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Applying the Systems Engineering Process for Establishing Requirements for the Safety and Health Monitoring System of the Waste Solidification Building at the Savannah River Site

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Abstract

The Safety and Health Monitoring (SHM) System technical basis document for the Waste Solidification Building (WSB) was developed by Systems Engineering with the integrated efforts of the WSRC Health Physics Technology (HPT), Design Authority, and the Design Team. The WSB is being designed and built to support the waste disposal needs of the Pit Disassembly and Conversion Facility (PDCF) and the Mixed Oxide Fuel Fabrication Facility (MFFF) at the Savannah River Site (SRS) in South Carolina. The main mission of the WSB is to process the radiological liquid waste streams from the PDCF and the MFFF into a solid waste form. The solid waste form, concrete encased waste, will be acceptable for shipment and disposal as transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, and as Low Level Waste (LLW). The SHM System will also monitor the job control waste from the PDCF, the MFFF, and the WSB. The SHM System will serve to monitor personnel radiation exposure and environmental releases. The HPT design serves as the basis for determining the air monitoring equipment required for the WSB. The Systems Engineering (SE) process was applied to define the functions and requirements necessary to design and operate the SHM System. The SE process is a proven disciplined approach that supports management in clearly defining the mission or problem, managing system functions and requirements, identifying and managing risk, establishing bases for informed decision making, and verifying that products and services meet customer needs. Applying the SE process to the SHM System was a major effort encompassing both Requirements Analysis and Interface Control. Use of the SE process combined with HPT design input resulted in requirements to support the procurement of a well-defined SHM System.

Key Words: System, Design, Monitors

Introduction

The Systems Engineering (SE) process at the Savannah River Site (SRS) has been developed through the partnering with industry leaders and site applications. The Waste Solidification Building (WSB) encompassed all the aspects of the SE process. The Safety and Health Monitoring (SHM) System is one of twenty systems that supports the WSB. The SHM System relied heavily on the Health Physics Technology's (HPTs) supporting documentation to define the requirements developed while using the SE process.

The SE process begins with the upper tier functions in the Facility Design Description (FDD) and traces the Functions and Requirements (F&Rs) through the System Design Descriptions (SDD) to the component requirements. This SE process was applied at the beginning of pre-conceptual design and continues to this day during the Final Design phase of the project. The FDDs, SDDs and baseline documents are updated on a regular basis as the design progresses. The information provided to explain the WSB, SHM System, and SE process was extracted from documents not releasable to the public so they are unable to be referenced.

Plutonium disposition Projects

The SRS plutonium disposition projects encompass the design and construction of a number of new facilities for handling, processing, and disposition of weapons grade plutonium. Immobilization will be accomplished by two facilities – The Pit Disassembly and Conversion Facility (PDCF) and the Mixed Oxide Fuel Fabrication Facility (MFFF). The PDCF will receive surplus weapons plutonium oxide for transfer to the MFFF. The MFFF is for fabricating mixed oxide fuel for commercial nuclear reactors. The WSB will serve to process and solidify this nuclear waste expected from PDCF and MFFF.

The location of these facilities is important to define because it determines design constraints (requirements) that will be imposed on these facilities and the SHM System. The SRS is a 300 square mile reserve located on the south side of South Carolina along the Savannah River near Augusta, Georgia.

The WSB will be built on the east-side of F-area in same the proximity of the PDCF and the MFFF.

Systems Engineering Process

The SE process is a method of program/project management. The SE process focuses on defining customer needs and required functionality early in the program/project development cycles, documenting and validating requirements, and then proceeding with solution synthesis and verification while considering all aspects of the solution through operation and decommissioning. The approach can be applied to any task regardless of size, complexity, risk or duration.

In essence, the process follows a simple, logical approach consisting of: 1. defining what must be done, 2. defining how well it must be done, 3. evaluating alternative solutions to getting it done, 4. selecting the best solution, and 5. verifying that the solution meets the requirements.

Fig. 1 shows a visual perspective of the SE process. Risk Management for the SE process is defined as a disciplined process for identifying and assessing risk, developing options for handling risk, and tracking risk and risk action item progress.

