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Integrating the Life-cycle Process Utilizing SysML

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Abstract. Sandia National Laboratories is developing and applying an Integrated Phase Gate (IPG) project structure to execute critical programs such as nuclear weapon Life Extension Projects (LEP) that require the utmost attention to reliability, function and other stakeholder requirements including safety and security. This emphasis on project rigor reflects a new directive from the Department of Energy's National Nuclear Security Agency (NNSA) to develop robust processes in order to ensure that the nation's nuclear deterrence will be effective and available for decades to come. To this end, Sandia's Advanced and Exploratory Systems Department is developing a SysML model of an integrated Product Lifecycle Management (PLM) environment with the intent of providing project teams with direct access to program templates, requirements, tools (both program and technical) and related databases. This paper will describe the current state and future direction of the integrated PLM environment SysML model.

Introduction

The National Nuclear Security Administration (NNSA), a separately organized agency within the Department of Energy (DoE), has responsibility for the management and security of the nation's nuclear weapons. Several national laboratories, including Sandia National Laboratories (SNL), are under contract to the NNSA to support that mission. The Sandia National Laboratories are responsible for the development, testing, and production of specialized nonnuclear components and quality assurance and systems engineering for all of the United States' nuclear weapons.

In May of 2006, NNSA established an integrated process team (IPT) across the Nuclear Security Enterprise (NSE) (formerly known as the NWC – Nuclear Weapons Complex) "To design and build the framework that communicates the minimum but essential NWC technical business policies, processes, and standards necessary to operate the NWC resulting in an effective environment to produce and perform Directed Stockpile Work (DSW) activities." (Tasking Memorandum, DoE, April 6, 2006) This tasking letter resulted in the Requirements Modernization and Integration (RMI) Project, that was tasked with building a new business system for the execution of technical programs in support of the NNSA nuclear stockpile mission. Multiple teams were identified to achieve this tasking, with one major area related to the product realization process. This team was tasked to improve the design and development process and was formally named the Integrated Phase Gate (IPG) team. The IPG team developed a set of six phases that consists of phases, tasks, and gates (widely known as decision

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gates). The objectives of the team were to create an improved product realization process that will define the activities required in each phase in the product life-cycle for all technical and programmatic functions.

The implementation of RMI at Sandia involves the Realize Product Sub-System (RPSS), which is a subset of the Nuclear Weapons Management System that is schematically depicted in Figure 1. The RPSS is represented in Figure 2 with the Product Design and Develop role expanded to reveal the underlying Integrated Phase Gate (IPG) program structure.

