration. The INL serves as part of the DOE, RPS community providing RPSs to customers for use in remote, harsh environments such as deep space.

![MMRTG RPS](image1)

**Figure 1.** MMRTG RPS

Facilities

The INL is an 860-square mile, federal reservation located in a remote, desert site of southeast Idaho. The Materials and Fuels Complex, located on the INL site, is home to the Space Nuclear Power and Isotope Technologies Division. Nuclear and non-nuclear facilities house equipment needed to perform required activities. Two primary facilities, located within the security-protected confines of MFC, are utilized to perform nuclear and non-nuclear activities, the Space and Security Power Systems Facility (SSPSF) (ref. Figure 2) and the Engineering Development Laboratory (EDL) (ref. Figure 3), respectively.

![SSPSF](image2)  ![EDL](image3)

**Figure 2.** SSPSF  **Figure 3.** EDL

SSPSF is categorized as a DOE Hazard Category 2 (HC-2) Non-Reactor Nuclear Facility based on the estimated inventory of radioactive materials. It is a two-story, 10,000 square foot building. The first floor houses RPS assembly and testing equipment, including gloveboxes, fume hoods, testing equipment and a high-bay (7.5-ton crane) for receipt and handling of Department of Transportation (DOT) shipping packages. EDL is a two-story, 4,000 square foot building. The first floor houses a high temperature vacuum furnace, electron beam welder, forming presses (30 ton) and laser etcher. The partial, second floor is a mezzanine and houses a graphite vacuum furnace with access to a glovebox, and two welding gloveboxes. An overhead crane (5-ton) is located on the second
floor that reaches to the first floor. Facility systems include heating and ventilation, process chilled water, glovebox-related vacuum pumps, and normal power.

**Human Resources**

The RPS Program is comprised of a multi-disciplined work force of degreed Engineers (mechanical, electrical, materials, instrumentation and control); certified Quality Engineers, Quality Assurance Inspectors, Nuclear Operators, and technicians (electrical, mechanical, and welding). The RPS Program is governed by a Quality Assurance Program Plan (QAPP)[4] which is dedicated to the RPS Program and described in more detail hereafter. The Engineering Staff provides System and Applied Engineering, Tool Design and Testing, Training Development and execution to support the RPS Processes and associated equipment. Nuclear Operators and technicians supply the trained, qualified work force to complete the hands-on nuclear and non-nuclear work scope. An RPS Program Manager, Nuclear Facility Manager, SSPSF Operations Manager, Laboratory Space Manager, RPS Department Manager and Technical Leads round out the Program providing Programmatic Project Management.

**Operations**

Operations at the INL include non-nuclear operations of module pre-assembly and bake-out and nuclear operations of General Purpose Heat Source (GPHS) Module Assembly (ref. Fig. 4) that generates heat through decay of Plutonium Oxide fuel pellets; assembly of GPHSs into an RPS (power system that converts the heat generated by the GPHS fuel pellet into electrical power), and RPS Acceptance Testing performed after RPS Assembly—Vibration Testing simulating the launch pad environment, Mass Properties Testing measuring the center of gravity and moment of inertia, Magnetics Testing mapping the magnetic-field strength generated by the electric-current generating RPS, thermal vacuum testing to collect power performance data when the RPS is placed in a near-earth space vacuum. The assembled and tested RPS is then maintained in storage until it is transported to a remote location for vehicle integration. Transportation and RPS integration activities take nuclear activities on the road to remote locations. Space missions dictate delivery of the RPS, a radioactive payload, to locations such as Kennedy Space Center for installation of flight hardware on the RPS, integrated system testing (powering a space vehicle for testing) and storage until the final integration before launch. Department of Transportation (DOT) certified, Type-B shipping casks are used to transport radioactive, payloads across the nation in the form of 1) radioactive, iridium clad, fuel pellets for INL assembly into GPHSs and 2) RPS units after they are fueled with GPHS and tested for end use. The INL is the custodian of these shipping casks and the transportation trailers used for transporting the shipping casks used for RPS transportation to the remote locations.

