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Highly Integrated Quality Assurance – An Empirical Case

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Abstract. The Radioisotope Power Systems Program of the Idaho National Laboratory makes an empirical case for a highly integrated quality assurance function pertaining to the preparation, assembly, testing, storage and transportation of ^{238}Pu fueled radioisotope thermoelectric generators. Case data represents multiple campaigns including the Pluto/New Horizons mission, the Mars Science Laboratory mission in progress, and other related projects. Applicability of this case extends to any high-value, long-term project where traceability and accountability are determining factors.

Keywords: Quality Assurance, Radioisotope Power Systems, Idaho National Laboratory

This paper describes an empirical example of a highly integrated quality assurance function encompassing the Radioisotope Power Systems (RPS) program at the Idaho National Laboratory. Due to the breadth of any topic relating to quality assurance, some historical context is provided for perspective. Although there are numerous types of Radioisotope Power Systems, this report focuses on Radioisotope Thermoelectric Generators (RTGs) produced at the INL.

This paper assumes the use of a standards based approach to the production cycle. ASME NQA-1-2008 is a standard that's commonly recognized in the nuclear industry. It describes the requirements "necessary to achieve safe, reliable, and efficient utilization of nuclear energy, and management and processing of radioactive materials." (NQA-1, 2008) In this nationally accredited organization, quality assurance is required to be independent of the work being performed, including the cost and schedule. Also, personnel performing quality assurance responsibilities are required to have direct access to appropriate levels of management.

HISTORICAL CONTEXT

Radioisotope Power Systems

Radionuclides are defined as unstable isotopes of an element that decay spontaneously, emitting energy in the form of radiation and heat. Radionuclides are often referred to by chemists and physicists as radioactive isotopes or radioisotopes. Energy from radioisotopes can be and has been used in a number of ways.

1. Radioisotope power sources produce electrical power when thermal energy from the natural decay of radioisotopic fuels (Pu-238, Ce-144, Sr-90) is harnessed using one of several conversion technologies – thermoelectric converters, turbine alternators, or linear alternators for example.
2. Nuclear reactor power sources produce thermal energy, generated by the fission of radioisotopic fuel, which is then converted to electrical power.
3. Radioisotope heater units (RHUs) use thermal energy from radioisotopic fuel decay directly to provide heat to terrestrial and aeronautical instruments which require a temperature controlled environment in order to function.

RTGs are one type of radioisotope power sources. They rely upon the conversion of heat, generated by radioactive decay of radioisotopes into electricity using thermocouples. Thermocouples, with no moving parts, have made RTGs a long-lived, reliable source of power, appropriate for a variety of applications. RTGs can be used in remote locales, under harsh conditions, when solar intensity or duration are too low for solar power options, and/or when a need to leave a system unattended, without refueling or maintenance, exists.

In the second half of the 1940's, the United States Atomic Energy Commission's (AEC) increased study of radioactive decay and its many possible applications combined with advances in the study of thermoelectric science led to refinement of the technology upon which RTG power generation/conversion is based. In the early 1950s, the US military provided funding to the AEC to research the possibility of using radioisotope fueled energy systems on satellites. Bench scale model RTGs were produced soon after, and although not used for satellite or other space applications immediately, RTGs developed from this research were used to provide power to remote research stations in Antarctica. (Nat. Ac. Sc, 2009)

Research relating to RPS applications for satellite power continued. Two radioisotope power systems were studied under the System for Nuclear Auxiliary Power (SNAP) program. Radioisotope power sources (most were RTGs) were assigned odd numbered SNAP unit designations. (Bennett, 2003) Nuclear reactor power sources were given even numbered SNAP designations. The first space application of an RTG came in 1961, when a SNAP-3 RTG was used to provide supplemental power to a navigational satellite. The SNAP-3 RTGs weighed less than five pounds and provided less than 3 watts of electrical power (3 W_e). (Bennett, 2003) Advancements were made in the SNAP design and in 1963, SNAP-9A was the first RTG to be used as the primary power source for a satellite; providing 25 W_e power to the satellite's systems. (Bennett, 2003)

On April 21st, 1963, the third SNAP-9A launch aborted in the atmosphere and burned up on reentry prompting an emphasis on safety requirements that required radioisotopic fuel used to power RTGs to survive atmospheric reentry and/or impact without release to the environment in the event of mission failure. (Nuclear News, 2003) Additionally, demands for higher efficiency and higher specific power led to advancements in RTG design. Multi-hundred Watt (MHW) RTG thermoelectric research used silicon-germanium alloys in the thermocouples, rather than telluride-based alloys used in earlier units. The MHW RTGs provided over 150 W_e at the beginning of mission (BOM). (Bennett, 2002)

The General Purpose Heat Source (GPHS), which is used in space applications today, was developed to incorporate a general use fuel form. GPHS RTGs also utilized a new converter design. The converter still relied upon the silicon-germanium alloy thermoelectric unicouples used in the MHW RTGs, but the new design allowed an increase in conversion of thermal power to 300 W_e (with an efficiency of approximately 6%) at BOM.