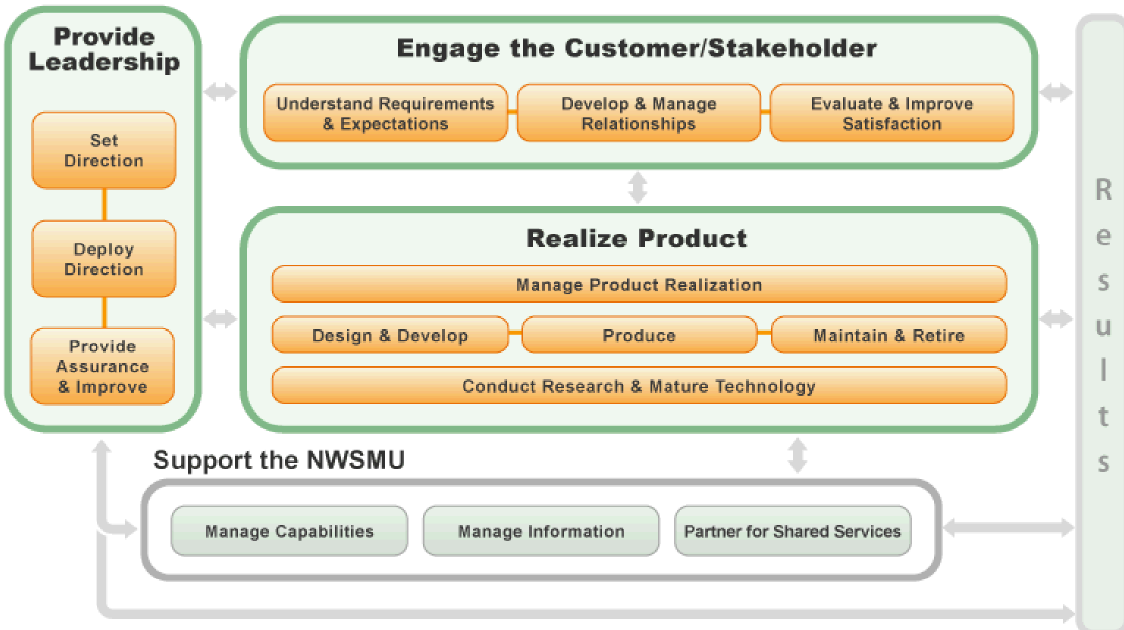

Figure 1. Enterprise Model for Nuclear Weapons Management

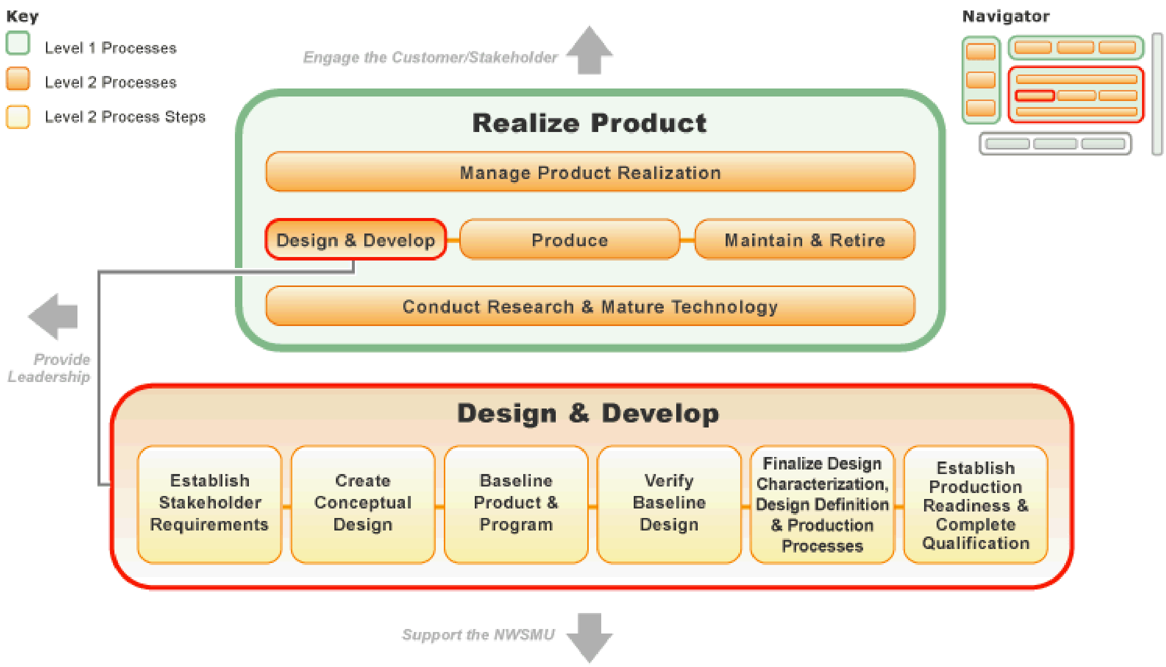

Figure 2. RPSS showing Integrated Phase Gate for "Design and Develop"

The IPG structure is a formal management construct comprised of six gated phases, which maps directly into the commonly accepted "V" model for systems engineering of products. The basic IPG construct is intended to be applied at each hierarchical level of system development including the subsystem and component elements as seen in Figure 3.

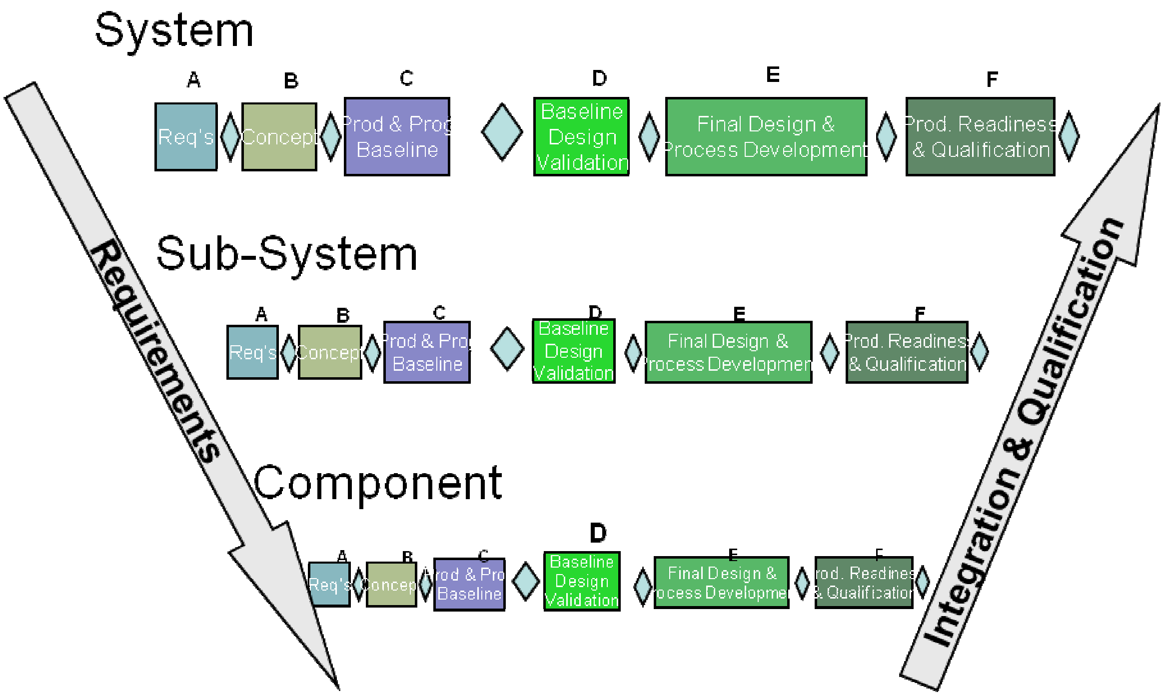

Figure 3. V-model Overlay with IPG at the System, Subsystem & Component Level

An earlier paper (Product Life-Cycle Modeling Utilizing SysML Modeling, IS2008) provided a structured model for defining and implementing the Integrated Phase Gate processes. Since that time, IPG program execution, at least through the first few gates, has been applied to a few major programs with some variance in rigor and precision. Upon reflection, there has been a realization that the lack of tools, both to guide the program team through the IPG process as well as integrate the product knowledge base across the phases, has been an impediment to efficient and broad adherence to the RPSS and the underlying IPG processes.

While continuity of product information has been problematic across the IPG phases of the "Design and Develop" activity in the RPSS process, there are additional hurdles to overcome as the product lifecycle transitions to the "Produce" and the "Maintain and Retire" phases (Figure 2) that is compounded by the transfer of responsibility for many of these activities to agencies and organizations outside of Sandia, which nonetheless require significant interaction and data exchange with Sandia product groups. Although Sandia has a limited role in actual production (directly responsible for only one major subsystem), for many of the "Maintain" responsibilities (see Fig. 4) Sandia is directly responsible – particularly with regard to assessing and verifying the readiness and viability of the stockpile. Despite ownership of many of the "Maintain" activities, past history has shown a persistent difficulty in "aligning" assessment activities with the pertinent development data.

One of the solutions to managing the project and product data across the lifecycle currently being considered and developed is applying a SysML based integrated development and product lifecycle management (PLM) environment to guide development teams and span the knowledge divides between major phases and activities. This paper will examine how SysML models can be the basis for integrating lifecycle management that, among other features, guides product development teams through the IPG process, while providing templates, guidelines and requirements for completion of critical tasks that are hyperlinked to model elements.

