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A Development Case of SysML Based Nuclear Power Plant Design Bases Model

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1. Introduction

The importance of the configuration management of nuclear power plants cannot be emphasized enough as it is critically related to all safety issues. During a life cycle of a nuclear power plant, design requirements, facility configuration and physical configuration should be conformed to one another. Unconformities among requirements, facility information, models, drawings and installed facilities can lead to safety accidents causing great losses.

However most nuclear power plant configuration management practices have been carried based on Design Bases Document(DBD). DBD is a key document of configuration management as it contains requirements, design bases, parameters and supporting information and their relationships that should be managed through the plant life cycle. But in a document-based environment, it is almost impossible to reflect changed or updated information simultaneously to a DBD. The concept of Model-Based Configuration Management(MBCM) has been introduced to overcome the stated limitation of Document-based Configuration Management(DBCM). In the view of MBCM, all manageable configurations are modelled and the model is managed to maintain the consistency of plant's configuration. In Korea, there have been steady researches on an integrated configuration management system[2,3] for nuclear power plants in order to systemically manage all the information produced and changed during the plant life cycle, but researches on MBCM and modeling haven't progressed much.

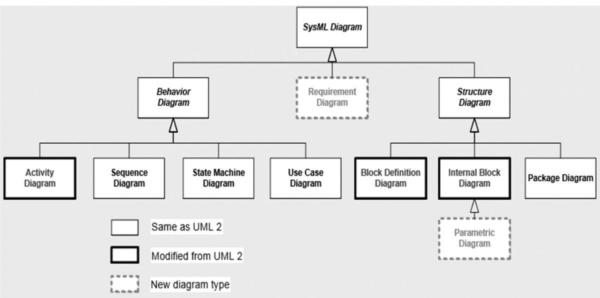

Fig. 1. 9 Diagrams of SysML

In the context of MBCM, the most important and fundamental task is to establish an integrated system model which represents a nuclear power plant's requirements, facility configuration and relationships among them. Through the right modeling we can define what to manage. Systems Modeling Language(SysML), which is a graphical modeling language standard developed by Object Management Group(OMG) is a compatible language to establish the right model. SysML is designed to represent general systems in 9 different views and is suitable to model requirements, structures and behaviors of a certain system.

So in the paper, as the first step toward an implementation of MBCM to the nuclear power plant engineering we have developed a case of SysML based nuclear power plant design bases model.

2. SysML Based Nuclear Power Plant Design Bases Model Overview

2.1 Modeling Scope

Auxiliary Feedwater System(AFWS) of a reference nuclear power plant was chosen as a target system for modeling.

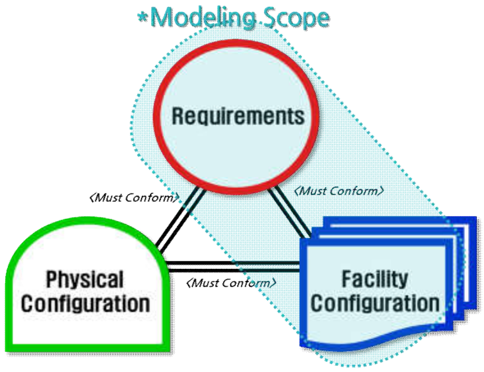

Fig. 2. Modeling scope

As shown in Figure 2, in the view of CM equilibrium model, the modeling scope of AFWS is from requirements to facility configuration of AFWS, which covers the scope of Design Bases Document(DBD) of AFWS.

2.1 Structure of Design Bases Document

According to NRC regulation 10 CFR 50.2, design bases of a nuclear power plant identify the specific functions to be performed by a structure, system, or component(SSC) of a facility, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design[4]. The relationship among Design bases and related information supporting or specifying the design bases defined in NRC Regulatory Guide 1.186[5] can be illustrated as shown in Figure 3.

