MANAGING SPACECRAFT RISK WITH SPACE ENVIRONMENTS TESTING VIA PROCESS SAFETY MANAGEMENT AT THE NASA NEIL A. ARMSTRONG TEST FACILITY

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ABSTRACT
The NASA Glenn Research Center’s Neil A. Armstrong Test Facility (GRC-ATF) is home to several unique, world class aerospace test facilities, including the In-Space Propulsion (ISP) Facility. The ISP Facility is NASA’s largest chamber designed to store and transfer large quantities of liquid hydrogen and liquid oxygen; and is designed to support developmental testing of upper stage chemical propulsion systems as well as fully integrated stages. The facility is also capable of providing thermal-vacuum simulation services to support testing of aerospace hardware, Cryogenic Fluid Management (CFM) systems and other In-Space propulsion programs. The U.S. Occupational Safety and Health Administration’s (OSHA) Process Safety Management (PSM) of Highly Hazardous Chemicals Standard (29 CFR 1910.119) is an analytical tool focused on preventing the release of chemicals and other energy sources. In a short timeframe, GRC-ATF was required to restore a PSM Program at the Facility. Although the summarized work is specific to the ground testing of rockets and space vehicles, the ISP Facility is used to verify system level requirements, some of these are safety requirements, and thus key to managing risks in space.

1. INTRODUCTION
The ISP Facility, Fig. 1, is located at GRC-ATF, in Sandusky, Ohio. GRC-ATF is a 6400-acre field center that is managed by the NASA Glenn Research Center (GRC). Commissioned in the late 1960’s, ISP is the only facility in the world that combines long-duration, high vacuum space environment simulation, hot fire test capability and engine restart capability within a single chamber.

The central feature of the ISP Facility is a 38’ diameter, 67’ tall vertically oriented cylindrical vacuum chamber. Test articles are installed in the chamber via a large, hinged hatch using a 20-ton overhead crane as shown in Fig. 2. Vacuum levels up to 1x10^-7 Torr are achieved using oil diffusion pumps backed by three stages of mechanical vacuum pumps.
vacuum operations with an 11’ fast operating valve. During hot fire sequences, rocket engine exhaust is directed through an 11’ diameter straight diffuser into the Spray Chamber, where it is quenched and condensed with chilled water. Non-condensable engine exhaust by-products are removed via multi-stage steam ejectors. The motive steam for the ejectors is generated by a boiler and stored in accumulator tanks adjacent to the ejectors.

Liquid oxygen and liquid hydrogen are supplied from stationary dewars located exterior to the ISP Facility. The propellants are pressure transferred to the chamber through vacuum jacketed piping, which are equipped with vents, relief protection, isolation valves and instrumentation. Propellant overboard tanks are permanently positioned in the spray chamber to safely remove propellants from a stage or test article during a test abort. The multi-level facility is outfitted with safety features including combustible gas detectors, oxygen detectors, infrared fire detectors for leak detection and personnel safety. Fig. 3 shows the details that have been described above.

After a test article is integrated into the facility and verified functional, a typical propulsion test at ISP is a highly orchestrated sequence. Once initial setups are completed, operations are conducted from a control room that is 2460’ from the ISP Facility, where support systems and test hardware can be operated and monitored remotely. Basic propulsion test operations include the following steps:

- charge the accumulators with motive steam for ejector operations
- begin pulling a vacuum on the test chamber to the desired pressure
- fill the cryoshroud with LN2
- energize IR lamps to thermally condition the test article for the customer-specified length of time
- when ready for engine testing, evacuate atmospheric pressure from the spray chamber utilizing auxiliary steam ejectors
- fill the test article’s propellant tanks
- equalize pressure between the vacuum chamber and the spray chamber to allow fast operation of the 11’ valve that isolates the vacuum chamber from the spray chamber
- begin circulating water to cool the engine exhaust
- bring the main steam ejectors online to maintain vacuum during engine firing
- command the 11’ valve open
- provide firing signal to the test article’s rocket engines

Test conditions can be maintained for up to 5 minutes. At the conclusion of the engine firing sequence, the 11’ valve is closed, the water circulation system is shut down and the steam ejectors operations are halted. Thermal vacuum conditions can resume and after replenishment of commodities and motive steam, the engine firing process can be repeated.

