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# Application of Plant Information Models to Manage Design Knowledge through the Nuclear Power Plant Life Cycle

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# APPLICATION OF PLANT INFORMATION MODELS TO MANAGE DESIGN KNOWLEDGE THROUGH THE NUCLEAR POWER PLANT LIFE CYCLE

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
www.iaea.org/publications


For further information on this publication, please contact:


Nuclear Knowledge Management Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org




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# FOREWORD

Nuclear power plants use multiple information systems and databases from different vendors for different purposes. Most of these systems are not integrated with one another and cannot easily share plant data during different phases of the nuclear power plant life cycle, such as design, operation and decommissioning. This results in redundancies in capturing, handling, transferring, maintaining and preserving plant data. This lack of interoperability stems from the fragmented nature of the industry, paper based document control systems, a lack of standardization and inconsistent technology adoption among stakeholders.

With the exponential growth in computational networking capability, coupled with more powerful and flexible software applications, it is possible to apply information technologies in all phases of the nuclear power plant life cycle, creating the potential for data interoperability and for streamlining these historically fragmented information systems.

The IAEA was requested by Member States to assist in strengthening and maintaining the effective management and use of design knowledge and information over the entire life cycle of nuclear power plants. Management of the risks of design knowledge and information loss is challenging owing to the long lifetime of nuclear power plants. It is essential to maintain and ensure the integrity and validity of design knowledge and information over time to support the safe and efficient operation of nuclear power plants and effective decision making, and to mitigate the risk of knowledge and information loss.

New nuclear power plants are being designed, procured and constructed using multidimensional modelling computer aided design and engineering systems and a multitude of design information sources such as databases, such as digital databases and electronic documents. These computer based technologies and applications form an advanced virtual plant information environment. As a result, new nuclear power plants can be delivered with an information environment that is comprehensive, detailed, and interoperable and able to be readily integrated with the information management systems of the operating organization.

The primary challenge with these advanced computer based plant information environments is that they typically consist of one or more information models that are interfaced for information exchange with a limited level of information interoperability between systems.

These advanced computer technologies provide an opportunity to radically improve knowledge, information and data capture, integration, use and transfer among stakeholders, if industry-wide standards and good practices are adopted and a knowledge-centric plant information model is developed and leveraged to better support, manage and enable seamless sharing, transfer and use of sustainable design knowledge and information within and across each nuclear power plant life cycle phase.

This publication is the result of collaboration among representatives of Member States, subject matter experts and software solution vendors. The IAEA officers responsible for this report were M. Gladyshev, M. Ovanes and K. Kang of the Division of Planning, Information and Knowledge Management.

**CONTENTS**

# 1. INTRODUCTION

## 1.1. BACKGROUND

Following the action plan on Nuclear Safety (GOV/2011/59-GC (55)/14) [1], the IAEA was requested to assist Member States in strengthening and maintaining the effective management of nuclear design basis knowledge and information over the entire life cycle for licensed nuclear facilities, including design, construction, commissioning, operations, maintenance, long-term operation and decommissioning. Management of the risks of design basis knowledge and information loss is challenging due to the long lifetime of this asset. It is essential to maintain and ensure the integrity and validity of design basis knowledge and information over time to support the safe and efficient operation of nuclear power plants (NPPs), support effective decision-making and mitigate the risk of knowledge and information loss.

As indicated in IAEA Data Reference Series No. 2, 2017 edition [2], 328 of the NPP units operating at the end of 2018 were commissioned earlier than 1990. For these NPPs, much of the information regarding their design was initially provided on paper or through multiple information systems and databases from different vendors with different purposes. It is now possible to apply powerful information technologies to all phases of an NPP life cycle. This can create an environment to support effective, sustainable information interoperability, and thus improve these historically diverse NPP information systems.