![Figure 4. GPHS Assembly](image)

**READINESS ASSESSMENTS**

Title 10 of the Code of Federal Regulations (CFR), Part 830[1] governs DOE and its contractors conducting activities that affect, or may affect, the safety of DOE Nuclear Facilities. Further, DOE Order 425.1[2] and 414.1[3] establish requirements to verify readiness for startup or re-start of Hazard Category 1, 2, and 3 nuclear-facility
activities and to ensure products and services meet or exceed customer’s requirements and expectations, respectively. Readiness for start-up is determined through independent assessments and programmatic reviews[5] against established acceptance criteria to ensure activities can be performed safely and within a well-defined nuclear safety envelope[6] and to the quality of the product that will be provided meets the DOE quality requirements[4]. A number of DOE approved, INL procedures implement the requirements of these DOE Orders and regulatory requirements. INL performs a screening[7] to determine the level of independent readiness verification needed to perform an identified scope of work. INL presents a plan of action to determine readiness to the DOE Operational Safety Board for approval. DOE examines the operation or activity and determines the level of independent verification of readiness needed to start or restart operations in a Hazard Category 1, 2 or 3 nuclear facility. A graded, assessment approach for readiness verification is used and can be as simple as no assessment requirement to a DOE Readiness Assessment (DOE RA) or an Operational Readiness Review (ORR). DOE grants approval to perform the nuclear operations based upon successful completion of any assessment requirements including satisfactory resolution of assessment issues. In preparation for the DOE assessments, the INL would determine a plan of action ensuring readiness to perform the same nuclear activity. If the screening identifies a DOE-level assessment, then the INL performs a Management Self Assessment (MSA) and a Contractor Readiness Assessment in preparation for performance of the DOE-level assessment.

Historically, RPS Program, nuclear activities screen to perform DOE-level assessments and Programmatic Reviews. The INL typically conducts the following assessments/reviews in the following order of progression before authority to perform the activities is granted: Management Self Assessment (MSA), Contractor Readiness Assessment (CRA), DOE Readiness Assessment (DOE RA), Production Readiness Review (PRR) and lastly, the Segmented Readiness Review (SRR). Twelve assessment criteria are reviewed and a selection of the criteria is identified for assessment on a graded approach. Review criteria typically requires, at a minimum, review of operating instructions to ensure technical safety requirements are adequately identified, review of training records to ensure personnel are adequately trained to perform the specified work scope, personnel are interviewed to determine adequacy of level of knowledge for work scope, and a high-fidelity performance of the operation to ensure the operating instructions and conduct of operations are adequate to perform the work scope. As each assessment/review is conducted, a formal report delineating any issues in the form of findings, observations, and noteworthy practices will be issued. Before start-up approval is obtained, all issues must be resolved to the satisfaction of the individual teams. Approval for start-up is formally communicated by memorandum from DOE. Programmatic approval is documented in the SRR where vested Program representatives in the RPS community (to include DOE Nuclear Energy (DOE NE) and DOE Idaho Operations Office (DOE ID) representatives) ensure personnel, documentation, and materials are in place to perform the activity.
The requirements governing assessment activities relating to the RPS Program at the INL are described in multiple documents at several tiers ranging from Federal Law to program specific instructions. Each tier encapsulates the tier above and adds specific implementing requirements within their scope as shown in Figure 5. These tiers and their associated assessment related requirements are described here in more detail.

**Code of Federal Regulations**

The Code of Federal Regulations (CFR) is an annual codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the Federal Government[8]. The purpose of the CFR is to present the official and complete text of agency regulations in one organized publication[8]. The coding system is based on Titles, Parts and Subparts. For example, Title 10: Energy PART 830 – NUCLEAR SAFETY MANAGEMENT Subpart A – Quality Assurance Requirements[1], would be shortened to read 10 CFR 830 Subpart A when referenced in program documents. Many CFRs apply to specific activities performed at the INL. Most CFRs apply only to a sub-population of the INL, for example, 10 CFR 71 Packaging and Transportation of Radioactive Material. Only one CFR applies to the entire INL, 10 CFR 830 Subpart A.