Since the facility’s commissioning over five decades ago, there is a long list of test customers that have utilized ISP for its unique capabilities. The facility was designed and first used to test the propulsion system of the Centaur upper stage rocket in the 1970s and was later used to test hardware for Delta III Programs throughout the 1990s. With OSHA’s enactment of PSM in 1992, the Delta III program was the first ISP test effort that invoked the facility’s compliance with the standard. Since that time, numerous test customers have come to ISP with smaller-scale propulsion and non-

Figure 3. Cutaway showing ISP’s multiple levels
propulsion systems and payloads, however none of these efforts involved propellants in amounts that exceeded PSM’s threshold quantity of highly hazardous chemicals. When Delta III ended their test program at ISP, much of the facility’s funding disappeared and the rigorous effort to maintain PSM compliance dissipated.

Approximately 20 years after the Delta III program ended, a NASA-in-house research and development project materialized that involved evaluation of in-space propellant storage at space-like conditions at ISP. The project was part of NASA’s Evolvable Cryogenics Project (eCryo), and although it did not involve firing rocket engines, it did require storage and use of liquid hydrogen in quantities that exceeded the PSM threshold. The facility was faced with the task of reactivating PSM compliance over a six-month period in order to support the eCryo test.

While some aspects of PSM are inherent to NASA GRC’s current policies and processes, several of the 14 PSM elements are not and thus required some level of effort and changes in procedure to attain compliance. For instance, due to NASA’s strong initiatives in mishap planning and investigations, virtually no effort was necessary to demonstrate compliance with “Incident Investigation” element of PSM. Conversely, the configuration management process at GRC did not sufficiently cover the minimum requirements for PSM’s Management of Change (MOC) and an entirely new process and culture shift were necessary to meet the intent of this critical element of PSM. In the case of most elements, there were components and framework to support PSM, but additional work was necessary to meet the full intent of the federal regulation.

Within the 6-month window, the ISP Facility was able to reach a state of compliance that was considered satisfactory to NASA GRC Management and the eCryo project was successfully completed. At the conclusion of the eCryo project, additional test efforts were planned that would invoke PSM. GRC and ATF saw this as an opportunity to evaluate and improve upon their existing PSM program and redoubled their efforts to strengthen their processes for long-term compliance.

Large, unique facilities such as ISP are considered national assets, but will often go for prolonged periods without a test customer that utilizes the full capabilities of the facility, as was the case after the Delta III test program. During extended downtimes between tests, workforce levels fluctuate, resulting in loss of facility knowledge, and established facility processes are sometimes altered or abandoned in an effort to reduce costs.

GRC and ATF are aiming to establish a long-term PSM compliance program at ISP that creates such inherent value that the processes are upheld regardless of a test project’s exceedance of the threshold quantities of highly hazardous chemicals.

2. IN-SPACE PROPULSION FACILITY HAZARDS LINK TO SPACECRAFT RISKS

Although some basic research and development testing has been performed, the typical customers using the facilities at GRC-ATF, including ISP, are performing either Qualification or Acceptance testing for spaceflight. Thus the formal verification, and closure of, Programmatic Requirements are key in allowing the vehicle under test to move on to the next phase of System Integration Reviews (SIR), Certification reviews, Certification of Flight Readiness (CoFR), etc. Many of these Programmatic Requirements are specific to Quality, Reliability, and Safety of the vehicle and its components. Thus, PSM compliance helps ensure that customers of ISP, Fig. 4 as an example, have their ground test data comply with Quality, Reliability, and Safety best practices, standards, and requirements to reduce flight risks pertaining to their space vehicles. PSM compliance also reduces “surprises” during testing and assists in holding to schedule.
3. PROCESS SAFETY MANAGEMENT PRINCIPLES

A facility such as ISP at ATF capable of testing spacecraft engine firing under space flight conditions must manage the unique hazards. These include the high energy release of ignition and containment of exhaust products, the on-site storage of large quantities of fuel and oxidizer, and the required high energy steam systems necessary to create vacuum and remove exhaust products. The priority is safety of on-site operators and test personnel, protection of the test facility, protection of the high cost test article (spacecraft), as well as ensuring potential off-site consequences are eliminated. Process Safety (as opposed to occupational safety) is concerned with minimizing these risks by reducing the likelihood of a release of energy, fuels, and oxidizers from the test systems.