Mission Definition and Analysis

In order to develop adequate requirements, the mission and objectives need to be defined so that the requirements can be validated. This validation shows that the requirements meet the intent of what the facility was designed to accomplish. A key part of the SE process was being involved early in the design to help establish the overall mission and F&Rs for the WSB. The WSB supports the PDCF project mission, which is to convert surplus plutonium metal to plutonium oxide for conversion to Mixed Oxide fuel to be used in existing commercial nuclear power reactors. The primary mission for the WSB project is to process the following waste streams from PDCF and the [MFFF]:

- PDCF Laboratory Liquid Stream,
- MFFF High Alpha Stream, and
- MFFF Stripped Uranium Stream
- MFFF Drummed TRU Waste, and

- PDCF Drummed TRU Waste.

The liquid streams are processed into solid waste forms acceptable for shipment and disposal as transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP) and as low level waste (LLW). The drummed TRU waste is loaded into Transuranic Packaging and Transporters (TRUPACTs) and shipped to WIPP.

The objectives of the WSB were defined by the customer, National Nuclear Security Administration (NNSA), and have been incorporated into the FDD upper level functions. As part of the plutonium disposition mission at the Savannah River Site (SRS), the WSB will process the three PDCF and MFFF liquid waste streams into a solid waste form. The waste streams will enter the WSB via dedicated underground transfer lines from their respective facilities. The solidification process employed by the WSB will be a cementation process for the waste streams. Following waste stream preparation, the waste is mixed with a cement-like additive (dependant on stream) and solidified. Cementation was chosen following a Technology Selection Study, performed early in the Conceptual Design. The WSB is being designed in accordance with Resource Conservation and Recovery Act (RCRA) requirements and constraints, but it is anticipated that the WSB will be able to operate under a waste water treatment permit. A graphic representation of the WSB process is shown in Fig. 2. The SHM System supports the WSB design by providing radiological monitoring, personnel contamination monitoring, personnel dose monitoring and an office/laboratory for measuring and decontamination.

F&R Analysis and Allocation

The F&R analysis involves the breaking down of functions into a hierarchy of functions and sub-functions until discrete tasks can be defined and related to mission originating requirements. Functions and sub-functions are allocated to the systems, structures, and components. Also as part of this step:

1) Performance requirements are identified and allocated to functions,

2) Design constraints are allocated to systems, structures, and components, and

3) Interface requirements are identified for system to system interfaces. External interfaces to the facility are a major input to this step.

Upper Level Functions

Once the mission is defined for the facility, functions are developed and documented in the FDD document. The top facility level functions and the customer objectives for the WSB are flowed down to the system level. The SHM System SDD documents all the functions that are performed by the SHM System. The SHM System is linked to the FDD by the following function:

F.1 Provide Radiological, Safety and Health Monitoring

Monitor radiological and non-radiological safety and health parameters for worker protection.

The rest of the functions for the SHM System flow from this upper tier facility function.

Hierarchy

The functions in the FDD were separated into hierarchies and decomposed if further definitions of the function were needed. The functions of the FDD were then transferred to each SDD to further develop the functions to the component level.

Requirements

The tracing of the F&Rs is presented from the FDD functions, through the SDD functions, and includes the SDD requirements. The requirement statement is where HPT supplied the most support. The performance requirements for the monitoring functions utilize the HPT document, WSRC-IM-2001-00001 (Burger 2001). The requirements in this document are invoked by the performance requirement statements. The functions and performance requirements of the SHM System that relate to the HPT are:

F.1.1 Monitor Radiological Parameters

F.1.1.1 Monitor Airborne Radiological Concentrations

Provide radiological air monitoring for areas in the WSB and exhaust streams where there is a potential for airborne radiological concentrations.

R.1.1.1.A Portable alpha Continuous Air Monitors (CAMs) shall meet the performance requirements in WSRC-IM-2001-00001 (Burger 2001), Chapter 7, Item PCAM-001, Sections 3.1 & 3.2.