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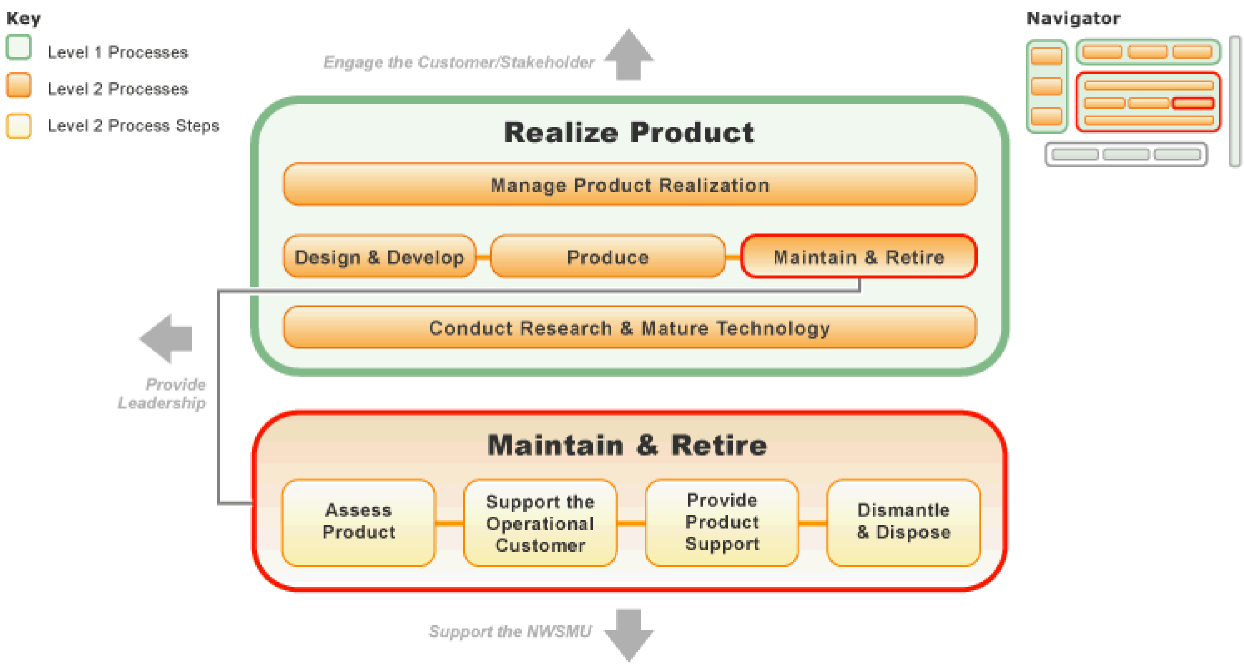

Figure 4. Sandia has a direct role in the first three activities of "Maintain & Retire"

Documenting the Life-Cycle Process

Process Architecture

On-line Database and Web Portals. As illustrated in Figures 1, 2 and 4, Sandia has initiated a significant effort to organize and structure the requirements and process guidelines for implementing IPG and RPSS in particular. The purpose of the SysML model is not to replace the structure and organization that is already in place, but rather to make it more accessible and ordered for the benefit of the working engineer and program teams as well as develop a central access point for all pertinent project information. What is not possible to show is all the depth of the information that currently exists within the system that is accessible via the web based portal. For example, Figure 5 is the portal to the templates, requirements and guidelines associated with Stage A of the IPG process, "Establish Stakeholder Requirements." There are similar sets of documents associated with every "leaf" link in figures 2 and 4, and there are many more leaf links not illustrated in the paper.

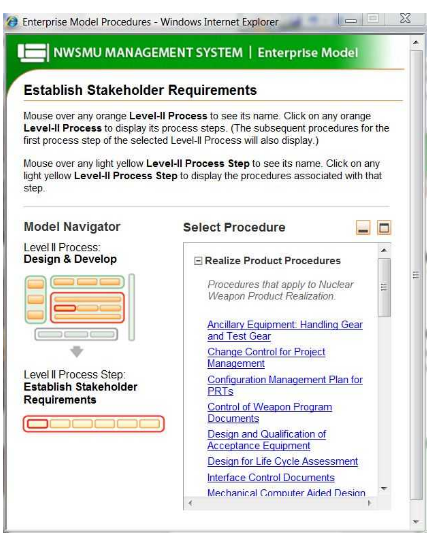

Figure 5: An IPG Web Portal

The advantage, from a modeling perspective, is that much of the underlying work of providing and organizing the knowledge base is done, and the focus now is to enhance the accessibility of that information. What is needed is a means of organizing and linking the documents for each phase of a program into a logical sequence that is readily understandable and immediately applicable.

SysML Model

Objective. If the only objective of the SysML modeling was to make existing data and documents more readily accessible and useable, the project would be relatively straightforward. However, that is only part of the story, to truly transform the development of product and improve both program efficiency and responsiveness to stakeholder needs; a higher level of project data integration is required. Specifically, there are two primary objectives; one is to develop a system in which a data element only needs to be entered once throughout the project lifetime. In current practice, often the same or a very similar data element must be entered independently and repeatedly into various tools and data sets depending on the purpose (technical, design, test, programmatic, documentation, etc.) or the particular point in the project schedule (draft, review, final, revision, etc.). Not only does the repeated manual entry of the same information have the potential of introducing error, but then the need to manually synchronize disparate, but related data sets, becomes an onerous burden to the project, consuming resources that could be better applied elsewhere.

The other objective is to properly relate the various data elements into an interlocking mosaic of mutually supporting data threads that ensure that requirements are understood, applied and realized throughout the product lifecycle from inception through retirement. This requires a sustained continuity not just in the basic data, but also in the relationships between data elements that spans, not just a particular project activity, but for the duration of the product lifetime that can literally span multiple decades for nuclear weapons. Closely related to developing and relating data elements is capturing much of the meta-data including e-mails and other undocumented data elements that often becomes the underlying rationale for critical project and technical decisions.

The steps to building the SysML model or modeling environment, which are done iteratively, in achieving a full specification of the structural and behavioral elements of a project based on the IPG process include:

- Develop a model view into the existing RPSS database
- Construct links into the RPSS and project databases to facilitate a dynamic project environment that is also a common portal into all the project data threads
- Develop supporting tools and model elements to integrate related data elements into a cohesive and mutually supporting whole.