New NPPs are being designed, procured, and constructed using advanced computer-aided design and engineering (CAD/CAE) systems, multidimensional modelling and design information sources such as data, databases, and electronic documents. This technology forms an advanced computer-based plant information environment. As a result, new NPPs can be delivered with an advanced computer-based plant information environment that is comprehensive, detailed and able to be integrated and interoperable with the information systems of the operating organization. The primary challenge with these advanced computer-based plant information environments is that they typically consist of one or more plant information models (PIMs) that are interfaced for information exchanges with a limited level of information interoperability among them.

These advanced computer technologies provide an opportunity to radically improve knowledge, information and data capture, integration, sharing, transfer and use between stakeholders if industry-wide standards and good practices are adopted and knowledge-centric information frameworks are developed, incorporated and widely used. A knowledge-centric plant information model (K-PIM) could be developed and leveraged as a modern and efficient approach to better support, manage and enable seamless sharing, transfer and use of sustainable nuclear design knowledge and information within and across all NPP life cycle phases. K-PIM is not only applicable to new NPPs and other new licensed nuclear facilities, but also applicable to all operating NPPs, and those entering decommissioning.

## 1.2. OBJECTIVES

The purpose of this publication is to provide an overview of PIMs, as well as stress the importance of the application of PIMs in support and management of design knowledge throughout the NPP life cycle and introduce a knowledge-centric plant information model that builds on the basic concept of a PIM.

The targeted users of this publication are Member State organizations that need, acquire and use plant information system for decision making with input from designer, constructor and regulatory authority during design, construction, commissioning, licensing, operation, maintenance, modification and decommissioning of NPPs. Thus, the primary users of this publication include the decision-making organizations in countries with experience with nuclear power programmes and those embarking on new nuclear power programmes.

### 1.3. SCOPE

The scope of this publication is to:

— provide general awareness of PIMs for support and management of design knowledge over the lifetime of the NPP on improving the safety and sustainability of NPPs;
— describe the concepts of a PIM to support NPP design knowledge management;
— assist NPPs in the retention, transfer and utilization of design and design knowledge information, and to maintain and build capacity for the competencies of new and existing workforce;
— increase awareness of the concepts of a knowledge-centric PIM for design knowledge management to help ensure the integrity and validation of the design basis to support effective decision-making and achievement of plant safety and economics.

### 1.4. STRUCTURE

Two plant information model concepts are described in this publication. Section 2 explains the commonly used PIM concept, its limitations and benefits, and describes current PIM practices in the nuclear sector. Section 3 introduces the concept of K-PIM and explains its differences compared with PIM. This section also underlines the importance of K-PIM to support design management for the nuclear industry and identifies the main challenges for K-PIM development. Section 4 describes the summary and conclusions. Each of these nuclear build environments still requires continued improvement in strengthening and maintaining the effective management of nuclear design basis knowledge and information.

Appendix 1 explains the benefits and values of current PIM practices. Annex 1 and 2 further showcase the lessons learned from other industries related to development of an NPP K-PIM and case studies on design, construction management and operation of complex engineering facilities based on PIM-technologies. In Annex 3 and 4, the life cycle approach to NPP information modeling in the French nuclear industry and Krsko NPP in Slovenia is introduced. Finally, the plant information management and application of PIMs are described in Annex 5.

## 2. PLANT INFORMATION MODELLING

### 2.1. INTRODUCTION TO PLANT INFORMATION MODELS

A PIM is a set of interlinked information about plant structures, systems and components, incorporating plant data, relationships and rules used to integrate, represent, and describe nuclear facility processes and data for each phase of the facility life cycle. This definition describes current industry practice and most existing PIMs in use today. PIMs are usually applied to specific phases during the NPP's lifetime, as they frequently do not include, alone, the context necessary to transfer design information across the plant life cycle. To understand what a PIM is, one first needs to understand that a PIM is fundamentally a specific type of information model matched to the business model for an NPP.