Although a unique spacecraft test facility such as this is very different from processes found at chemical or petroleum plants, process safety management principles can be applied in much the same way and with similar positive results. Both face potential explosive release of energy, destructive fire, and perhaps hazardous material release to surrounding areas. OSHA’s PSM standard, 29 CFR 1910.119, originated in the early 1990s as a result of multiple process disasters, such as:

- Bhopal, India (1984)
  2,000 deaths & 500,000 injuries
  90,000 lbs methyl isocyanate released
  Threshold Quantity is currently 250 lbs

- Pasadena, TX (1989)
  23 deaths & 314 injuries
  85,000 lbs ethylene/isobutane explosion

- Sterlington, LA (1991)
  8 deaths & 128 injuries
  Propane/nitromethane explosion

The goal is to avoid the release of large quantities of flammable and or highly toxic materials. Facilities subject to this regulation are those which store and use quantities of these materials over a specified threshold quantity limit. In the case of a facility such as ISP, the capability to test fire spacecraft engines for a sufficient length of time requires a high-volume storage of fuels making it a “covered process” and invoking the standard.

Even if ISP was not a “covered process”, following the same Process Safety Management (PSM) principles would make sense. There are 14 elements which must be applied [3] and listed in Table 1.

Methods to apply these can vary with the type and size of the facility but must follow some basic requirements OSHA has provided [4]. All elements are crucial to minimizing risk, but a few are key in almost any situation including the ISP Facility.

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Employee participation is first on the list for a reason. Without involving all personnel associated with the test operations, including maintenance, operators, and engineers, the rest of the elements are near meaningless. Process Hazard Analyses (PHA) if done properly, brings together the right people along with the necessary knowledge, to objectively review and brainstorm the process design to identify anything that has been missed or changed in the process that may lead to an incident or major disaster. Management must commit the resources needed to perform these well. This means of course the people and sufficient time dedicated to the task. It also requires diligence in developing and maintaining the Process Safety Information (PSI) necessary for the PHAs and safe operation. One overlooked benefit of thorough hazard analyses and well documented PSI is the increased knowledge of the entire process technology and associated hazards by all affected employees. Anyone who has participated in a PHA of a complex process can attest to achieving a better understanding of the need for detailed, accurate and up to date process drawings, instrument and control system actions and data, and all process equipment records.

PHAs go hand in hand with Management of Change (MOC) and depend on quality Operating Procedures and personnel Training. Historically changes made to existing processes or even designs of new ones, which are overlooked from a hazard review perspective have led to disastrous events. Adequate training and following approved procedures significantly reduce the probability of human factor caused incidents. Another large management commitment is Mechanical Integrity. In the case of ISP, similar to the process industries, a master list, along with all records verifying code compliance, must be maintained for all equipment covered by the PSM standard & equipment that is critical to the safety of the process. Depending on the
process the mechanical integrity program may include: pressure vessels and storage tanks, piping systems including valves and other piping components, relief and vent systems and devices, emergency shutdown systems, monitoring devices/ sensors/ alarms/ interlocks, pumps, rotating equipment, heat exchange equipment, electrical generation & distribution equipment, emergency power supply equipment, and fire protection equipment.