The last objective that envisions a long range goal for project management via an integrated modeling environment is well beyond current capabilities, and will likely take years to achieve, but there are already encouraging developments in this direction. For example InterCAX, LLC has demonstrated that a SysML model can be used to link critical parameters in a system model to a related parameters in a CAD model. Along these lines, Sandia has a contract in place with InterCAX to develop a dynamic interface between SysML and a Sandia developed simulation environment for systems that is also being linked to the stockpile test and evaluation environment. The objective is to achieve end-to-end traceable linkage from initial stakeholder needs to lifetime customer support via a common system modeling environment. The initial phases of this effort will be described later in this paper.

The RPSS Model View. Figure 6 is a model view of the RPSS that is represented in part by figures 2 and 4. While the included image does not have the embedded hyperlinks, every block and note in the original model is linked either to the existing RPSS web portal or to other model elements. To date only the "Design & Develop" block, with the IPG based Stage A through F blocks, is being expanded into other model elements. Therefore, hyperlinks into the existing RPSS web portal occur via the related notes with the html text. For example the note in the upper left corner titled "Establishing Stakeholder Requirements" is a direct link to the portal as seen in figure 5 above. All the blocks in figure 6, with the exception of the six "stage" blocks, links to a specific related page in the online web portal. Figure 7 below is the Stage A activity diagram.