Basis: Ensures CAMs will perform as needed, be approved for use, be compatible with and be maintainable within the SRS Radiological Monitoring Equipment (RME) program, and meet the requirements of 10 CFR 835. (Code 2003a)

Sample requirements from WSRC-IM-2001-00001 (Burger 2001) that relate to CAM detectors are:

- Passivated Implanted Planar Silicon
- Active area: 1700 mm^2
- Resolution of approximately 450 KeV (^{239}Pu)
- Alpha detection efficiency greater than 25% (4 pi)
- Sensitivity of 8 DAC-hr for ^{239}Pu (laboratory conditions)

Other requirements in WSRC-IM-2001-00001 (Burger 2001) that relate to CAMs define: multi-channel spectrum, airflow rates, calibration capability, alarms, control unit data display, and code compliance.

R.1.1.1.B The exhaust stream shall be continuously monitored by instrumentation that meets the performance requirements in HPS ASC N13.1 and 40 CFR 61 Subpart H. (Code 2003b, Health 1999)

Basis: Compliance with Environmental Protection Agency requirements. Monitoring based on calculations (un-releasable calculations).

F.1.1.2 Monitor Area Radiation Dose Rates

Monitor radiation dose rates in areas normally accessible by personnel with the potential for radiation.

R.1.1.2.A Similar requirement and basis to R.1.1.1.A, but refers to installed (neutron, gamma) Area Radiation Monitors (ARMs).

Sample requirements from WSRC-IM-2001-00001 (Burger 2001) that relate to ARMs are:

- Accuracy: + or – 10%
- Operating Temperature Range: -30°C to 60°C and humidity range: 20% to 99% non-condensing.

F.1.1.3 Monitor Contamination Level

Monitor personnel for radiological contamination in transition areas from the Contamination Area to Radiological Buffer Area (RBA) and from RBA to clean areas.

R.1.1.3.A Similar requirements and bases to R.1.1.1.A, but refer to Automated Personnel Contamination Monitors (PCMs).

Sample requirements from WSRC-IM-2001-00001 (Burger 2001) that relate to PCMs are:

- Efficiency: (2 pi) ^{239}Pu alpha ~ > 15%, ^{99}Tc beta ~ > 15%
- Sensitivity: < 83.33 bq/100 cm^2 beta, < 8.33 bq/100 cm^2 alpha
- Coverage: Detector coverage of 80% of body, including hands and feet
- Display: Digital or analog with alarm messaging capability

R.1.1.3.B Similar requirements and bases to R.1.1.1.A, but refer to Portable alpha/beta contamination survey instruments. (To save space, no sample requirements are listed here).

R.1.1.3.C Similar requirements and bases to R.1.1.1.A, but refer to Particulate smear analysis equipment. (To save space, no sample requirements are listed here).

Design Requirements

The design requirements help further define the essential features and other aspects of the SHM System. They define the codes that the SHM System must meet and additional individual requirements that define how the SHM System is supposed to operate. Design requirements specify amounts, cycle time, sensitivity, accuracy, and sample types.

Some examples of design requirements that defined the stack monitor were:

R.1 Representative samples of airborne radioactive particulate effluent released from the stack shall be collected for analysis.

Basis: To confirm compliance to air emission permit.

R.2 Flow through the stack particulate monitor shall be manually adjustable between 1.4 x 10^{-3} and 2.4 x 10^{-3} m^3/s.

Basis: Required to provide a representative air sample.

Alternative Solutions & Evaluations and Selections

Alternatives to the design were discussed during pre-conceptual design. The facility design was documented in the conceptual design report. During preliminary design studies were also conducted to formulate alternative designs of the components.

The SHM System was supported by WSRC-IM-2001-00001 (Burger 2001) and therefore all the alternatives were already defined and thoroughly verified, so that the monitors would function for the needs of the WSB.

Validation and Verification

Validation of the WSB design is performed to determine if the requirements adequately satisfy the user's needs. The validation portion was accomplished by a formal design review at the end of preliminary design. A team of subject matter experts, which included specialists from HPT, was formed to review the complete design at defined intervals to determine if the preliminary design met the intended mission.

Verification of the design is performed to determine that the design satisfies the requirements. The verification portion will be accomplished by developing a traceability matrix and supported by design reviews (internal and external to the team). The matrix will be developed during final design and will link all the requirements defined on the WSB to a design output document, which is the solution to that requirement. These design documents can be drawings, flow diagrams, or specifications.