This must be designed, constructed, and maintained properly for the demanding functions. Failure of even minor components can lead to mis-operation and devastating consequences. We often think of large pressure vessels and severe service piping in this regard, but the BP Texas City event in 2005 which killed 15, occurred in large part due to a lack of process instrumentation maintenance. Proper maintenance is assumed by hazard analysis teams when looking at the adequacy of redundant instrumentation to control risk. But once an element of a redundant system fails, and without repair, redundancy is lost. In fact, the PHA process depends on the entire design matching what’s constructed in the field and that it is maintained accordingly.

When incidents occur, Emergency Planning and Response is of utmost importance. If not planned for and practiced, incident results may be much worse. Incident Investigation is a learning and teaching tool. If we don’t learn from even seemingly minor events, we’ll never understand just what can and might happen.

The above discussion focuses on the ground-based facility process safety. Another advantage to some of these elements such as PHAs and Mechanical Integrity is how they lead to an understanding of the systems by all personnel. This may not just be of the ground-based systems but of the test article or spacecraft itself. The customer when involved in process reviews or evaluating its own mechanical equipment or control systems will likely learn some key points about its equipment and how it must interact with the facility. And may lead to a safer space flight mission. This brings up another key point regarding process safety which can be missed. It’s critical in a complex high hazard process, that all associated systems be reviewed together with the right team made up of personnel familiar with both the facility and the test article. Often items are shown as a black box fed with fuel and oxidizers from the facility. Hazards and necessary controls (or lack of) can be missed in this circumstance. The PSM element of Trade Secrets addresses this. OSHA requires all information be available to personnel to comply with relevant elements of the standard without regard to possible trade secret status of such information. PHA notes, worksheets and associated PSI are of primary interest to OSHA auditors or incident investigators. Gaps in information are likely to be cited as violations of the standard and need to be addressed in the PHAs, PSI and the entire PSM effort. Non-disclosure agreements and extra attention to all information needed by the team to sufficiently recognize hazards, and document such, may be needed.

Ground based testing is performed in an environment in which a failure is not catastrophic such as it would be in space, but due diligence must be performed to ensure ground based facilities, personnel and surrounding communities are kept as safe as possible as well. In addition, performing the 14 elements of PSM as intended, such as at NASA’s ISP Facility, gives flight system owners the confidence to perform the testing needed to ensure safety when that craft is launched into space.

4. CURRENT STATUS OF PSM AT ISP

The ISP Facility at ATF is currently working towards long term PSM compliance. Shown below is a current status of the elements of PSM that are being actively addressed. Each of the 14 elements are interrelated and influenced the development of the various programs and documents at ISP.

4.1. The Gap Analysis

A gap analysis was completed to identify gaps that require closure prior to long term PSM compliance. Some of the requirements were being met at ISP, but the gap analysis highlighted the elements that could use improvement in terms of content, process, or program development. The identified gaps were assigned actions and actionees and a PSM Workgroup was created to track progress. Actions were prioritized based on the level of commitment needed to implement and influence on other elements / gaps. A logical plan forward was identified, and those elements were given priority. PSM compliance requires closure of all of the gaps identified. GRC Management has final approval on PSM compliance at ISP.

4.2. Employee Participation

Employee participation is key to implementing and maintaining compliance with each of the elements of PSM. In order to define employee involvement within the program, an Employee Participation Plan (EPP) was developed to document the process safety management program implemented at ISP.

ATF utilizes an online Knowledge Management System, also known as the “Wiki,” as a tool to create a central location for PSM documentation that is accessible by all employees. This encourages employee participation, which is one of the elements of PSM,
through group collaboration and review of documentation. The EPP is available on the Wiki.

4.3. Process Safety Information

PSI was one of the initial areas of focus as it feeds directly into the development of other elements, especially the PHA, operating procedures and mechanical integrity. System Managers were identified for all of the systems at the ISP Facility. The System Managers are responsible for ensuring that the PSI is available for their assigned system, hazards and risk are appropriately identified, and maintenance plans are developed, documented, and implemented. The PSI is located on the Wiki under each of the system pages to allow employees access to information relating to the covered system process.