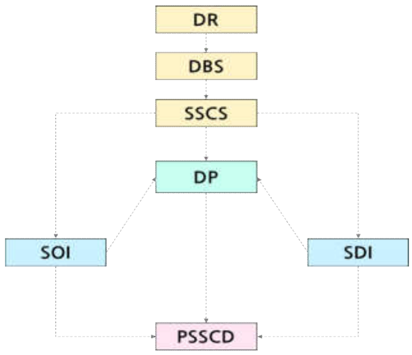

Fig. 3. Structure of Design Bases Document(DBD)[1]

In detail, Design Bases Specification(DBS) is derived from Design Requirements(DR) and is refined by System, Structure, Component Specification(SSCS) which specifies specific design functions and performances. And Design Parameter(DP) specifies certain ranges of values to satisfy DR, DBS and SSCS. Supporting Operating Information(SOI) and Supporting Design Information(SDI) identify engineering documents supporting DPs. Physical System, Structure and Component Data(PSSCD) refer to plant operation data which should meet the operating ranges defined by DPs.

2.2 Structure of SysML Based Design Bases Model

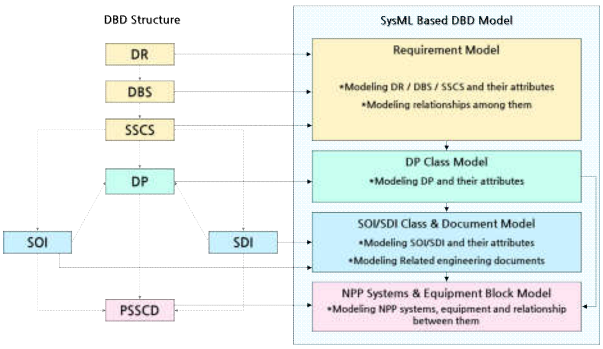

Fig. 4. Structure of SysML based design bases model

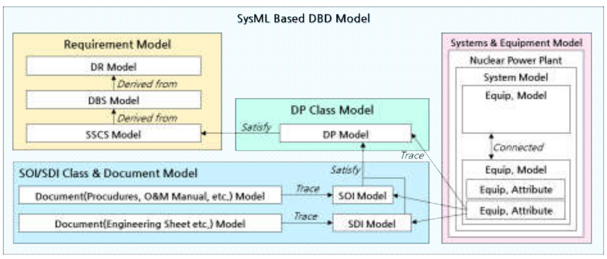

Fig. 5. Detailed structure of SysML based design bases model and relationships among inner models

Figure 4 shows the structure of SysML based design bases model. The model is consisted of 4 parts: Requirement model, DP class model, SOI/SDI class & document model and Nuclear power plant systems & equipment block model. Each model represents following items of DBD.

1. **Requirement model**: DR, DBS and SSCS elements and their attributes.
2. **DP class model**: DP elements and their attributes.
3. **SOI/SDI class & Document Model**: SOI/SDI elements and their attributes and structured document models specified by SOI and SDI elements
4. **Nuclear Power Plant Systems & Equipment Block Model**: A product breakdown structure(PBS) of a target system and interconnections of equipment in the system.

Figure 5 shows more detailed relationships showing how models composing the SysML bases DBD model are associated with one another.

3. SysML Based Nuclear Power Plant Design Bases Model Example

3.1 Requirement Model

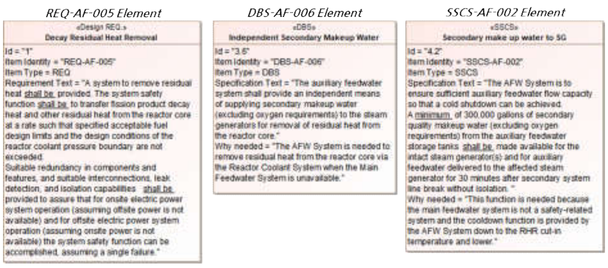

Fig. 6. Examples of Requirement Elements

As shown in Figure 6, individual DR, DBS and SSCS items were modeled as an independent requirement element. Each element has its own properties such as id, item identity, item type and specification text.

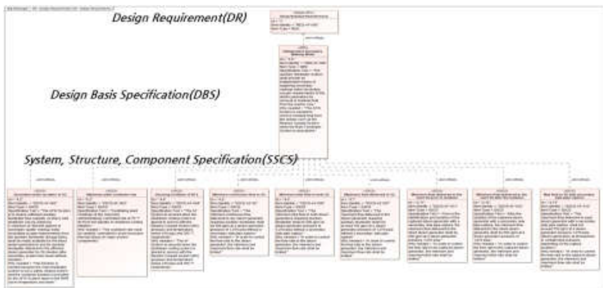

Fig. 7. Relationships among requirements

Then, using standard relationships defined in SysML, relationships among requirement elements were defined. Figure 7 shows how a top-level requirement DR derives to related DBS and SSCS. By defining these relationships, traceability among requirements can be achieved.