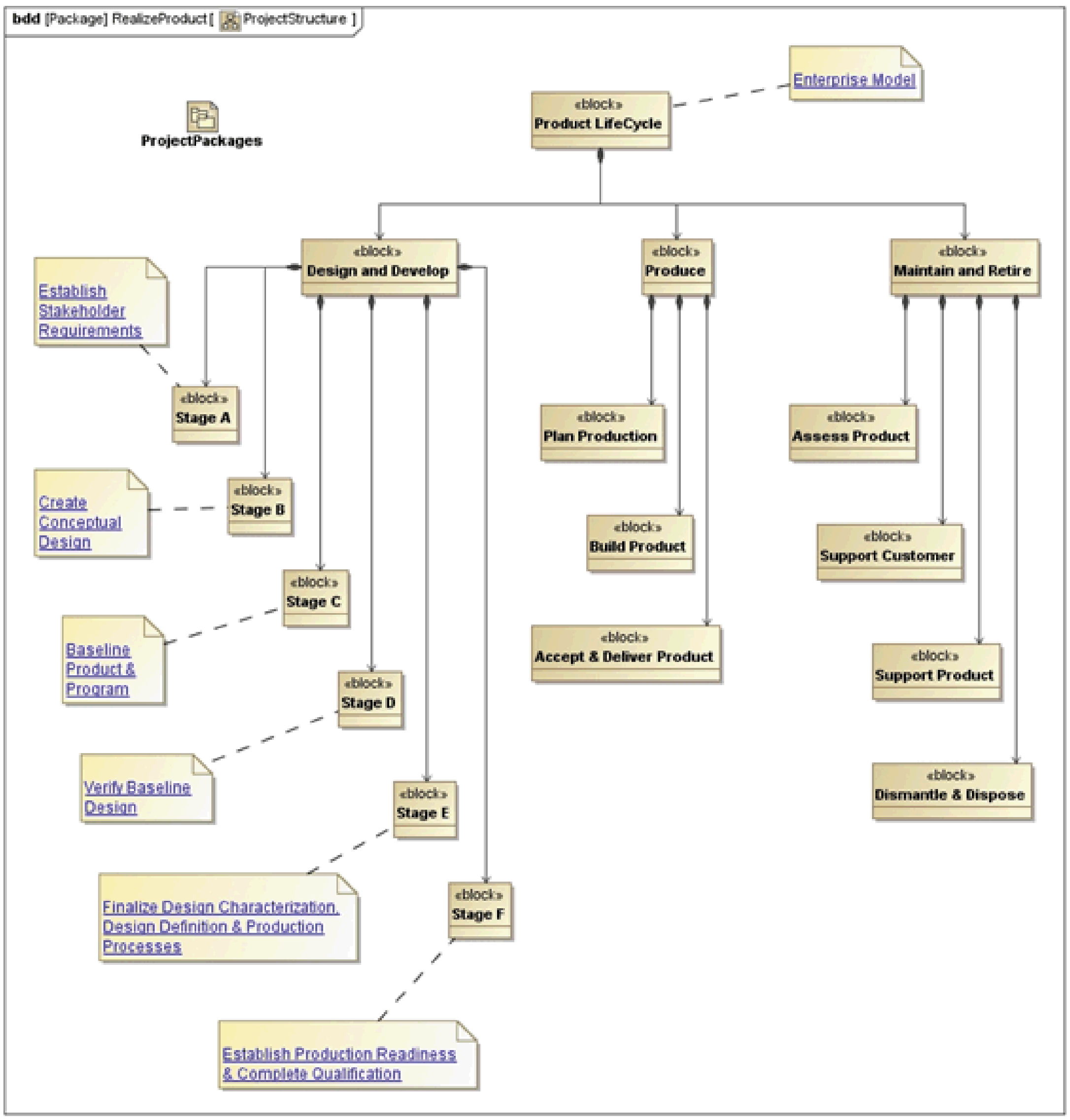

Figure 6: Model View of Online RPSS Web Portal

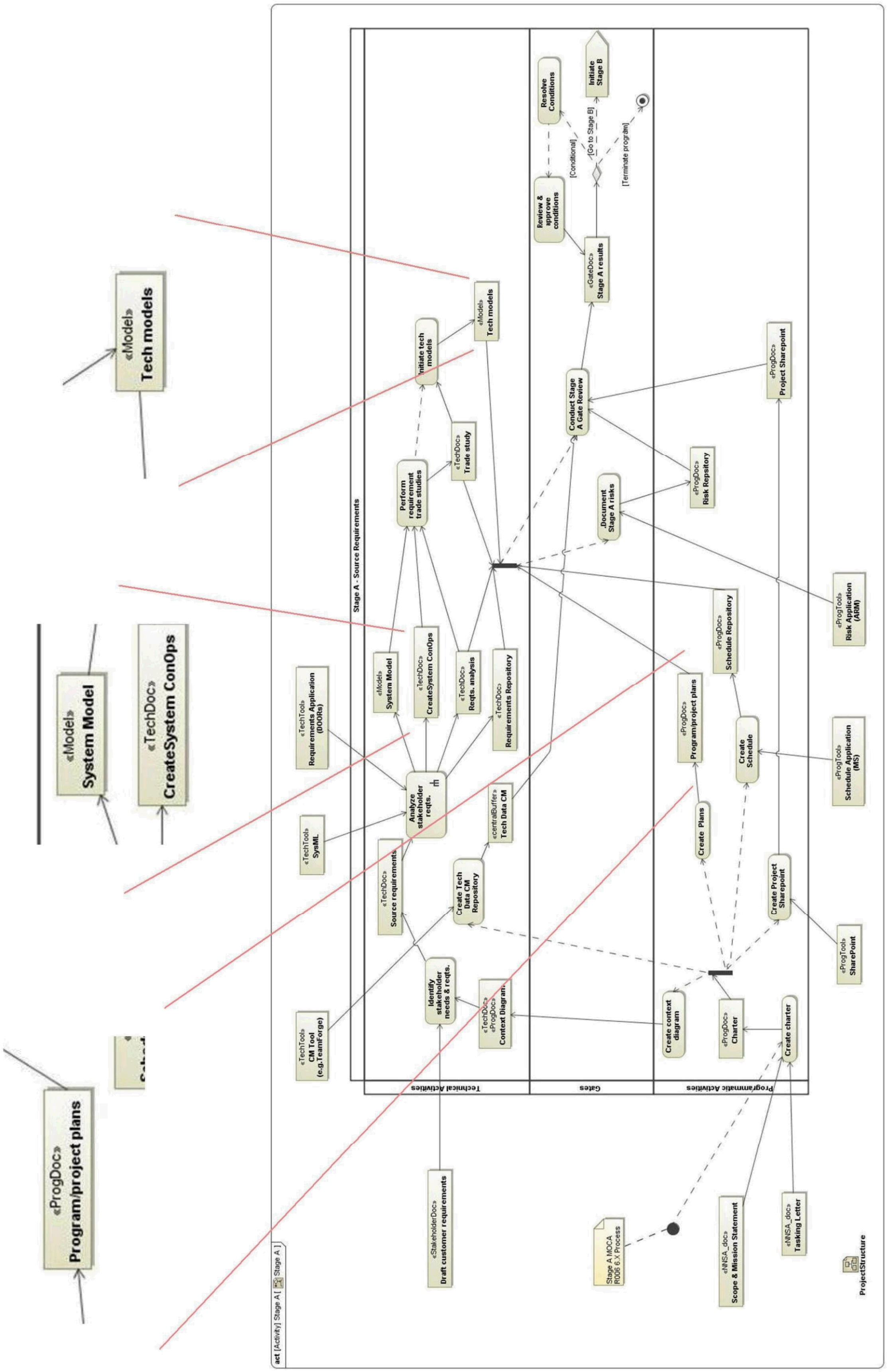

Figure 7. IPG Stage A activity diagram with activities and related hyperlinked artifacts

In the activity diagram of Figure 7 the object nodes are hyperlinked into specific RPSS documents and related project data that is pertinent to Stage A. Tools that are useful for generating and managing project data are also accessed via similar object node hyperlinks. Later in the paper, some of these links will be detailed further.

For clarity, custom stereotypes have been applied to the object nodes to unambiguously identify the type and basic purpose of each of the artifacts produced. You may also notice the "ProjectPackages" icon in figures 6 (upper left) and 9 (lower left) which is a hyperlink to that package diagram (Figure 8) and serves as a navigation aid to maneuver around the model. Where applicable, the packages in figure 8 are hyperlinked to the top level diagram in each folder. Thus the package diagram serves as both a high level structural view of the model as well as an index into the sub elements.