4.4. Process Hazard Analysis

The Propulsion Test Complex (PTC) utilizes two methods for conducting the PHA. The most commonly used method is a hybrid of the What-If and Checklists, where the hazard, cause and consequence are identified, controls are listed, along with a risk assessment before and after implementation of the controls. The Wiki is used to manage and track the control verifications to completion. Records of completion are kept electronically. The second method of PHA is the Hazard and Operability Study (HAZOP). This method is used for systems that are considered to be high risk or operationally critical.

HAZOPs are in progress for the critical systems at ISP. Critical systems are defined as any system considered to be high risk or operationally critical and includes any system covered under PSM. Systems identified as critical systems at the ISP Facility include liquid hydrogen, liquid oxygen, and steam ejector systems. The HAZOP methodology reviews the process in-depth and analyses potential deviations, safeguards, and risk.

A team of employees participate in the preparation of new PHAs and review of existing PHAs prior to start-up of operations involving the covered process. tabletop reviews were adopted at the facility to allow for collaboration among the various stakeholders in the process, such as the engineers, technicians, and safety. Findings and recommendations that result from the team review are recorded and dispositioned prior to on-site delivery of the process commodity.

PHAs for the facility systems are maintained through the system pages on the Wiki with a 3-year review cycle per the Glenn Safety Manual (GSM) [5] and are accessible to all PTC personnel.

4.5. Operating Procedures

ATF utilizes checksheets as an equivalent to operating procedures. Checksheets for covered processes at ISP were updated to include the proper steps and information listed per PSM requirements, including PSI, emergency shutdown and operations specific to the procedure, and start up following an emergency shutdown. Checkouts for safety and control systems, specifically those that are safety critical, were completed through checksheets prior to the on-site delivery of the commodity. To encourage employee participation, tabletop exercises were utilized when developing and reviewing the checksheets identified for covered processes.

A Checksheet Dashboard was developed on the Wiki, which shows the active and non-active checksheets and their signatory status. Reviews are completed annually through the Wiki and signatures are collected electronically. Once the checksheets related to operation of the covered process were approved, training was provided on the specific steps, emergency procedures, and operations of the process.

4.6. Training

All employees involved with the process are provided with the appropriate training based on the job description and requirements. System Managers are responsible for developing training programs and requirements for qualified operators. Qualifications are based on the operator’s completion of the various training requirements identified by the System Manager. Additional training on the hazards and exclusion zones is provided to employees at the facility and on-site at ATF by the System Manager on an as-needed basis.

4.7. Contractors

Contractors are selected through a source selection process. Quarterly evaluations are completed on the contract to ensure that the Contractor is fulfilling their obligations. Part of those obligations include following the PSM procedures and protocols put into place by NASA. As ISP continues to work towards long term compliance, the Contractor on-site is included in discussions relating to PSM as part of employee participation.

Baseline hazard communication training was provided to Contractor employees on-site at ATF prior to the delivery of the commodity on-site. The training provided an overview of the hazards and protocols in place for the use of liquid hydrogen.

4.8. Pre-startup Safety Review
The ISP Facility utilizes Operational Readiness Reviews (ORR) as a final check prior to starting testing as a way to ensure that documentation is in order and hazards are appropriately mitigated. PSM requires a Pre-Startup Safety Review (PSSR) to confirm that construction and equipment meets design specifications, procedures are in place and adequate, the PHA is completed and recommendations and/or MOC have been resolved and implemented, and training has been completed. GRC decided to utilize the ORR team as the PSSR team as well. A PSSR form was created and available for use to guide the PSSR/ORR team during the review.

Training was provided to the ORR team, which included a general overview of PSM as well as details on what was expected during the PSSR.

4.9. Mechanical Integrity

Mechanical integrity refers to the maintenance, inspection and testing of equipment to ensure quality and functionality. ISP utilizes a wide variety of pressure vessels, pressure systems, controls, and electrical systems to operate, so it is important to test programs that the facility and its equipment operate as expected.

NASA GRC has a Pressure Systems Office (PSO) that certifies and completes inspections and Non-Destructive Evaluation (NDE) on Pressure Systems and Vessels (PVS). Records of certification and inspections are maintained by the PSO. Pressure system engineers complete a risk assessment of the PVS, which includes calculations relating to remaining life, relief valve capacity, and any additional areas that require further review.

