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V-Model based Configuration Management Program for New-Build Nuclear Power Plant

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1. Introduction

The Korea Hydro and Nuclear Power Corporation (KHNP) is the world's leading fleet nuclear electric utility, with substantial experience as an owner-operator. In addition, KHNP developed its own designed APR+ Nuclear Power Plant (NPP) to complement this environment, and this presents new challenges in areas of design control, design basis, licensing and regulation, maintenance, materials and spares, and training and qualification as an Engineering, Procurement and Construction (EPC) in bringing this design to market. As NPP operators undertook design basis reconstitution efforts, they began to realize that the design basis is a foundation for Configuration Management (CM). This realization was made evident in the magnitude of the problems that were being observed. This experience also raised serious questions about how the information being developed to produce the design basis documents would be kept up to date in the future. A process to reconstitute the design basis is likely to be ineffective if CM controls are not in place. The right IT solution for CM depends upon a number of factors, including the nuclear power plant culture, budget, target technology, and the nuclear power plant owner/operator's standards, requirements and limitations for its generating fleet [1]. A solid, well-understood and well-integrated CM Program for the new NPP will significantly add to the quality and marketability of this new technology.

CM is a process of identifying and documenting the characteristics of a plant's structures, systems and components, and of ensuring that changes to these characteristics are properly developed, assessed, approved, issued, implemented and verified. Comprehensive CM Program for NPP is the single greatest strategy to meet the commitment to nuclear excellence. The safety and viability of nuclear power, particularly at the fleet level, depends upon the development of positive design control and design basis to better understanding plant operating dynamics and margin management, along with technology to control the realization of such design in the physical plant. However the most of plant facilities are modified many times, often without suitable support needed to confirm with their design base and to update their engineering data, maintenance rules and operating procedures. This lack of equilibrium between the requirements, design information and physical plant still remains a important issue. This study focuses on how to manage the configuration information of NPP using systems engineering V-model approach, and proposes data model to manage the configuration information in relation to manage their life cycle.

2. NPP Life Cycle and CM

2.1 Life Cycle of NPP

The period of NPP life cycle includes the early conceptual phase, design, construction, operation (including life extensions), shutdown, and decommissioning. The NPP operational life is defined during the design phase but in many cases is extended during operation when supported by a justification for extended life. This operation phase will determine the amount of total electricity generated by the plant and enable the calculation of the revenue earned.

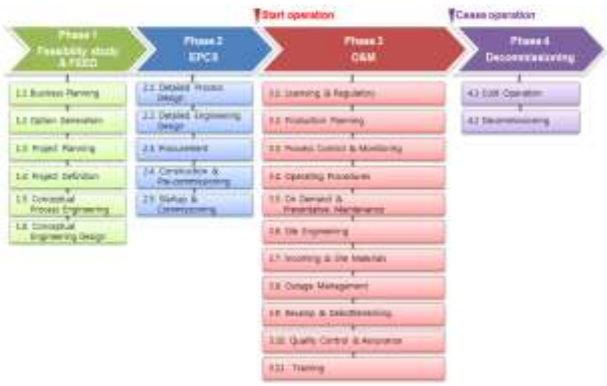

Fig. 1. Life cycle stage of nuclear power plant.

During the life cycle of a NPP, many decisions have to be taken which can influence safe operation. Life cycle management is the combination of safety management, ageing management and business management, together with economic considerations in order to:

− Maintain an acceptable level of performance including safety.

− Optimize the operation, maintenance and service life of structures, systems and components (SSCs).

− Maximize returns on investment over the operational life of the NPP.

− Take account of national strategies for life cycle funding (including decommissioning), fuel management and waste management.

The NPP life cycle should therefore be considered as a single period covering all stages from design through decommissioning [2, 3].

2.2 Definition of CM in NPP

CM (Configuration Management) is the process of identifying and documenting the characteristics of a facility's structures, systems and components (including computer systems and software), and of ensuring that changes to these characteristics are properly developed, assessed, approved, issued, implemented, verified, recorded and incorporated into the facility documentation. In turn, this ensures the physical configuration of the plant is maintained in accordance with the design basis, licensing basis information, regulatory requirements, and permits for operation. The CM process provides a readily available, accurate source of design basis and licensing basis information through information management processes [3]. CM objective is graphically illustrated as design requirements, physical configuration, and facility configuration information in Fig. 2. Each aspect of CM is subject to continual changes that can affect design and operating configuration. These changes may be desired changes such as design improvements in operating procedures. They may be unintended events or external factors such as changes to licensing requirements, human error, or unexpected material degradation. In each case, the same CM process is used to return to a state of CM equilibrium [4].