Until now, space applications of RTGs have relied upon thermoelectric conversion systems for conversion of radioisotopic energy to electric energy. Although very reliable and having no moving parts, the efficiency in these "static" thermoelectric conversion systems is relatively low. "Dynamic" conversion systems which would provide higher efficiencies are being studied. A potential drawback to dynamic systems is that they employ moving parts, which are more likely to fail.

Dynamic-type generators include turbine alternators and linear alternators. In a turbine alternator, a heated gas or liquid is used to drive a turbine, which drives an electric generator. The heat, as in the case of RTGs, is supplied by radioactive decay of radioisotopic fuel. The first SNAP unit used a Rankine (or liquid-based) turbine conversion system. (Bennett, 2002) Linear alternators use a piston, rather than a turbine, in conjunction with a heated gas to generate electricity. Compared to static thermoelectric conversion, dynamic conversion technologies can provide efficiencies of approximately 30%. (Nat. Ac, Sc, 2009) With the supply of radioisotopes used in RPSs dwindling, the increased efficiency offered by dynamic units, even with the risk of failure associated with moving parts, has made their potential use in space applications a viable alternative worthy of further research.

Idaho National Laboratory

"In the United States, only the Department of Energy (DOE) is authorized to own space nuclear power systems." (Nat. Ac. Sc, 2009)

When a NASA mission calls for the use of a radioisotope power system, DOE is responsible for the production and delivery of the power system to NASA. (MOU, 1991) The design of each power system is based on NASA specifications. A DOE selected Design Agency (DA)is awarded a contract and is then responsible for designing the power system, which in the case of the RTGs currently in use, includes a converter employing one or more radioisotope heat sources. The converter is built and tested to the DA's specifications, either by the DA or by its subcontractor. The converter is then delivered to a DOE contractor nuclear facility where the radioisotope heat source(s) are built, installed into the converter, and the entire system is tested to ensure NASA and DA requirements are met.

Following the events of 9/11 and based on the results of a DOE Safeguards and Security Review of all its complexes, DOE announced the transfer of production and testing capabilities of the RPS program from the Mound Site in Miamisburg, Ohio (Mound) to the Idaho National Laboratory (INL) in August 2002. INL was required to perform design, procurement, construction, installation, and testing operations for the new building and related facility equipment under a very compressed schedule. The 10,000 square foot Performance Category 3, Hazard Category 2, non-reactor nuclear facility (DOE-STD-1027, 1992) was completed 24 months following issuance of the EPA Record of Decision allowing the transfer of the RPS program from Mound to the INL. (Johnson, 2010)

The stringent quality assurance model in place at the Mound facility for the RPS program was developed using their experience in nuclear weapon parts production previously performed at that location. When the RPS program was transferred to the INL, this quality assurance model was also adopted rather than the model in place at the INL, a model more aligned to research and development activities. This more stringent set of quality assurance requirements is integrated with INL's quality management system to provide the necessary support from the laboratory while maintaining the level of rigor required by the RPS program sponsors.

Additionally, 320 tons of historical production and test equipment and tools, transported in 28 semi-tractor trailers, were packaged and transferred from Mound to the INL during the same time period. Equipment moved from Mound to the INL included fabrication, test, and transportation systems. (Johnson, 2010) INL was fortunate that former Mound employees as well as DOE headquarters personnel were available to provide historical expertise and guidance. In addition, INL had access to historical Mound procedures which could be modified for use at the INL, rather than having to start from scratch with unfamiliar material and equipment.

From the day the decision was made to move the RPS program to the INL to the day the first RTG was built and tested at the INL and was shipped to Kennedy Space Center for launch covered a time period of slightly more than 3 years.

QUALITY ASSURANCE ORGANIZATIONAL MODELS

Traditional quality assurance models would attempt to reduce cost by minimizing the role of dedicated quality assurance personnel in favor of either functional tasking or peer-based implementations. A review of the most common organizational models is presented here for comparison.