The philosophy and goal of PIM models is to achieve a higher level of common understanding, and accommodate the interchange of data, between business enterprises or technical entities: for example, the common information model (CIM) for computing is an open standard that defines how managed elements in an information technology (IT) environment are represented as a common set of objects and relationships between them. CIM for electricity, a standard developed by the electric power industry that has been officially adopted by the International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE), aims to allow application software to exchange information about an electrical network [3].

Another example is the facility information model. A facility information model is an information model of an individual facility that is integrated with data and documents about the facility. The facility can be any large facility that is designed, fabricated, constructed and installed, operated, maintained and modified; for example, a complete infrastructure network, a process plant, a building, a highway, or a ship or an airplane [4].

### 2.1.1. Why do we need a PIM

A common challenge within the nuclear power industry is the need to communicate NPP knowledge and information between entities. The worldwide new nuclear build programme has brought this into sharp focus with the need to transfer design knowledge information from the engineering, procurement and construction (EPC) organization to the owner/operator (O/O) organization. Although a similar need may arise in operational plants when two or more power plants are commercially contracted together through a merger or an acquisition, or even within plants between operations and maintenance.

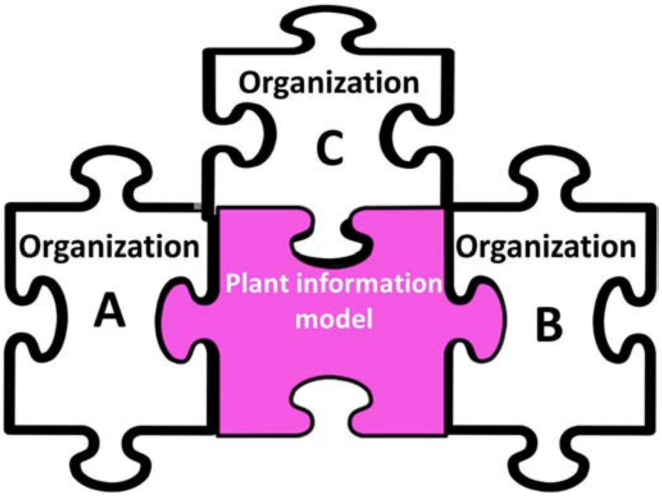


*FIG.1. Coordination of organization information through plant information model*

The PIM describes a common NPP language through which interactions and sharing of information can be managed (Fig. 1). The PIM is not only an IT data repository or a digital data hub, but the principles defined in the PIM will help build a common language to support IT systems.

### 2.1.2. Examples of PIMs

The definition and models above should become clearer if they are used to describe practical PIMs. This section describes three different scenarios in which a PIM may be represented or established in an organization.

*2.1.2.1. Scenario one*

Scenario one involves a PIM formed from existing IT systems that are determined to support PIM best practices, while meeting functionality requirements for the NPP. This first scenario describes the case where the concepts of a PIM are invested in a few major IT systems. This is the most common method in use today. This model has the elements of what would make up a PIM: information, relationships, rules, knowledge, objects and attributes are integrated and embedded within the organizations' systems and data. Many organizations approach the representation of the concepts of a PIM through single large combined suite of IT systems such as an enterprise asset management system, often combined with configuration management (CM) system and maintenance, repair and overhaul (MRO) systems for operating plants, to provide a database for PIM-related processes, functions and data.

Information interoperability is the ability of different IT systems and software applications to communicate and exchange information, and then use the information that has been exchanged effectively. This may lead to the selection of external applications that effectively interact and integrate with each, even if better individual functionality may exist in alternative systems or in an application suite.

Given a choice of software domains, most IT system vendors will naturally encourage priority for their product or software tools over a competitor or in-house application, perhaps even based on the interoperable argument. In the end, the user organization must strike a balance as to where functionality and, therefore, information and data are vested, versus compatibility fit or commercial convenience, in the target IT architecture adopted by the NPP. IT system(s) selection and purchase criteria, therefore, must include information interoperability and overall concepts of a PIM support, in addition to pure functionality.