Design Requirements is an engineering requirement reflected in design output information (document and/or data) that defines the form, fit and function, including capabilities, capacities, physical sizes and dimensions, limits and set points, specified by the design authority for a structure, system or component of the facility. Design Basis is the range of conditions and events taken explicitly into account in the design of a facility, according to established criteria, such that the facility can withstand them w/o exceeding authorized limits by the planned operation of safety systems.

Facility Configuration Information is record information that describes, specifies reports, certifies, or provides data or results regarding the design requirements or design basis, or pertains to other information attributes associated with the facility and its structures, systems and components. Design Information is a subset of Facility Configuration Information that includes the documentation of Design Requirements information and the design basis information. Operational Configuration Information is recorded information that describes the acceptable configuration of facility Structures, Systems and Components (SSCs), when variable configuration conditions may exist, based on operational needs.

Physical Configuration is a term includes all the configuration of hardware (includes SSCs) with its functional software. SSCs is the elements that make up a facility. A structure is an element that provides support or enclosure. A system is a collection of components assembled to perform a specific facility function; this includes supporting software. A component is an active or passive item of equipment.

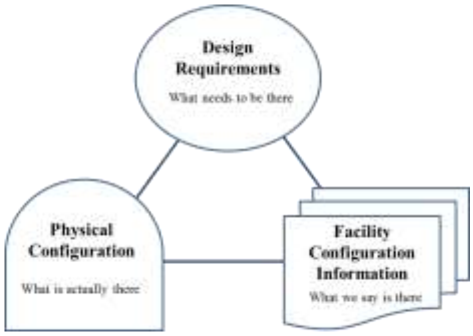

Fig. 2. CM Objective and its CM Equilibrium Diagram.

2.3 Related Codes, Standards, and Guides

There is a large amount of published guidance on life cycle management and CM for NPP, from the IAEA and other internationally recognized bodies. The topics have not been directly addressed in one publication, as the topics have emerged as NPP have moved through the life cycle stages, and the owners and utilities have addressed the topics when the need arose. The Table I is the relevant regulatory, IAEA, industry and NGO standards that affect and guide nuclear CM Programs and supporting elements

Table I: CM Related Guides.

10 CFR 50	-Appendix A : General Design Criteria -Appendix B : Quality Assurance Requirements -50.2 : Definitions -50.59: Changes, Tests and Experiments -50.71: Maintenance of Records, making reports
NRC Reg.guide	-1.186: Guidance And Examples for Identifying 10 CFR 50.2 Design Bases
NEI97-04	-Design Basis Program Guidelines
IAEA	-TECDOC-1335: CM in NPP -GS-R-3: The management systems for facilities and activities
DOE	-STD-1073 : Configuration Management
NIRMA	-CM 1.0-2000: CM of Nuclear Facilities
INPO	-AP-932: New Plant CM development & implementation process -AP-929: CM Process Description -AP-907: Information Management Process Description & Guideline -AP-913: Equipment Reliability Process Description -05-005: Guidelines for performance Improvement at NPSs -05-003: Performance Objective & Criteria
ISO	-10007: Guidelines for CM

3. V-Model based CM Program

3.1 Current Status of CM Development

CM Programs are mandated by virtually every regulatory and advisory organization in the nuclear industry. The IAEA includes requirements for establishment of a CM Program from the beginning of planning for the NPP [5, 6]. While virtually every NPP gives acknowledgement to the importance of CM, and will indicate that the NPP, or the development program for a new-build NPP, has an active CM Program, the reality is somewhat different. NPP's will always cite at least some reference to a CM Program in their plant programs or QA plan, and will even have some high-level procedures for implementation. The methods and degree of actual implementation of a CM Program, however, varies widely among world NPP's. WANO assessments of design control and CM nearly always cite at least some elements of CM that are non- or poorly-functional, according to IAEA TECDOC-1335, CM in NPP. The leading CM assessment shortfall centers around lack of document or FCI(Fluid Components International) control, or ability to access FCI, with poor design control and relating design events to FCI or SSC's coming next. The second most common CM issue concerns NPP's that take credit for a CM Program solely on the basis of a software solution. Many NPP's will claim a CM Program on the basis of having an MRO(Maintenance, Repair and Overhaul) or ERP software solution but, in fact, do not fully understand the processes required to be in place to fully utilize such information, or even which data is most significant for CM.