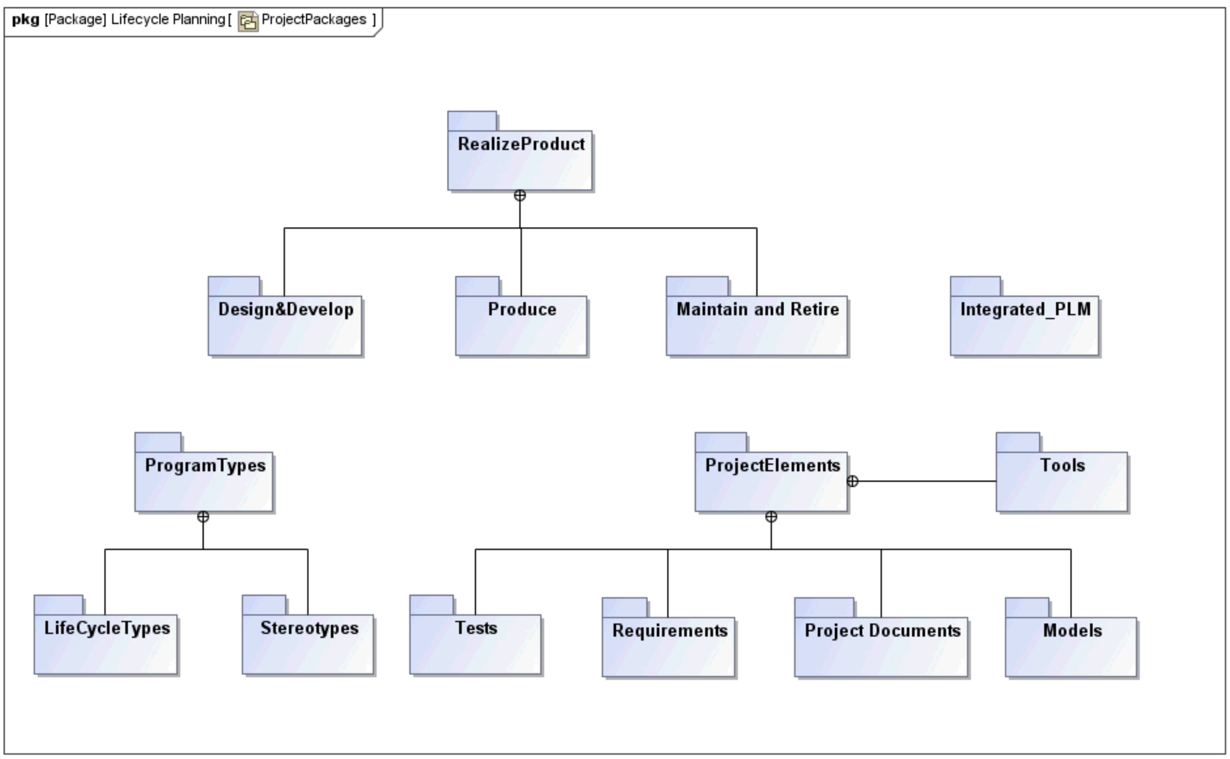

Figure 8. Package layout of RPSS SysML model

Integrated Product Lifecycle Management. The potential of developing an integrated PLM environment was briefly discussed earlier. While the vision would encompass the full breadth of a product's lifecycle, the current focus is much more narrowly scoped in order to demonstrate a proof-of-principle that is nonetheless beneficial to project execution. In figure 8 one of the packages is labeled "Integrated_PLM," but before diving into that path some background explanation is in order.

In the activity diagram of figure 7 in the upper right hand corner is an object node titled "Tech models" and nearby is one titled "System Model." Those object nodes are hyperlinked to the block definition diagram of Figure 9, which depicts the type of models likely to be produced during the course of a technical project. Included along with the types of models is an expansion of model descriptors including "Purpose" and "Temporal Domain." What is interesting about these descriptors is that they apply equally well to testing and modeling.

Specifically models or tests that are generated for the purpose of product "Verification," i.e. to show that the product satisfies the requirements, could theoretically be applied during development, production and stockpile evaluation. Preferably, there should at least be a correlation of data generated across these project phases since, presumably, the product requirements would apply in each of these domains with the understanding that certain requirements will change during the development phase. There is also a comparable correlation between the types of models generated and the types of tests conducted. Based on this strong correlation of type between models and tests over the lifecycle of the product, there is an apparent opportunity for integration.

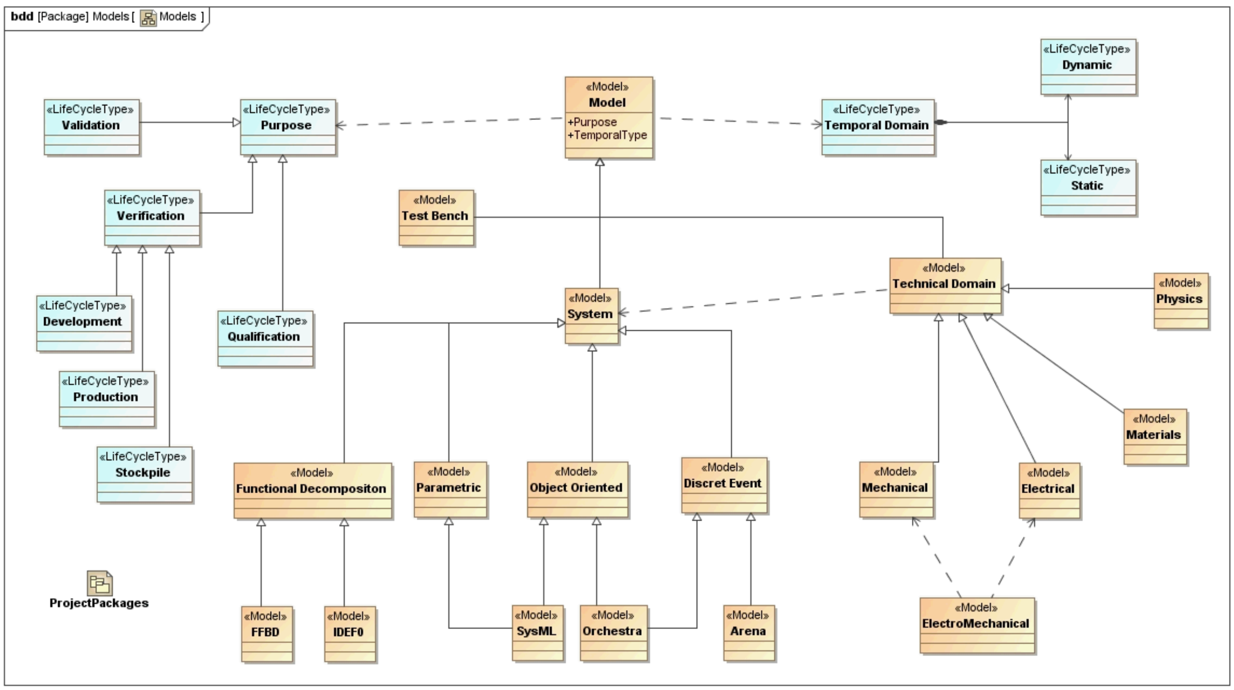

Figure 9. bdd of the "model" object nodes in the Stage A activity diagram of figure 7

Indeed, Figure 10 is a rather imperfect attempt to depict that potential integration. The initial focus of the diagram is intended to be between the "System" model and the "System" block, both of which are defined or specified by the product requirements shown along the top of the diagram. What may not be quite as clear is that not only is there a strong correlation between the two types of systems depicted, there is also a high correlation between the test benches used to evaluate and verify those systems. The correlation is potentially so high that there should be a high level of transparency and similarity with respect to the acquired data, whether that data originated with a pure model, an actual system, or some hybrid of the two. In fact, the correlation of data should be so high that the software used to reduce and evaluate the data, in this case the Sandia developed "WAVE" application, should be able to acquire and analyze data from either the model or the real system without significant distinction being made as to the source. The potential advantages of this capability are significant in terms of reducing the resources needed to develop and validate the production and stockpile test environments, as well as the greater visibility into the system and the ability to understand the effects of off-normal and over-stress conditions that can often only be developed within a modeling and simulation environment.