3.2 Design Parameter(DP) Model

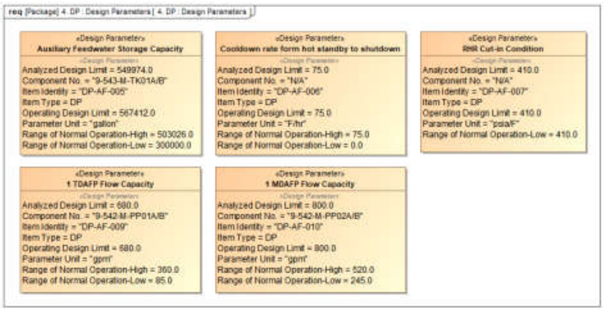

Fig. 8. Examples of DP elements

As shown in Figure 8, DP items were also modeled as independent elements containing their own parameters defining operating conditions. Parameters contained in each DP element are also independent elements with their own address so it helps to manage changes in parameters easily.

3.3 Supporting Operating Information(SOI)/Supporting Design Information(SDI) & Document Model

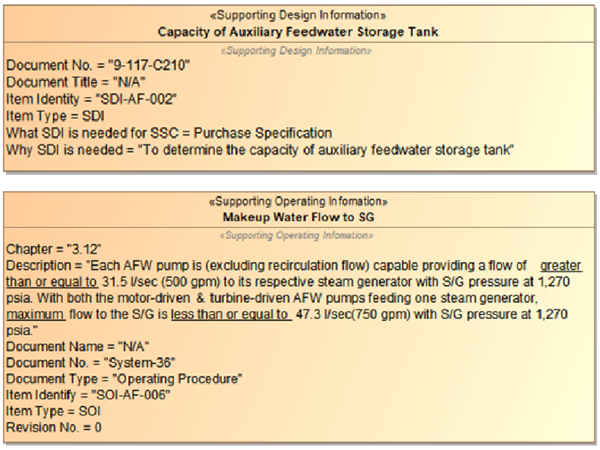

Fig. 9. Examples of SDI/SOI elements

Figure 9 shows each modeled SDI and SOI element examples. Properties of Supporting Information element specify documents justifying parameters defined in DP and SSCS. However, as SDI/SOI only shows what the related document is and cited description related to DP and SSCS, it is hard to trace information when there are changes made in documents. So we have developed a case of a document model. Figure 10 shows a document model example of an operating manual. The table of contents and descriptions belong to each article were modeled as a structured template so that each paragraph of the operating manual can be managed individually. Figure 11 shows a relationship defined between SOI element and a related paragraph element in the operating manual document model.

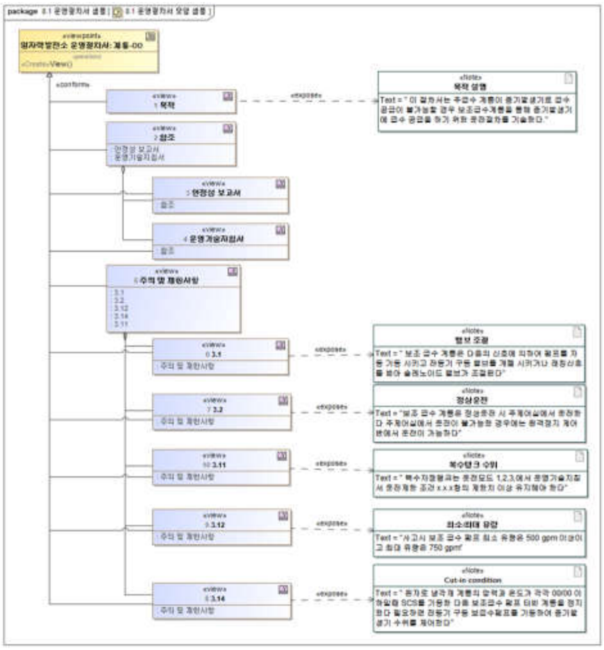

Fig. 10. Document model example

Fig. 11. Defining relationship between SOI and the paragraph from the document model