In general, the NPP CM Program provides:

− The SSCs design requirements, as well as supporting software and hardware, are verified and documented.

− The changes in the design requirements are identified, documented, controlled, evaluated and subsequently approved or rejected through a structured engineering design change process.

− The approved changes in the design and their stage of implementation are documented and taken into account throughout the life cycle of the plant, which means precise and timely incorporation of the information from the input design documents in the plant physical configuration (i.e. a status of "as-built" corresponds immediately to the contents of the design documents).

− CM Design documents, such as drawings, calculations, and design basis items like FSAR (Final Safety Analysis Report) and Technical Specifications.

− CM operating documents, such as procedures for operation, maintenance and repair, testing, installation, purchase, requirements to inspection and training are updated and maintained in accordance with the current design of the plant.

− The CM process serves to support long-term NPP asset life cycle management processes and data.

− The CM Program implementation effectiveness shall be periodically assessed about its positive impact in accordance with the IMS(Integrated Management System).

The objectives for the development and implementation of the V-Model based New-Build NPP CM Program are to provide the following technologies, requirements, and relevant information. This process focuses on design creation and control, along with interfaces for vendors, major suppliers and the owner/operator.

− Establish a comprehensive CM Program that controls design basis, utilizing current, modern process and technology

− Provide a source of continuous, reliable information related to the status of fleet NPP CM

− How to utilize CM and Design Basis information to optimize fleet NPP safety, reliability and viability

− Supply and describe the high-level functional requirements for the CM Program

− Preparation of the overall requirements for the development of CM process and IT system

− How to leverage the CM System investment into total NPP fleet MRO and NPP Business Systems

− Integrating the benefits of Integrated Management Systems and Knowledge Management into the overall CM Program and technology

− Maintaining the "CM Equilibrium" for the new-build NPP utilizing proven processes, and practices, and advanced technology

3.2 Methods

The V-Model based CM Program addresses the requirements and elements for ensuring conformance between physical configuration, design requirements and facility documentation. At the start of NPP design and construction, CM Program Management Planning includes directing and monitoring the development and implementation of an NPP CM Program for the project, subcontractors and ultimately, the operating NPP. Successful accomplishment of the project requires all participants to be provided with accurate, timely and traceable information concerning CM and the plant design basis for the project and deliverables at any point in NPP life cycle. As the project proceeds through its life cycle, the number and types of participants will grow significantly, while the volume of information grows exponentially. CM, along with the Information Management System (IMS), provides methods to manage, control, and utilize this information.

The CM Program describes the organizations, roles and responsibilities for CM planning, execution and technology within the context and requirements of the Designer's Quality Plan, the Integrated Management System and IAEA GS-R-3. Utilizing IAEA standards including TC-1651 and Safety Report Series No. 65 for systems, procedures and technology for Nuclear CM, the CM Program should include systems for the compliance and recording of the plant design basis and engineering design controls. CM processes are to be designed for standardized Owner, EPC and supplier collaboration and implementation on a modern PLM(Product Life cycle Management) based design and CM platform. The CM processes and technology, in turn, control and manage the design basis relationships of Master Equipment List (MEL), Controlled Documents, Engineering Design, Installation and Maintenance, Materials Qualification and Management, and other CM elements to ensure the content of the NPP is documented and matches the actual plant design. CM for nuclear safety management includes development of Document and Content Management, Design Basis Control and Configuration Management Systems for joint NPP, EPC and Owner's Engineer control of CM. Systems are provided in ISO 9001 and 14001 standards, and enhanced according to IAEA TC-1651, GS-R-3 and industry standards from WANO (World Association of Nuclear Operators), EPRI (Electric Power Research Institute) and INPO (Institute of Nuclear Power Operations) for CM and IMS requirements for nuclear safety and best practices for nuclear power new-build and operation.