*2.1.2.2. Scenario two*

In scenario two, the PIM is formed from the design engineering (or computer added engineering) software for 2-dimensional (2D) or 3-dimensional (3D) models. In this case, the concepts of a PIM are vested into a multidimensional modelling technology that can be potentially used throughout the plant lifetime. This scenario is typical for most new NPPs under construction today, as they were most likely designed through a CAD/CAE system. The application of multidimensional models, especially within a plant life management (PLiM) philosophy, is growing within the nuclear industry. The nuclear industry is learning from other industries, such as the aerospace and automotive sectors, and the 2D or 3D models originally developed within the design phase are being used in later construction and even operation phases (visualization, training, and eventually decommissioning). While the multidimensional modelling requirements for each NPP life cycle phase may be different, the bulk of the PIM information and knowledge content remains relevant.

*2.1.2.3. Scenario three*

In scenario three, the PIM is represented in a stand-alone, custom-developed information model based on metadata semantics and modelling of business processes. Once the PIM is represented, the software that can best support it may then be identified. In this scenario, the PIM is semantically-organized and structured into separate layers consisting of an item/data lexicon, an abstracted model layer that describes the information with relationships, rules, knowledge, objects, attributes, etc., and represented and managed within the systems and processes of an organization.

This is the most theoretical and idealistic among the three scenarios, as currently there is no industry standard or best practice that is mature enough, or even knowledge-centric enough, to fully represent this enhanced PIM concept. This is, therefore, the one scenario that in fact justifies the need for the development of a K-PIM that could then be used when purchasing or developing IT systems. The K-PIM is described more fully in Section 3, but the K-PIM would provide the semantically-enhanced and organized foundational inter-operability infrastructure, knowledge-centric framework and common language for the seamless exchange and transfer of sustainable design knowledge information across the NPP life cycle in a more useful way: understandable, logical, traceable, reproducible and manageable.

The major software and solution vendors will, in the near future, adopt the concept and support development of a K-PIM, and integrate it into more commercial off-the-shelf (COTS) IT systems that would then automatically be interoperable with other IT systems developed or purchased during the lifetime of the plant. This would, in turn, make the process of selecting and implementing PIM-based IT systems and software applications for the new NPP easier and more effective.

### 2.1.3. PIM benefits and value

Experience of world's largest companies in nuclear and hydraulic power generation, oil and gas, and chemical industries proves the necessity of PIM application backing engineering and technical information and configuration management systems of complex industrial facilities integrated through the information both with life cycle subjects and information systems used at different life cycle phases. PIM values are as follows:

*2.1.3.1. Designing phase*

- To improve quality of design, working and design documentation, and to significantly reduce design collisions;
- To shorten design completion periods through the use of unified designing standards and tools, human factor minimization based on a single information support of design and engineering activities, unified designing and engineering software environments, generation of consolidated centralized resources of accumulation and follow-up of designing works results, and usage of common accessible knowledge base;
- To develop in design institutions additional business directions basing on 3D designing results and multidimensional modelling technologies for allocation of services on facilities operation, upgrading, repair, rehabilitation and decommissioning maintenance.

*2.1.3.2. NPP construction and start-up*

- To increase effectiveness of interaction among contractor, design organizations, construction and installation companies and suppliers of equipment/materials, regulatory and supervisory authorities, involved in the work, through building and application of an industry standard PIM;
- To optimize rehabilitation/building periods and nonmanufacturing costs owing to detecting collisions of activities/supplies planning at early phases by means of work schedules visual representation on a design model;
- To minimize the human factor for rehabilitation/building quality owing to graphic sketches, textual and animated manuals on optimal consequence of assembling and installation of building structures and process equipment, as well as usage of data on spatial arrangement of building elements or objects that are handled by construction machinery;

- To reach transparency of construction and installation works (CIW) planning and management processes through online monitoring of workflow and scope and, thus, to facilitate timely detection and elimination of potential non-conformities and conflicts among project stakeholders, and allow for immediate correction of the work schedule;
- To ensure compliance of CIW results to an initial design at early phases through comparison of "as-designed" PIM with "as-is" PIM;
- To acquire reliable data aimed at developing an "as built" model during commissioning.