**DOE Orders**

DOE Orders encapsulate CFR requirements and mandate any additional requirements for the DOE and its contractors. DOE Orders are numbered with the current revision in the title. The associated DOE Order to 10 CFR 830 Subpart A is DOE O 414.1D, QUALITY ASSURANCE, Admin Chg 1[3]. The criteria that apply to the INL are identical to the criteria found in 10 CFR 830 Subpart A. There are ten criteria with specific requirements for each topic area. The DOE Order adds two additional requirements, one regarding the prevention of suspect/counterfeit items and another regarding safety software utilized in nuclear facilities.

Criterion 9 and Criterion 10 apply specifically to assessment:

**Criterion 9**—Assessment/Management Assessment. Ensure that managers assess their management processes and identify and correct problems that hinder the organization from achieving its objectives.
Criterion 10—Assessment/Independent Assessment.
   a. Plan and conduct independent assessments to measure item and service quality, to measure the adequacy of work performance, and to promote improvement.
   b. Establish sufficient authority and freedom from line management for independent assessment teams.
   c. Ensure persons who perform independent assessments are technically qualified and knowledgeable in the areas to be assessed.[1,9]

INL Contract with the DOE-ID Field Office
The American Society of Mechanical Engineers (ASME) NQA-1-2008 with the 2009 addenda[9] is an American national consensus standard called out in the contract between INL and DOE-ID and is structured with eighteen requirements. The requirements in NQA-1 completely encompass the requirements found in 10 CFR 830 as well as DOE O 414.1D and add additional rigor or specificity in several areas. Requirement 18 - Audits has eight sections that apply directly to the INL audit function. These sections are:

100 Basic
200 Scheduling
300 Preparation
400 Performance
500 Reporting
600 Response
700 Follow-Up Action
800 Records[2]

Each of these sections directly impact the format, content and mechanisms used for assessment at the INL and subsequently within the RPS Program.

INL Quality Assurance Program Description (QAPD)
The INL QAPD, found in PDD-13000, Quality Assurance Program Description encapsulates all of the contractual requirements for the INL as a whole[11]. The purpose statement summarizes the intent of the document.

This Idaho National Laboratory (INL) quality assurance program (QAP) program description document (PDD) is the top-level document that describes the quality assurance policy, applicable contractual quality assurance requirements, assigns major functional responsibilities for INL work activities conducted by or for INL, describes the application of the graded approach for those QA requirements and implementing procedures documented in the requirements management system database, and describes the management systems that incorporate QA requirements[11].

All work activities at the INL are covered within the scope of PDD-13000. As part of the Program Description, “Performance and improvements require thorough, rigorous assessments and effective corrective actions …[11]” Section 6.18 specifically addresses the implementation of assessments and audits at the INL. The goals of the INL assessment program are to:

- Identify and correct problems that hinder INL from achieving its mission and objectives
- Measure items and service quality
- Measure adequacy of work performance
- Promote improvement
- Verify compliance to QAP requirements
- Verify that performance criteria are met
- Determine the effectiveness of the program[11]

Section 6.18.1, Quality Assurance Program Audits, states “QAP audits of activities are performed in such a manner as to assure that an audit of all applicable QAP elements is completed within a period of 3 years. QAP audits are
scheduled based on an approved triennial topics schedule in a manner to provide coverage and coordination with ongoing activities, based on the status and importance of the activity." \[11\]

The RPS Program Quality Assurance team performs these audits within the Program, the results of which are verified by the 3rd party auditors on a periodic basis. Corrective actions identified are also managed within the program unless entities outside of the Program are impacted.