Interface Control

Interfaces interact with all the steps of the SE process. They have the biggest impact on the F&R analysis and allocation step since defining the interfaces is vital to determining adequate requirements.

The WSB internal system to system interfaces are described in the 20 individual SDDs. The internal interfaces were developed using interface diagrams, captured with interface requirements, and managed within a software program for coordinating the requirements.

The external interfaces are outside the boundary and the direct control of the WSB and some of the interfaces are outside the boundary and the control of the SRS. The SHM System has only internal system to system interfaces.

The SHM System works in conjunction with 5 other systems to accomplish the needs of the SHM System. Fig. 3 shows the interfaces of the SHM System in visual perspective and defines the functions between each system.

Risk Management

The purpose of risk management is to minimize the probability and/or consequence of adverse events, thereby decreasing the likelihood of unanticipated cost overruns, schedule delays, and/or compromises in quality and safety. Risk management is integral to all steps of the SE process. As part of the risk management plan, the SWB design team identified the risks to the project, analyzed those risks, and determined risk handling strategies to reduce, mitigate or avoid the risk. The risk analyses were completed for each project phase and several intermediate parts. This helped the design team to focus their development efforts on the risk that provided the greatest return on safety and cost.

Risk Analysis

The risk analysis process was initiated during the pre-conceptual stage of the project. The risk analysis indicated that the highest risk to the facility was that cementation and process operations are not fully defined and may require additional worker protection features for Alpha confinement/shielding. The design team established a working relationship with the HPT to support a safe operational design that would provide As Low As Reasonably Achievable (ALARA) requirements. This handling strategy will reduce the risk by performing a facility dose assessment early in Final Design.

Conclusion

The SE process successfully implemented all the aspects of defining the mission, allocating the F&Rs, determining alternative solutions, and verifying the design of the WSB. The completion of the preliminary design of the SHM System resulted in the approved locations for the monitors in the WSB as shown in Fig. 4. By using the SE process combined with the expertise of the HPT the following observations were made:

- The implementation of the SE process is helping the WSB design meet the specified mission.
- Up-front F&R analysis and risk management work to design a feasible facility.
- The WSB design team was able to design a functional solution using an adequately developed set of requirements.
- Through implementing the risk handling strategy of working with HPT a safe operational design was created.
- By developing the SHM SDD, the WSB design team was able to produce and document a radiologically sound design to support ALARA concepts.

The SE process gave a coordinated disciplined process to define the customers needs and developed a path to provide a solution to the needed requirements. The advantages of the SE process far outweighed the cost of implementation and with the help of HPT the process assured a functional design.

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Fig. 1. System Engineering Process