Maintenance plans are currently being developed to ensure that the system and components are appropriately inspected and maintained based on recognized and generally accepted good engineering practices. The plans apply to the fluid, exhaust, and control systems at PTC. Work orders are generated through a Computerized Maintenance Management System (CMMS) to ensure that inspections and preventative maintenance are completed within the required time frame. An important piece of mechanical integrity is records for verification and validation. Inspection records are kept in the CMMS to document the inspection findings and any recommendations. The recommendations are developed into actions that are tracked to completion on the facility Wiki.

The system safety systems are an important part of testing and mitigating risk, so assuring that the controls and safety systems are operating properly is important. Checkouts of the safety systems are completed prior to commencing testing through a checksheet.

4.10. Hot Work Permit

ATF complies with the GRC’s policy on Hot Work Permits, which is compliant with OSHA and with the PSM requirements.

4.11. Management of Change

The ISP Facility previously utilized a GRC Squawk Sheet for documenting discrepancies during test operations. The squawk sheets were maintained in a binder in the control room, where anyone on the team could log a discrepant condition, which were then transferred into an electronic form at the end of each test shift. The Squawk Sheet was used as an interim method for documenting non-conformances, but ISP recognized that a more robust method for capturing, categorizing, and dispositioning discrepant conditions across the facility was necessary.

PTC developed a MOC Plan to capture the applicability of the MOC review as well as PTC’s approach and process. A wiki-based form was developed that includes the appropriate considerations such as the technical basis and impact of the change. The Wiki logic ensures that the appropriate personnel review the proposed change for approval prior to implementation. The forms are recorded electronically within the Wiki. In order to track the status of submitted MOC’s, a MOC Dashboard was developed on the Wiki that identifies the status of the MOC, including submitted, approved and in-work, complete, or withdrawn.

4.12. Incident Investigation

ATF complies with NPR 8621.1, NASA Procedural Requirements for Mishap Reporting, Investigating, and Recordkeeping [6], and the Mishap Preparedness and Contingency Plan for GRC. NASA GRC conducts mishap investigations in accordance with these procedures. The procedures are compliant with the PSM requirements for incident investigation.

The NASA Mishap Information System (NMIS) is used at GRC to report and record mishap details. The system is used to document details, resolution and corrective actions relating to the mishap or close call. In addition, PTC developed a tool on the Wiki to upload any lessons learned with details of the event and resolution.

4.13. Emergency Planning and Response

Portions of this element existed at ISP, but the documentation was not located in one central location. In order to ensure that the emergencies were captured and easily accessible to employees, an Emergency Action Plan was developed. Emergency procedures based on the hazards of each system were created and
added to the plan. A team of System Managers and Engineers met to review the procedures and the Environmental, Security, and Safety and Health disciplines reviewed the plan as well.

4.14. Compliance Audits

An internal assessment was completed by the GRC Safety and Health Division to assess compliance and identify any remaining gaps. The assessment identified three elements with minor non-compliance, which included the PHA, Mechanical Integrity, and Training. The residual risk of non-compliance was presented to GRC Management, with long term actions identified relating to these elements. GRC determined that the risk was acceptable, with the follow-on actions captured. The facility is continuing to work towards closure of the actions.

In order to assess compliance quarterly, a Compliance Tracker tool was developed in the Wiki. The tool illustrates the gaps remaining as a snapshot in time and highlights each of the 14 elements and their status relating to long term PSM compliance.

4.15. Trade Secrets

PSM Policy within the GSM contains information for trade secrets. The PTC Wiki is a central location of documentation and allows Sensitive data to be posted as only NASA employees can access the site or a special request must be submitted.

4.16. GRC PSM Policy Development

A Policy was developed and added to the GSM specifically to address the requirements of Process Safety Management at GRC. The Policy addresses each of the 14 elements of PSM and references the applicable safety and health programs already developed at GRC, such as safety permits for facilities and testing, hot work permits, and lockout/tagout.