Common Models

The most common quality assurance models are: Functional, Product, Customer, Geographic, Process, Team, Cells, Boundary-less, and Matrix. Of these models, Functional, Teams, and Matrix are of the most interest in relationship to this topic.

The functional organization is one of the most frequent ways to group activities. (Westcott, 2005) This model groups personnel by their discipline or function within the organization, i.e. a quality department, a finance department, an operations department. From a quality assurance point of view, functional tasking is often used when specific examinations (e.g. NDE, precision dimensional) are required. In this type of organization, quality assurance personnel are usually drawn from a pool of resources and utilized in a just-in-time fashion. Typically, this constrains quality assurance personnel to not be present for the whole process, making them dependant on others for information. Additionally, functional tasking requires that critical features be predetermined to determine proper hold points for examination. More likely in the functional model is the possibility of non-conforming situations being miscategorized or overlooked as quality assurance personnel are only present when requested.

A team structure (also known as cross-functional teams) brings functional assets together into a task group, led by a team leader. Cross functional teams are often generated to accomplish a common goal within a program that requires a variety of resources. An example would be initiating a team to focus on reducing the amount of nonconformances being generated or implementing quality assurance tools such as six sigma or lean manufacturing. In this model individuals are taken from relevant organizations and form a team under direct control of the team leader. This team leader then reports to their work organization manager who is responsible for the work of the team. Typically, once the goal has been achieved the team is disbanded. This model is less desirable in that quality assurance personnel report directly to the team leader, hence losing their independence and being more susceptible to schedule and budget pressures.

A matrixed quality assurance organization is a combination of the previous mentioned quality assurance models, functional and teams. Matrixed quality assurance occurs when quality assurance personnel are dedicated to a specific program and interface throughout all phases of its projects including conception to beyond its grave. In this model, quality assurance is still independent of the work being performed because they report to their home organization or quality assurance organization. However, quality assurance personnel are also assigned to the program full-time and report to the program’s work organization manager for day to day tasks. This model may sound similar to a cross functional team in that individuals from relevant organizations interface to accomplish a common goal; however, in a matrixed quality assurance model personnel are responsible for reporting to both the home and work organization managers.

Some organizations achieve quality without dedicated quality assurance personnel. This peer-based approach can be described as an independent verification performed by an individual whose main role is the same as the performer. An example would be an engineer independently verifying a calculation performed by another engineer (also called peer review) or a technician verifying a torque performed by another technician. This approach is becoming more prevalent in software development arenas in the form of the Agile or Extreme Programming models. Peer based models may be less effective as a replacement for quality assurance personnel. "Peer review is not currently designed to detect deception, nor does it guarantee the validity of research findings." (Lee, 2006) Personnel who are too familiar with a process tend to overlook details that more independent personnel would identify as requiring attention. Also, an individual who has a specialty in the scope of work and is then required to perform quality assurance functions may have a learning model that is too broad for the depth of understanding required to perform the function. An example would be where a nuclear operator is performing work in a glovebox with another nuclear operator acting as a peer reviewer. The scope of knowledge of a nuclear operator would include only a cursory knowledge of quality assurance skills and processes. Utilizing personnel skilled in quality assurance as their primary knowledge increases the likelihood of identifying situations when they occur, reduces the amount of time to process related documentation and reduces the training burden for personnel performing outside of their focus area.

EFFECTS OF INTEGRATION

The quality assurance function within the RPS Program at the INL operates as a matrixed cross-functional team, where personnel belonging to the quality assurance organization are dedicated to the RPS Program full-time and form cross functional teams with Nuclear Operations and Engineering personnel on a project by project basis. The result is a highly integrated quality assurance program. The RPS Quality Manager reports directly to the Director for quality assurance at the INL as well as the Program Manager responsible for the RPS Program in the Nuclear Science and Technology directorate. This dual reporting maintains the independence required for objective quality assurance activities as well as garnering the benefit of quality assurance involvement in the full scope of the program.

Benefits

A highly integrated quality assurance program adds value by placing trained quality inspectors on the production floor side-by-side with nuclear facility operators to enhance team dynamics, reduce inspection wait time, and provide for immediate, independent feedback. Value is also added by maintaining dedicated quality engineers to provide for rapid identification and resolution of corrective action, enhanced and expedited supply chain interfaces, improved controlled storage capabilities, and technical resources for requirements management including data package development and Certificates of Inspection. A broad examination of cost-benefit indicates a highly integrated quality assurance program can reduce cost through the early identification and mitigation of risk as well as reducing administrative burden thereby allowing engineers to be engineers, nuclear operators to be nuclear operators, and the cross-functional team to operate more efficiently.