*2.1.3.3. Operation*

- To provide all operation stakeholders at all levels of short-term and strategic decisions making related to NPP as a whole and its certain elements with the necessary design and engineering, production, operation and other relevant technical information;
- To maintain better information exchange among operator, design and engineering, and scientific research institutions about current spatial configuration of the power unit making it possible to upgrade the design and engineering solutions quality and shorten their preparation period resulting in shortened periods of NPP retrofitting and higher quality of works;
- To improve the personnel training quality, to train personnel in complex repair works and operating tasks, eliminating emergency situations using training simulators, simulation models, and interactive training guides on PIM basis;
- To enhance the emergency preparedness and response through implementation of various engineering calculations based on PIM including assessments for preventive technical maintenance, as well as through the possibility to perform complicate technical analysis and to find out implicit regularities by means of complicated search requests that collect the information from several integrated operational information system (IS) and return results in the form of data overlaid on 3D engineering model;
- To reinforce operation safety and reduce overhead costs through the capability to jointly represent and analyze radiation environments and fire scenarios, conditions of active and passive fire protecting systems and equipment, data from job-order/permit-to-work systems, information on equipment, pipelines and another elements arrangement.

*2.1.3.4. Decommissioning*

- To provide all decommissioning project stakeholders with the required design, engineering, production, operation and other relevant engineering and technical information through a single repository;
- To facilitate development of integrated 5Dor 6D simulation models based on PIM for disassembling high-level equipment and structures of NPP with concurrent calculation of radiation dose rates, generated radwaste amount, required activities, schedules, resources, and cost evaluation;
- To calculate generated radwaste amount based on data about NPP radiation condition, contamination and geometry accumulated in PIM;
- To ensure effective and safe decommissioning performance pursuant to a design with the aim to reach specified final state by means of developing and further using a PIM that consolidates all required engineering data, comprehensive engineering and radiation survey (CERS) data, as well as visual representing of decommissioning works in progress on simulating models.

#### 2.1.4. PIM and information interoperability

A principal concept of PIM modelling is the information interoperability. The term "seamless" is often applied to successful interoperability products, where the exchange of data and the ability to depend on the semantics of such data is so fundamental to the software design that a powerful integration and scalability is available in the software that opens up the opportunity for establishing a true PIM and K-PIM.

Information interoperability is a topic that impacts most large capital asset industries. it can be a great benefit to safety, workflow and efficiency, as well as a source of significant work streamlining and cost savings.

PIMs are distinguished by the type and content of the organization, for the data contained in the PIM applications, and are normally driven by the mission and business model of the enterprise. Interoperability, therefore, can take on several forms and levels of sophistication to fit the requirement and structure of the existing IT solutions. At the lowest level, it is considered sufficient to match the metadata formats, lengths and edits to permit interchange of data between two simple IT solutions. At the industry and enterprise level, a full ontology and semantic mapping of metadata would be required to meet the ISO-15926 initiative [5].

From the very beginning of an NPP life cycle, it is essential to recognize the roles and contributions of all stakeholders that will generate, store, utilize or transfer design knowledge related to the NPP. This involvement evolves with time and does not end when the construction of an NPP is completed, but rather grows throughout its operational lifetime as the number of users, vendors and sub-contractors increases over its life cycle. Design changes that occur throughout the life cycle require the continuing management of the design basis and the ongoing accumulation of design knowledge (Fig. 2).