5. FUTURE PLANS

ATF is continually working towards closing the gaps identified to reach long term compliance with PSM. Several initiatives are either in progress or planned at ATF, including policy and program development. The goal is to achieve long term compliance with PSM.

5.1. Employee Participation

The Employee Participation Plan will be maintained on the Wiki. Updates will continually be made to the plan to ensure that it is accurate. The plan is accessible, and employees will be made aware of any changes to the plan.

5.2. Process Safety Information

System Managers will continue to update and maintain facility PSI on the Wiki system pages. While not all of the systems at ISP fall under the requirements of PSM, the System Managers concur that it is a good practice to adopt defining the facility PSI as it influences the PHA, operating procedures and mechanical integrity of the systems.

The Wiki will also be used to capture test-specific PSI. Currently, there is not a way to formally capture this information. A form will be developed on the Wiki, which will record the information electronically. The test-specific PSI will be important for Facility preparation for upcoming test programs to ensure that the facility’s processes are adequately designed and maintained, and the risks are mitigated.

A System Manager Policy for ATF is under development. The Policy will define the roles and responsibilities of the System Managers and reference what is required per PSM for covered processes.

5.3. Process Hazard Analysis

ATF will continue to utilize the two methods of PHAs, which are a hybrid of the What-If and Checklists and HAZOP. Other PHA methods may be adopted, as applicable to the process. HAZOPs will be completed for the critical systems at ISP and be uploaded to the Wiki as controlled documents. The Wiki includes a feature to apply review cycles to the controlled documents and PHAs to ensure the documents are reviewed and revalidated every 3 years.

A HAZOP Methodology is being developed to capture when a HAZOP should be completed for a process as well as how to perform a HAZOP, including required team members and the process used at ISP. Appropriate PHA training will be provided to the team prior to starting.

Future discussions on how PHAs will be captured are
planned. The current options include a developed template or PHA software.

5.4. Operating Procedures

ISP will annually review and revalidate the checksheets for covered processes under PSM. The Wiki logic developed in the Checksheet Dashboard includes a review cycle and signature requirement for hazardous operations, which will ensure that adequate review is completed. Any updates or changes will be captured as a change request through the Wiki, which requires approval prior to implementation. Employees whose work tasks will be affected by the change will be notified of the updates to the checksheets.

A Knowledge Management System (KMS) Managed Work Instruction Development and Execution Policy is in progress for ATF. The Policy discusses the three different types of work instructions, including Facility Checksheet, Facility Procedure, and Facility System Manual, and how to develop and execute the work instruction. The intent of the policy is to ensure consistency among all of the facilities at ATF. As the Policy is developed and revised, certain elements of PSM may be added as applicable.

5.5. Training

Certain elements related to training exist at ATF; however, the facility recognizes the need for a more defined policy for a Qualified Operator Program. A working group has been created at ATF with a focus to develop and document a facility-wide Qualified Operator process.

System Managers have the capability to utilize the Wiki system pages to document the requirements for training related to operating and maintaining a system. As the policy related to Qualified Operators is developed, the Wiki will become a useful tool in documenting training requirements and identifying qualified operators.

5.6. Contractors

ATF will ensure that PSM requirements are incorporated into future contracts, as applicable, to the obligations defined.

5.7. Pre-startup Safety Review

Future PSSR teams will be provided with training related to PSM as well as the requirements specific to a PSSR. The PSSR form developed will continue to be used and records will be kept in the Wiki under the test programs. Depending on the complexity of the test program, external resources may be brought in to be part of the PSSR to ensure adequate review of the documentation and training provided, including PHA, checksheets, and maintenance.

5.8. Mechanical Integrity

Maintenance and inspections are important to the on-going integrity of the systems at the ISP Facility. System Managers are working on developing Maintenance Plans for each of the systems at ISP to capture the maintenance and inspection requirements. The Maintenance Plans will be uploaded to the Wiki and used as a guide for ensuring that preventative maintenance and inspections are completed in accordance with applicable Codes and Standards. Maximo is currently used to record the preventative maintenance and inspections completed.