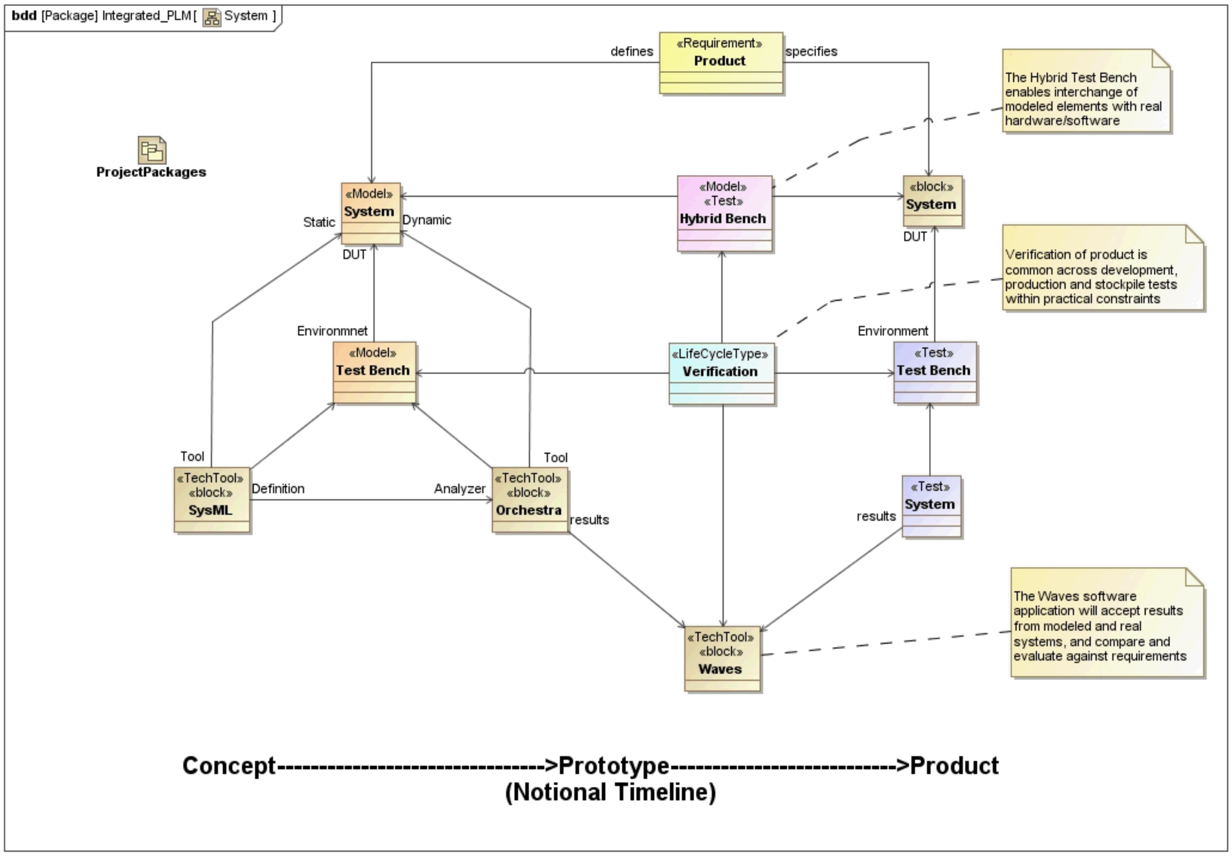

Figure 10. Proposed Product Lifecycle Integrated Modeling and Testing Environment

Other opportunities exist for integrating across the product lifecycle along the lines of the earlier reference to the work of InterCAX. Our intent is to follow up the development work on an integrated model and test environment as depicted in figure 10 with additional contracts and internal development for that purpose, but those concepts are too immature to develop further in this paper. What follows is a brief description of some of the other object node hyperlinks in the Stage A activity diagram. The other stages B through F are similarly constructed, but further presentation is far more detail than appropriate for this paper.

The Hyperlinked Business Requirements in the Model. The business requirements are contained in Word documents. These requirement documents reference other plans, tools, and templates to assist the engineer in the life cycle process. Figure 11 is an example of the type of documents created and the interfaces to the templates, tools, etc., and how those elements are hierarchically hyperlinked. All these documents are contained in the portal as shown earlier in Figure 5. The model was developed to connect the process with these various document sources by establishing the hyperlinks as shown in Figures 7 and 12 in which the diagram, "Project Plans," in the later figure is hyperlinked to the object node named "Program/project Plans" in figure 7. All object nodes in the IPG stage diagrams (e.g. figure

7) are hyperlinked either directly to an RMI based document and subsequently to the equivalent project document, or to a hierarchical diagram such as that in figure 12. In figure 12, the document "Parts" listed in the appropriate attribute space in the block are each hyperlinked to the appropriate document.

Therefore, the engineer can select the hyperlink in the model and it will connect to the document needed in the process. The advantage of the hyperlinked model is the creation of a self-contained environment so the engineer does not have to search multiple sites, creating a "one-stop shopping" approach to project and technical information management. Consequently, the hyperlinks serve as an assistant to the engineer that provides all the information necessary within each stage, and provides a convenient method to communicate project information to all members of the project team. With the significant amount of information and documentation that is required to manage a complex project, the model and hyperlinks provides all that is required thus preventing lost and missing information or guidance.