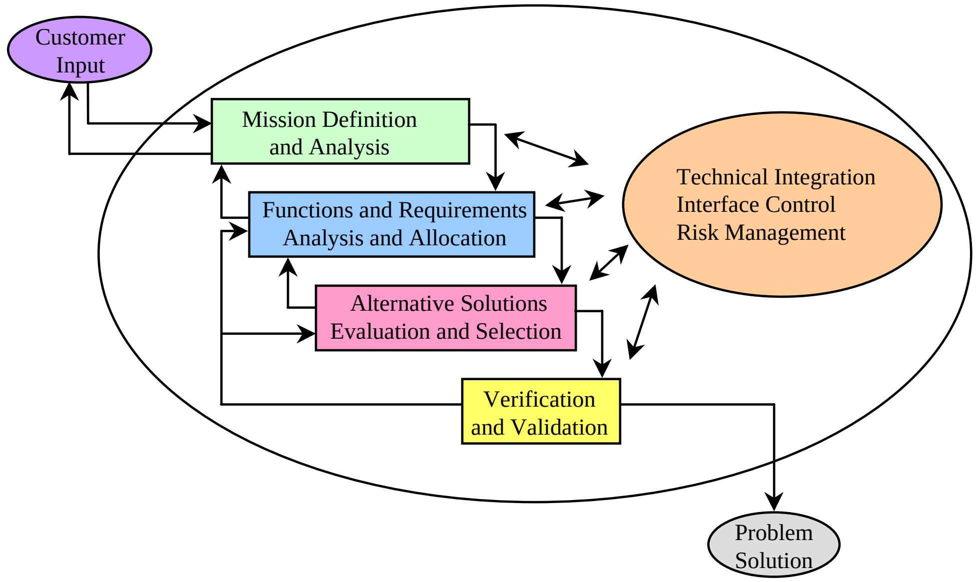


Fig. 2 Waste Solidification Process

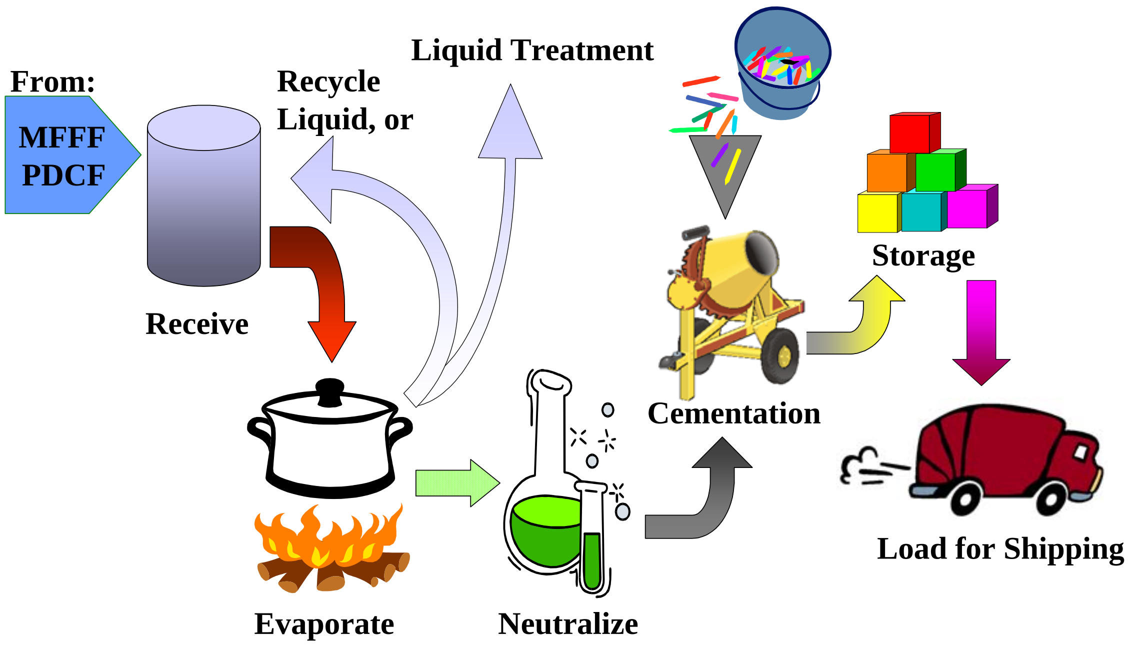


Fig. 3 Interfaces of the SHM System

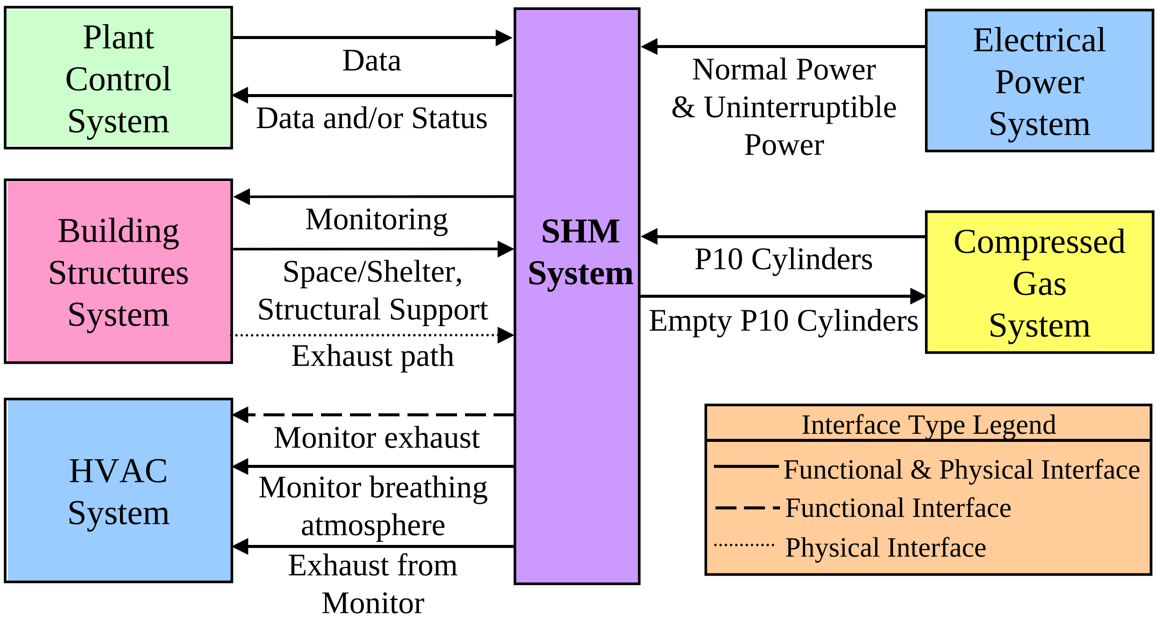