3.3 Structure of the CM Program

The V-Model based CM Program and its technologies interfaces with virtually all NPP functions and organizations, including engineering, maintenance, document control, procurement, warehouse, and equipment registry, as well as specific NPP functions, such as isolation and clearance. The CM Program also controls design basis and SSCs status during interim and design change notices/field changes for plant modeling, design, fabrication and construction. The CM Program is oriented to the delivery of the plant design and design basis, and as such is EPC and manufacturer/designer based in scope. This includes the licensing, initial design, construction, change management, testing, quality assessment and turnover of the NPP to the owner/operator.

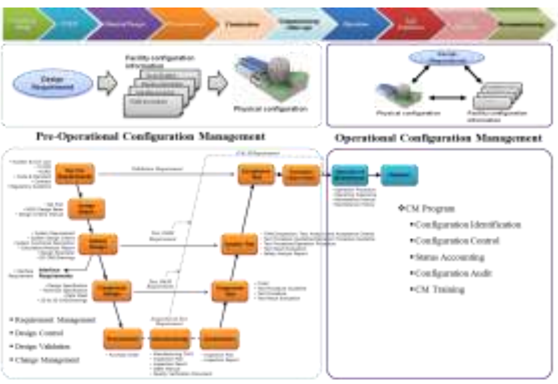

Fig. 3. V-Model adoption to NPP Life cycle.

Also included are the training and interfaces of designers, manufacturers and constructors, as well as the vendor relationships involving design integration and nuclear qualification of manufactured parts and systems.

These interfaces need to be identified once the project organization for design, construction, and commissioning is defined. Likewise the functional interfaces for the operating plant need to be identified once the operating plant organization is defined. However, for both the project and the operating plant it is important to ensure that the required functional interfaces are defined in order to maintain consistency between design requirements, design documentation, and physical configuration. The following interfaces must be considered:

− ***Program Management:*** The Program Management element shall address the management of the CM Program. It shall provide guidance for the control and monitoring of the CM Program Elements as defined by the CM Program Plan. Therefore, this element interfaces with all the CM Program Elements.

− ***Design Requirements:*** Plant design requirements provide justification that the plant can be operated in a safe, reliable, and environmentally acceptable manner. Design requirements consist of design output (engineering) data such as plant drawings and system specifications that provide the specific requirements to which the plant must be designed. These requirements must in turn reflect the design basis of the plant. The design basis consists of design inputs (such as heat removal calculations, plant safety analysis, and system specifications), which provide a basis for all plant operations. Design requirements provides input to the MEL by identifying boundaries for safety systems, by proving a method of classifying structures, systems, and components and other information. Design requirements provides input to the change control process by providing a basis for all changes to the plant.

− ***Information Control:*** Information Control covers document control and records management. Document control ensures that plant documents are generated, revised, distributed, and controlled. Records management stores plant records and ensures that plant personnel have access to those records.

− ***Change Control:*** The Change Control element ensures that changes to the plant are properly generated, reviewed, and approved. It is considered to be the most important element in a CM Program once the design requirements and design bases are established. This element's main interfaces with the other CM Program elements are:

- Design Requirements: Change control ensures that plant design requirements are used in proposing and approving changes to the plant.
- Document Control: Change control ensures that the latest documents are used when performing changes.

- Records Management: Change control ensures that the appropriate records are retrievable in order to document changes to the plant
- MEL: Change control ensures that the MEL is updated to reflect changes to SSCs.

− ***MEL:*** The MEL is not a separate CM element, but is a key feature of the CM Program. The MEL is an integral part of design requirements. The MEL maintains a list of SSC's for the NPP. It also provides a means to cross reference equipment to plant documentation.

− ***CM Program Assessments:*** The CM Program assessment element interfaces with all of the other CM elements because it provides the framework for performing plant assessments and monitoring the effectiveness of the CM Program at NPP.

4. IMS for V-Model based CM Program

4.1 Background and Objectives

The Integrated IMS for NPP CM controls the processes, procedures, roles, responsibilities and organization in accordance with ISO and IAEA GS-R-3 requirements and standards. Integrated Management also includes the process control technologies and qualification/training status controls for staff. An IAEA GS-R-3 and GS-G-3.5-compliant Integrated IMS should be developed to establish, oversee and control integrated NPP quality systems. The CM Program will then utilize the IMS for specific CM Processes and nuclear business controls, including procedures and instructions to control CM Program and required interfaces. The IMS will facilitate collaborated and unified process development for NPP, the owner's engineer, state regulator, EPC and major suppliers. The IMS is then applied to the process, systems and procedures for CM, NKM (Nuclear Knowledge Management) and other nuclear processes and programs.