5.9. Hot Work Permit

ATF will maintain compliance with the GRC’s policy on Hot Work Permits, which is compliant with OSHA’s Regulatory Permit Requirements and with the PSM requirements.

5.10. Management of Change

The initial MOC Plan released is being developed into a more defined process. The document will be used as guidance on the PTC Wiki MOC page to help employees with creating a MOC.

The Wiki will continue to be utilized and developed for MOC submissions and review. The logic set-up within the Wiki will help ensure that the MOC process is followed at ISP.

5.11. Incident Investigation

ATF will maintain compliance with NPR 8621.1, and GLSBU 8621.1, Mishap Preparedness and Contingency Plan for GRC.

5.12. Emergency Planning and Response

The ISP Emergency Action Plan (EAP) will be maintained, revalidated, and updated, as needed, using tools on the Wiki. The controlled document will be on an annual review cycle. Future policy related to the EAP will be developed to ensure the electronic and printed copies in the facility are accurate. The policy will define the roles and responsibilities related to the EAP, including the EAP Coordinator who ensures the plan is revalidated annually by the System Managers and updates the relevant sections, as needed, and the System Managers who will work with the EAP Coordinator to update their specific system emergency procedures within the plan. Future discussions are planned for
developing a centralized Emergency Action Plan at the other facilities at ATF.

5.13.  Compliance Audits
As the non-conformances identified by the gap analysis continue to be closed, internal assessments will be completed by the GRC Safety and Health Division. The Compliance Tracker tool within the Wiki will capture a snapshot of the compliance status with PSM at ISP.

The PSM Regulation requires a compliance audit a minimum of every 3-years. Once GRC Management agrees that ISP has reached PSM compliance, the clock will start towards the 3-year audit. An external resource is planned to be brought in for the audit.

5.14.  Trade Secrets
For future test programs with trade secrets, the Process Owner and GRC’s Office of Protective Services will determine applicability of trade secrets and proprietary or classified information to covered processes and how process information will be provided to employees, as needed to meet the requirements of PSM. The Wiki is capable of providing tools for future test programs with trade secrets.

5.15.  Future ATF Policy Development
ATF Management recognizes the importance of capturing how ATF complies with and applies the PSM requirements. The PSM Working Group has started identifying the content for a policy of how ATF complies with the GSM Process Safety Management chapter. As ATF continues to develop processes and programs, the policy will be utilized to capture the initiatives and ensure that the processes and programs are implemented across ATF for covered processes.

6.  SUMMARY
Through use of established PSM processes and innovative web-based Wiki document management solutions, the ISP Facility at Armstrong Test Facility is minimizing risk to personnel, facility, and test articles. This reduction of ground test risk directly correlates to spaceflight risk reduction.

7.  ABBREVIATIONS AND ACRONYMS
CFM  Cryogenic Fluid Management
CFR  Code of Federal Regulations
CMMS  Computerized Maintenance Management System
CoFR  Certificate of Flight Readiness
EAP  Emergency Action Plan
EPP  Employee Participation Plan
GLP  Glenn Procedure
GRC  Glenn Research Center
GRC-ATF  GRCs Neil A. Armstrong Test Facility
GSM  Glenn Safety Manual
HAZOP  Hazard and Operability study
ISP  In-Space Propulsion (ISP) Facility
KMS  Knowledge Management System
MOC  Management Of Change
NDE  Non-Destructive Evaluation
NMIS  NASA Mishap
NPR  NASA Procedural Requirements
ORR  Operational Readiness Review
OSHA  Occupational Safety & Health Admin
PHA:  Process Hazard Analysis
PSI  Process Safety Information
PSM  Process Safety Management
PSO  Pressure Systems Office
PSSR  Pre-Startup Safety Review
PTC  Propulsion Test Complex
PVS  Pressure Systems and Vessels
SBU  Sensitive But Unclassified
SIR  System Integration Review

8.  REFERENCES