Additionally, people who feel as if they are part of a process, leaving their mark if you will, are more likely to take ownership. When this happens, individuals feel as if they are making a positive difference which improves the quality of your product. "In fact, employees with the highest levels of commitment perform 20% better and are 87% less likely to leave the organization, which indicates that engagement is linked to organizational performance." (Lockwood, 2007)

Within the RPS Program, quality assurance personnel are responsible for product from cradle to grave. This big picture responsibility ensures continuity as well as clarifies any ownership issues. These decisions are more relevant when lessons learned and other historical considerations are taken into account. RPS program quality assurance personnel are divided into two groups, quality engineers and quality inspectors. Quality inspectors perform the majority of quality related field work including receiving and in-process inspections, work observation, and inventory management. Quality Engineers manage the overall integration of quality related process including deficiency management, configuration management, control of quality records, and other related functions. Having dedicated quality engineers on a project by project basis allows for more informed decision making when the possibility of the need for corrective action arises. Quality Engineers are also trained as quality inspectors and both groups are qualified General Inspectors for the INL.

In order for the team to be more task balanced, quality assurance personnel are also trained in other areas where administrative burden can be reduced, such as controlled storage, records management, etc. This additional training gives quality assurance personnel additional perspective relating to the project at hand as well as overall program knowledge. They are also more capable of reducing the administrative burden generally placed on Engineering and Operations by performing these additional duties.

Several INL RPS processes make the involvement of quality assurance personnel more visible. The Document Configuration Control Board (DCCB) and Material Review Board (MRB) processes provide for high visibility configuration management and deficiency management activities, both managed by quality assurance. DCCB and MRB actions obtain review and approval for change and deficiency across projects and customers including design agencies, other national labs and the department of energy. Over eleven hundred DCCB actions have been processed since 2003.

The MRB process tracks deficiencies and the associated corrective actions through closure. Actions include class one, which involve the qualification status of product, class two, which contain all issues that do not meet specification that are not class one, and anomalies, which describe deviations within specification. Since 2003, quality assurance has processed 110 anomalies, 603 class two actions, and 233 class one actions including relevant actions from Oak Ridge National Laboratory (ORNL) and Los Alamos National Laboratory (LANL).

The processing of actions from ORNL and LANL are managed by the INL as the Lead Laboratory for the RPS program. In the capacity of the Lead Laboratory, RPS quality assurance personnel act as a central location for all program related configuration and deficiency management, coordinating comments and reviews from all three engineering groups, DOE Headquarters and other interested parties. This broad understanding of the entire process from specification, manufacturing, fuel processing, to final assembly gives RPS quality engineers a unique high level view of the program and a broad base to draw from in the execution of their responsibilities.

The status and location of all controlled materials are also tracked by quality assurance personnel by way of an electronic database. Items are checked in and out of controlled storage areas for training or operations as required and a stringent process is utilized to qualify an item for production use. This system is also utilized to manage calibration of test equipment and use logs for out of tolerance resolution.

Detriments

Cost is the most obvious detriment to the matrixed organization as more personnel are required to maintain balanced teams. Based on the volume of work at any given time, the funding required to maintain a highly integrated quality assurance staff in the RPS program is between 10% to 20% of total staffing related funds. Quality assurance personnel comprise approximately 20% of program personnel. This ratio decreases when projects staff up for a build and increases during periods of less activity.

Another detriment is a factor generally associated with cross-functional teams. When teams are formed, there is a natural “leveling” process where all team members come to consider themselves equal partners in the outcome. This leveling is rarely translated into balanced compensation. The greater the differential in compensation between team members, the more difficult it is to form a synergistic team over the long term. This factor can be offset by group recognition and team oriented awards.

CONCLUSION

INL RPS quality assurance personnel have been involved at the ground level; in the planning stages, in design reviews, in procurement planning and implementation, in the review and execution of test plans to test new and modified designs, to offer modification suggestions, to see where and why modification were made and to understand why they are important to the quality of final products. Quality assurance personnel train and earn qualifications alongside the operators and engineers. Quality assurance technicians and engineers support the extended shifts required to deliver a high quality product. Quality assurance personnel are a knowledgeable and essential part of getting one-of-a-kind, multi-million dollar production units to the customer on-time and within budget.

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