The overall implementation of the CM Program into NPP processes and procedures must be compatible with the EPC/designer and NPP information technology platforms and architecture, as well as offer the functionality to meet the CM process and data requirements. The IT environment must also support the required technology and organizational interfaces to completely fulfill CM requirements and accommodate collaboration platforms such as PLM.

The current taxonomies, technologies and products available to select, develop and deploy comprehensive, CM and PLM-based MRO, engineering design and supporting NPP fleet software solutions are related to advances in information technology as well as process. The installation of NPP components and replacement of parts during maintenance events (Maintenance Resource Optimization or MRO) is a CM element due to the relationship of the BoM (Bill of Material) and the equipment (SSC), as well as procedures, processes and technology to ensure the safe and orderly isolation of "live" components and air/power supplies during maintenance work. The components and parts utilized must meet the component qualification requirements, as well as the maintenance frequency, schedule and other nuclear regulatory and business requirements of maintenance.

4.2 Principles for Configuration Information Control

The objective of the information control element of CM is to identify and manage configuration information related to the physical configuration and the design requirements. The principles identified below apply to both electronic information and hardcopy documents.

− ***Identification:*** The types and sources of information that are to be maintained to effectively implement CM are determined, and responsible persons are assigned as owners of each of these sources of information. These persons are responsible for the technical content of the assigned information source and establish priorities for information revision and access. Where information is contained in documents and other information systems, a relationship between SSCs and specific documents and applicable information systems is established and maintained.

− ***Categorization:*** Sources of configuration information are categorized. The categories communicate relative validity and update frequency to potential users of the information. The facility personnel are able to determine which specific information in various sources (documents, databases, etc.) relates to a specific SSC and the relative reliability of the information in each source, e.g., verified, pending verification, etc.

− ***Storage:*** Configuration information is appropriately stored and protected. Backups or duplicate copies of individual documents or databases are considered on a graded approach basis. This applies to hardcopy originals or master copies of documents containing configuration information, as well as to electronic information treated as a controlled information source.

− ***Control and Tracking:*** Control and tracking systems make the user of configuration information aware of whether the information is historical, current (as-built) or pending (as-designed). Data needed for control and tracking such as the information title, revision level, current status, information custodian, pending changes and storage location is readily available to all persons who have a need to know. A graded approach to updating information sources is established (i.e., if and when updates are required). High priority information sources have changes incorporated in a timely manner.

− ***Retrieval:*** Configuration information is retrievable in a timely manner. Access and retrievability is based on priorities established to support business process requirements in a cost-effective manner. Where configuration information is contained in documents, these documents are identifiable from a database. This database establishes a relationship between documents, SSCs, types of SSCs, technical topics and other information to support identification (SSC vendor, for example).

− ***Operational Configuration Information Status Control:*** Appropriate method(s) are available to facility operators that enable them to be aware of the current operational configuration and relate it to the configuration presumed by the design bases. Information systems have been helpful in supporting this status control need; however, effective tracking of status changes requires direct operator action.

4.3 Data Centric Approach and Data Warehousing

The data requirements for NPP CM include a large amount of diverse information. This information, and the supporting information technology tools, must not only be complete and accurate, but accessible and available, to effectively support NPP CM and design basis–related activities. It is essential to plan for IT support of CM during preparation and construction of a new NPP. It is important to propose a data structure that will support NPP construction, commissioning, and operation. Data which is obtained during NPP construction will be well-utilized during operation as well [1]. Fig.4 illustrates the concept of a Data Centric approach. This Data-hub is utilized to store data and establish key data relationships (such as equipment to documents) which are then utilized in CM and design basis process, as well as other related NPP processes. The Data-hub illustrates the primary elements of a CM solution, and the fact that key relationships must be established to connect these elements to each other in a useful manner.

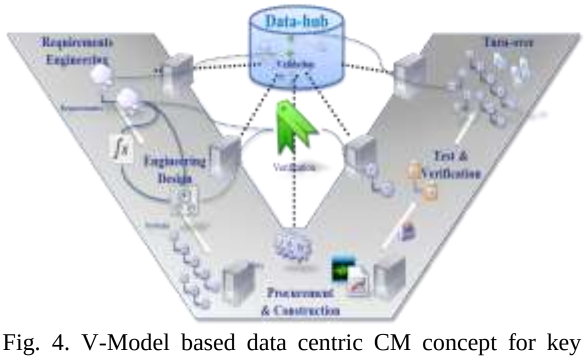

Fig. 4. V-Model based data centric CM concept for key relationship through life cycle perspective.