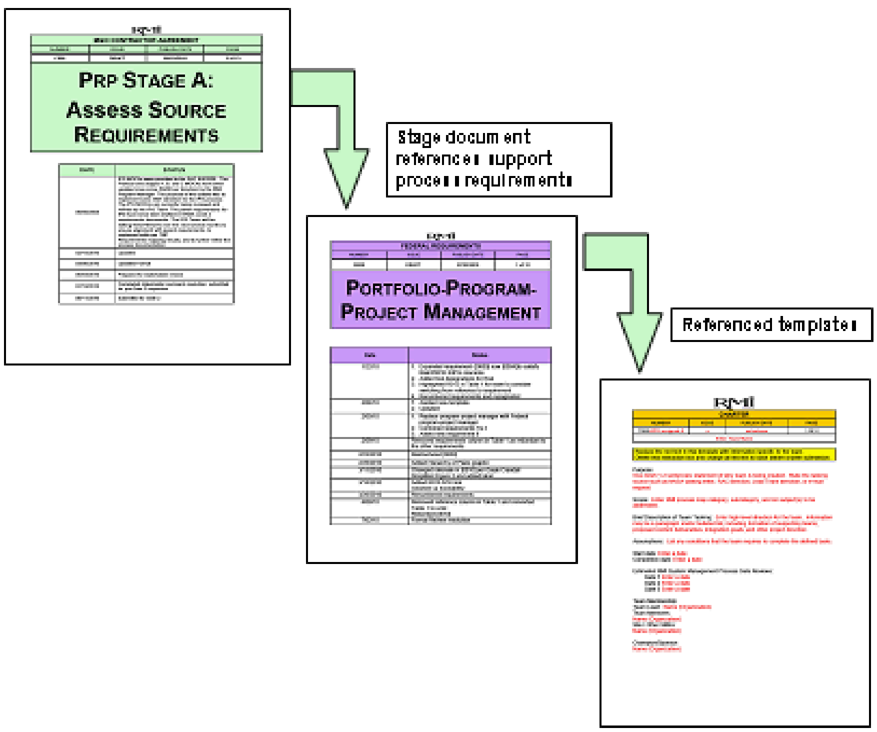

Figure 11: Business Requirements Documents and Templates

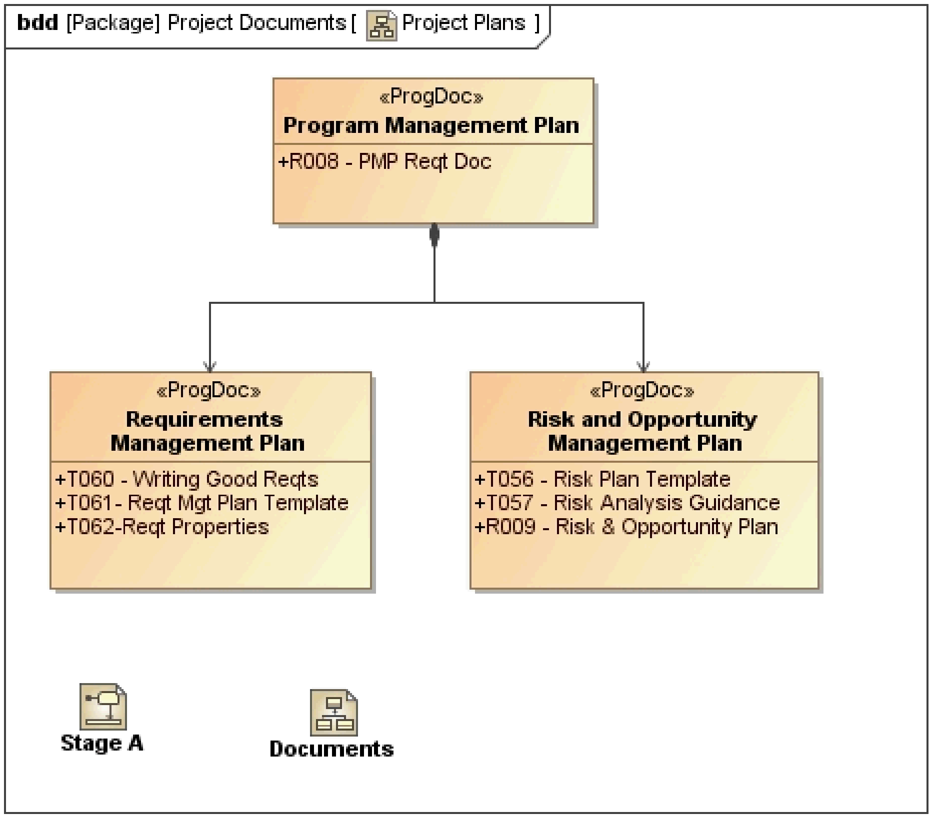

Figure 12: Hyperlinks to the Plans

Conclusions and Next Steps

Conclusion. The essential backbone of an integrated PLM environment based on a SysML model has been realized. The advantages of using SysML is the ability to represent both the structure and behavior of a project as well as directly link the pertinent external documents, web portals, tools, and databases into a single accessible and logical construct that will enable project leads, both novice and experienced, to satisfy the most rigorous project requirements. Also described is an approach using SysML models to integrate the technical data from analysis, modeling, testing, project reviews and even meta-data into an integrated and fully related environment that could reduce errors, improve efficiency and enhance team operations. While developing an integrated PLM environment appears to be feasible, the complexities associated with acquiring and managing complex technical data from a variety of sources and deriving the appropriate data links and relationships over the scope and lifetime of the product will require many years to fully formulate and implement.

Next Steps. While the basic SysML project model has been developed, much refinement is required before it is ready for general use. Also, at the time of this paper, the underlying RMI system of project requirements, templates and guidelines is still being developed. Thus the SysML model will need to track and adapt to expected changes in the underlying infrastructure. Finally, much work remains to realize a truly integrated project environment in which a data element need only be entered once and utilized, refined and maintained throughout the product lifecycle. This is a particularly daunting objective for the nuclear weapon enterprise in which product lifetimes are measured in multiple decades, and responsibility to manage these national assets can involve dozens of different organizations and hundreds if not thousands of individuals during that time, thus employing high project rigor in an efficient and adaptable process are essential to maintaining the nation's nuclear deterrence.

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Biography

Georgia Artery. Georgia Artery is a Weapons Integration Engineer with Sandia National Laboratories. She has a Bachelors of Science in Mechanical Engineering from the University of New Mexico, Masters of Science in Systems Engineering at Stevens Institute of Technology, and a Masters of Business Administration from Webster University. Georgia has worked at Sandia National Laboratories for 9 years with experience in Quality and Systems Engineering. Prior to Sandia, she worked at General Electric Aircraft Engines (GEAE) Division where she held multiple management and engineering roles in Quality, Manufacturing, and Process Engineering. In addition, she is a certified Six Sigma Black Belt from GE.

Mark De Spain. Mark De Spain has been an engineer at Sandia National Laboratories in Albuquerque New Mexico for over twenty years. He has worked in weapons components including sensing devices, firing sets and use control, and in weapon systems groups. Currently he is working as a systems engineer in the Advanced and Exploratory group for Nuclear Weapons. Prior to working at Sandia he worked as an engineer at Tektronix in Portland Oregon and at Sperry Flight Systems in Phoenix Arizona. He has a BSME from Oregon State University, an MSEE from the University of Portland, and a MS in Systems Engineering from Stevens Institute of Technology.

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