3.4 Nuclear Power Plant System, Equipment and Component Model

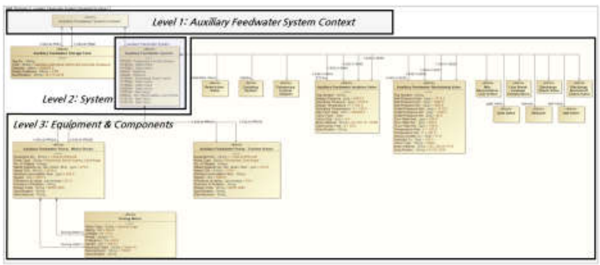

Fig. 11. Product breakdown structure(PBS) of an auxiliary feedwater system(AFWS)

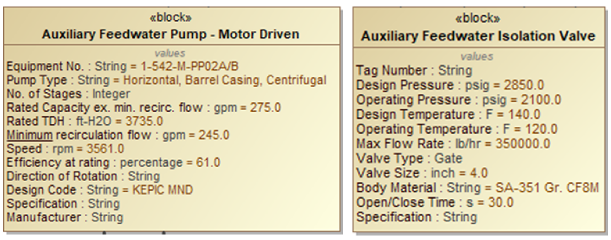

Fig. 12. Equipment and component element examples

The System, Equipment and Component Model shows an entire structure and a design of a nuclear power plant. Figure 11 shows a product breakdown structure(PBS) of an auxiliary feedwater system modeled with SysML. As shown in Figure 12, all equipment and component elements composing the auxiliary feedwater system model were modeled with SysML Block Definition Diagram(BDD). Properties of equipment and component that should be managed were all modeled so that each property can be managed individually.

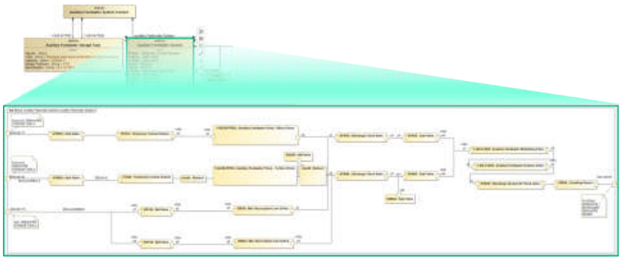

Fig. 13. Internal structure model of the auxiliary feedwater system

Using SysML Internal Block Diagram(IBD), the internal structure of the auxiliary feedwater system has been modeled too. Figure 13 shows how equipment and components composing the system connected to one another, inputs/outputs of them and interfaces with external systems. The model is expressed with a block and line diagram but basically it is identical to a process flow diagram(PFD). So it helps to manage pipelines connecting equipment and fluids flowing along the pipelines individually.

3.5 Defining relationships among model elements

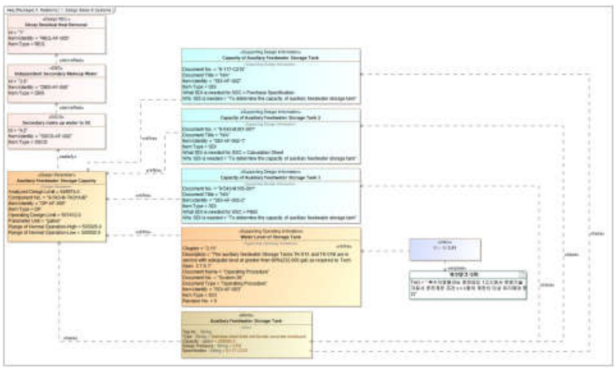

Fig. 14. Diagram showing relationships among DR, DBS, SSCS, DP, SOI/SDI and equipment properties

As a final step, relationships among requirements, DP, SOI/SDI and related document, Equipment properties has been defined as shown in Figure 14. So, through the SysML based auxiliary feedwater system DBD model, for example, we can trace how changes in DR or DBS or any other items affect properties of feedwater storage tanks easily as all information of DBD and the auxiliary feedwater system itself are modeled and connected with proper relationships.

3. Conclusions

The most important objective of configuration management is to keep the conformity among design requirements, facility configuration and physical configuration. To achieve this objective, all configuration information should be traceable but it is almost impossible to be done in traditional document-based environment. So as a first step toward an implementation of model-based configuration management(MBCM) we have developed a SysML based design bases document model that all items of DBD, system structure and system, equipment and component properties are defined and interconnected with a standard system modeling language.

ACKNOWLEDGEMENT

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