Data warehousing is the concept of collecting key CM data into a common location to be utilized for data queries and decision support. The data warehouse may not contain all data from enterprise IT sources, but will contain data elements that are considered important to query and information retrieval. This subset helps users focus on query results and reduces the data that must be reviewed for queries.

4.4 V-Model based IMS for NPP CM

The initial purpose of this study is focused on how to integrate NPP life cycle information which is generated from heterogeneous information system. V-Model approach is involved to solve the relationship between NPP life cycle stage and its information and the model can also provide how to manage configuration information through their life cycle. Author has developed an web based IMS which is called PLIMS – Plant Life cycle Information Management System [7, 8, 9], and the system provides capabilities to manage MEL, design requirements, engineering data, and plant configuration using the V-model approach. The system is developed using an ISO standard PLCS [10] to exchange and integrate the information in relation to manage their life cycle. In addition, this study conducted a research and development project and tests the prototype system using legacy plant information to verify its feasibility. It has been demonstrated that this approach can provide not only provide an explicit CM and control on the information, but can also provide a more efficient method to integrate, manage and visualize complex plant information. Fig. 5 illustrates the concept of PLIMS and business IT environment. Plant data is exported from a number of engineering applications, and consolidated as integrated plant life cycle information.

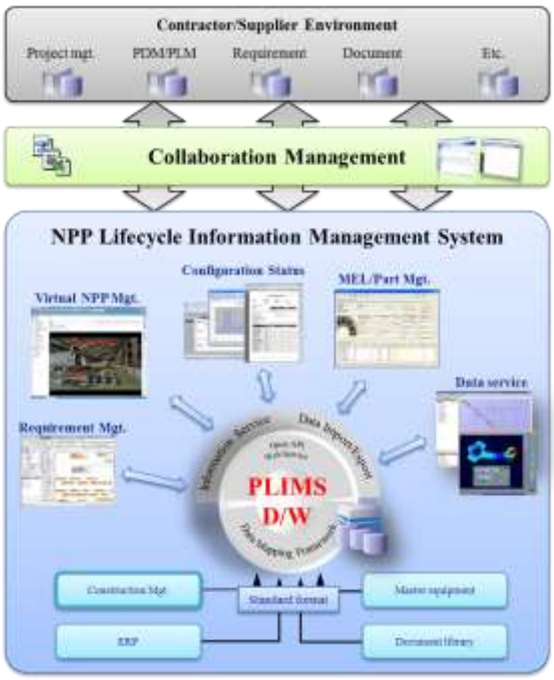

Fig. 5. Concept diagram for data centric Plant Life cycle Information Management and CM System – PLIMS.

Fig. 6 shows web based graphical user interface of PLIMS. User can find and navigate the complex plant information using 2D P&ID, 3D model, and various types of graphic diagrams. All the information is stored in PLIMS data warehouse which provides data centric information management capability. The data centric approach is involved to consolidating data from the heterogeneous applications into a central repository that is PLIMS data warehouse. This is the key idea behind the PLIMS. Data to be shared in an extended enterprise is extracted from source systems and integrated into PLIMS which then plays the role of an information repository, a collaboration hub.

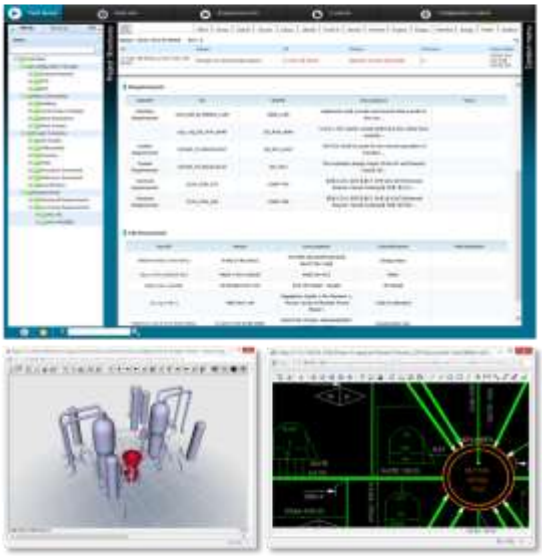

Fig. 6. PLIMS provides graphical user interface to navigate plant configuration information