Section 6.18 also defines the difference between Management Assessments and Independent Assessments. Their goals are different as well as the training and experience requirements needed to perform or participate in each. The goals of Management Assessments are to:

- Ensure that their organizations and functions are periodically assessed
- Determine how well they meet customer and performance expectations as well as mission objectives
- Identify strengths or improvement opportunities and correct problems
- Address the effective use of resources to achieve the organization’s goals and objectives

Independent Assessments have a different focus. They are used to evaluate the performance of work processes with regard to:

- Requirements
- Compliance
- Expectations for safely performing work
- Achieving the goals of the organization\[11\]

**Program Specific Requirements with the DOE-HQ Program Office**

The requirements specific to the RPS Program from the DOE Headquarters Program office are contained in SDPS/PQAR-1, SPACE AND DEFENSE POWER SYSTEMS PROGRAMMATIC QUALITY ASSURANCE REQUIREMENTS FOR SPACE AND TERRESTRIAL NUCLEAR POWER SYSTEMS\[12\]. Section 8 ASSESSMENTS, indicates that the DOE-HQ Program Office “… shall plan, schedule, and perform quality assessments of contractor operations and quality program implementation to measure adequacy of work performance, and to assess compliance with technical and quality criteria.\[11\]” Assessments of contractor operations has been described earlier. Assessments, of quality program implementation, are performed annually by a third-party audit team; consisting of personnel from TechSource Inc. and DOE-ID Field Office Quality Assurance Department. This oversight team audits compliance of the RPS Program to its own QAPP that encapsulates INL requirements and any additional customer-specific or mission-specific requirements. INL QAPD requirements are only considered when they impact the RPS Program directly. This level of oversight ensures that personnel are accustomed to a questioning attitude and are dedicated to the continuous improvement that oversight encourages.

Audits performed in FY13 and FY15 did not indicate any assessment or auditing related findings or observations. Third party auditing has found the RPS Program at the INL effective or highly effective since its start up at the INL.

**Quality Assurance Program Plans (QAPP)**

LWP-13012, Addressing Program/Project Specific Quality Assurance Requirements, authorizes individual programs to create quality plans in order to meet customer requirements that may conflict with or exceed specific requirements of the INL in general\[13\]. These plans are called QAPPS.

The RPS Program QAPP is structured to address the criteria from 10 CFR 830 and DOE O 414.1D directly. Therefore, section 9 addresses Management Assessments and section 10 addresses Independent Assessments. The Management Assessment section includes the mandate for periodic reporting and the content requirements for weekly, monthly, quarterly and annual reports.

The annual Management Assessment is mandated to contain the following in addition to any other items:

- List of assessment activities (inspections, surveillances, management assessments, independent assessments, etc.) pertinent to the RPS Program that were conducted during the reporting period
- List of INL RPS-related deficiencies for which no internal action was generated
• List of INL documents (e.g., Timely Orders, Standing Directives) and processes implemented in SSPSF which did not include RPS Program specific approval
• Results of review of deviations to INL procedures
• Summary of assessment activities required by RPS packaging SARPs

Independent Assessment within the RPS Program is conducted per the associated INL procedures using audit checklists that incorporate all INL top-tier requirements. RPS Program internal audit checklists also include the necessary evaluation to conform to 10 CFR 71[14] (SARPs) which applies to the RPS Program specifically due to the 9904 and 9516 casks as well as the transportation system to carry them that are managed by the Program. Due to the fact that 10 CFR 71 is structured like NQA-1, using the INL checklists with some minor modifications complies with both requirements.

CONCLUSION

DOE Regulations govern conducting nuclear activities that may affect the safety of DOE nuclear facilities. DOE orders require independent verification of operational readiness to a customer-expected level of quality before nuclear operations are performed in a nuclear facility. A graded approach to assessments and programmatic reviews are required to be performed to ensure deliverables are produced safely and at an expected quality standard. INL RPS assembly and testing operations to support the Mars 2020 Mission, the next planned space mission using a nuclear power system, will require about of year of assessments and reviews before the nuclear operations are performed in addition to the general assessments required regardless of any program scope.

REFERENCES

[2] DOE O 425.1, Verification of Readiness to Start Up or Restart Nuclear Facilities, Latest Revision
[3] DOE O 414.1, Quality Assurance, Latest Revision
[7] MCP-9902, Management Control Procedure, Verification of Readiness to Start Up or Restart Nuclear Facilities