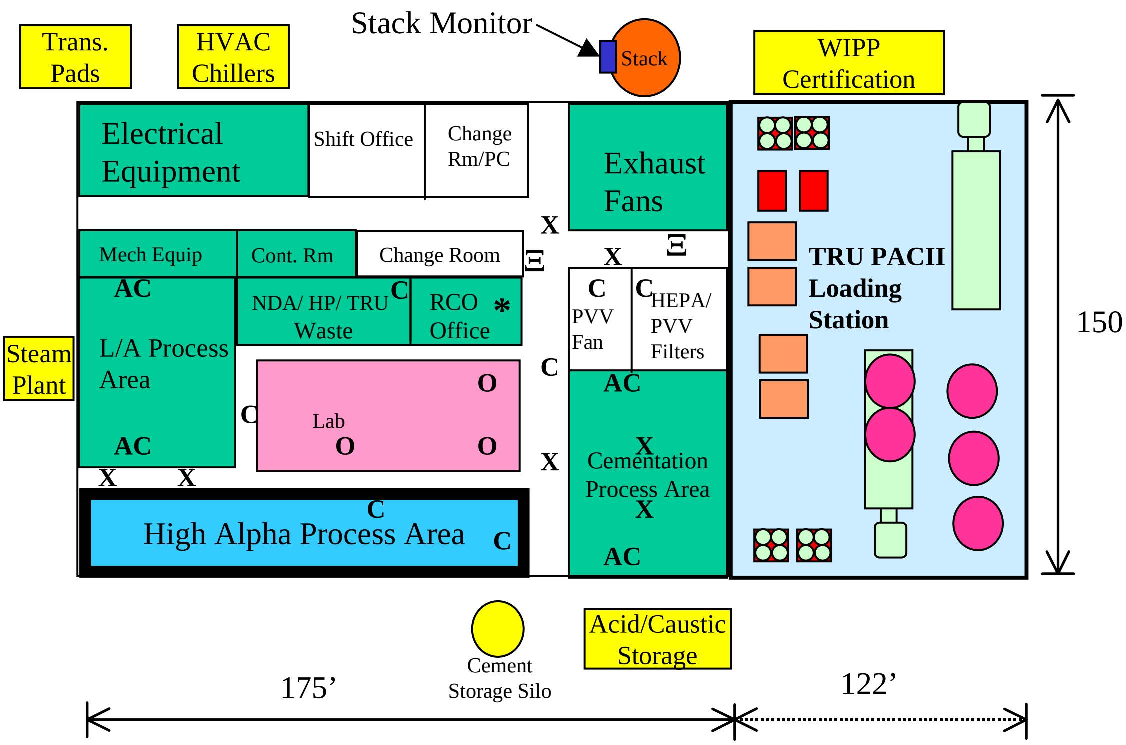


Fig. 4 WSB Monitor Locations



Key	
C - CAM	X - Count Rate Meter
A - ARM	O - Sampling Head CAM
Ξ - PCM	* - Count Meter