4.5 Feasibility Study using Operating NPP Data

As a feasibility study, the author applied the information integration and V-Model approach to real field data from operating power plant. Fig. 7 illustrates NPP engineering process and its outcomes. Author analysis legacy engineering data and integrate all related information such as plant TAG data, equipment master data, design basis, design requirements, component spec, P&ID, 3D model, and etc.. Also there ware previous study to validate engineering design specification for new-build NPP. They build requirement database using IBM-DOORS. Author integrates the data into PLIMS data warehouse and consolidates the requirements with SSCs and plant engineering data.

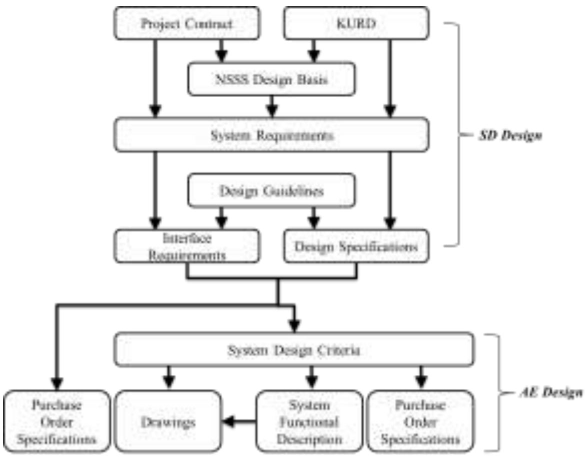

Fig. 7. Outcomes from engineering activities and its relationship

Fig. 8 shows the analyzed design requirement data which was generated from DOORS. Fig. 9 shows importing result in PLIMS data warehouse. User can navigate TAG data and tracing design requirement from the component requirements that is assigned to the TAG.

Fig. 10 shows PLIMS user interfaces which manage design bases information that is imported from design bases document (DBD). DBD is used for NPP CM in general.

From the feasibility study, author can recognize most of plant information is modified many times without proper support needed to confirm with their design base. This lack of equilibrium between the plant configuration information may bring significant accident.

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NDB_0086	All Seismic Category I and II SSCs required to maintain the integrity of the reactor systems and safety systems shall be designed for ......
SR232_0137	SSE loads shall be considered to occur during full power operation and 20 full cycles at maximum intensity.
DS_IHA_0115	In fatigue calculations, the SSE loads shall cycle about a mean value of zero for 20 full load cycles. As an alternative, the SSE loads may be applied for 240 half load cycles.

Fig. 8. NPP design requirement set for a plant component.

Fig. 9. PLIMS user interface to navigate TAG related requirements and its traceability.

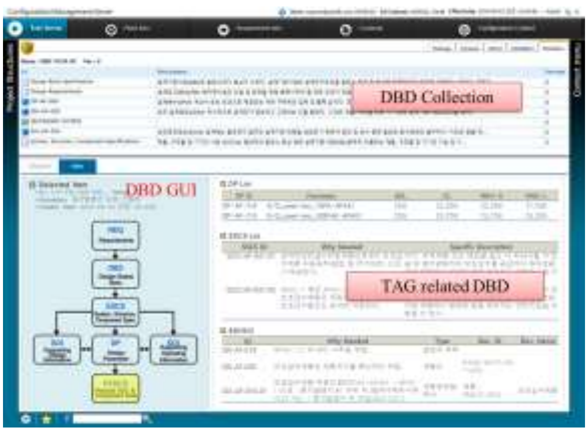

Fig. 10. PLIMS user interface to navigate TAG related DBD.

3. Conclusions

Comprehensive CM Program and IMS for NPP life cycle support is the greatest strategy to meet the commitment to nuclear safety. Author studies about NPP CM strategy and integrated life cycle information management, and propose V-Model based CM Program. Author develop a prototype system PLIMS which provides plant life cycle information integration and CM functionalities. The V-Model based CM Program and PLIMS supports the product-level implementation of a nuclear CM Program for a new-build NPP and help deliver on the advanced requirements for new-build NPP, which has incorporated the best of 60 years of worldwide PWR reactor experience and operation.

Acknowledgement

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