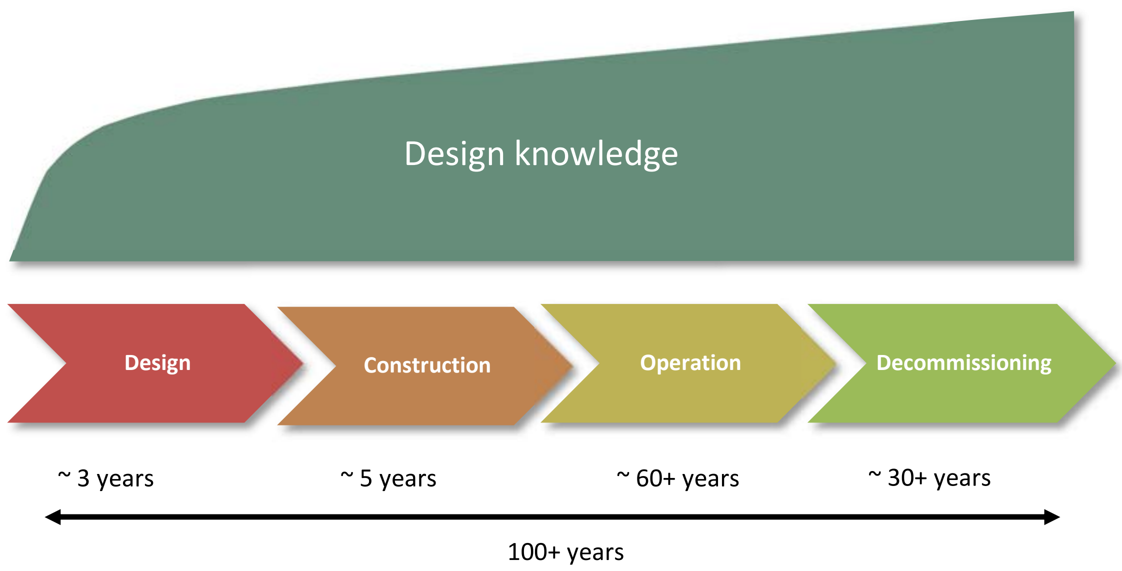


*FIG. 2. Knowledge available during NPP life cycle*

### 2.2. CURRENT PIM PRACTICES

The technology for data and knowledge management, and the infrastructure that supports the communication of such information between stakeholders is constantly evolving and changing. Currently, the level of technology that is available in organizations is the most important limit regarding how their PIMs support NPP design process management, design basis integrity and configuration management.

Most NPP IT systems have evolved during the life of the plant. In most cases, these IT systems were never intended to serve as a type of PIM that systematically unifies and preserves design knowledge, configuration management and other NPP information over its life cycle. IT systems were usually not selected with PIM infrastructure or functionality in mind, but rather were deployed to address existing business workflow and data collection requirements. The notions of knowledge capture and management, integration with other applications, sharing knowledge across organizations and the entire NPP life cycle, and (ultimately) establishing a plant information model, were, in the past, not usually considered in IT system selection. This creates a legacy approach to fitting existing IT systems into a concept of PIM architecture.

Because of this, PIM applications may contain information and knowledge from one phase of the NPP life cycle that may or may not be relevant or needed in subsequent phases. The need for information may also skip one or more phases. For example, basic design dimensional and physical data from the design and construction phase may not be needed again until decommissioning or a major modification. Preserving design knowledge over a long period of time (up to 100 years), multiple generations of management, vendors and workers, and through multiple life cycle phases, is likely the greatest challenge faced by PIM developers. This need may be resolved by the development of a K-PIM to be discussed in Section 3.0.

Figure 3 describes the general architecture for a PIM. Local metadata models and schemas are integrated as much as possible into PIM schemas to maximize interoperability and semantics. PIM models are customized into the various taxonomies needed to support the nuclear business model and related functionality, such as master equipment lists, design documents, engineering drawings, and maintenance requirements. The PIM schemas are also utilized to provide a path to integrate data for plant programs and use cases, such as CM, searches and document repositories.

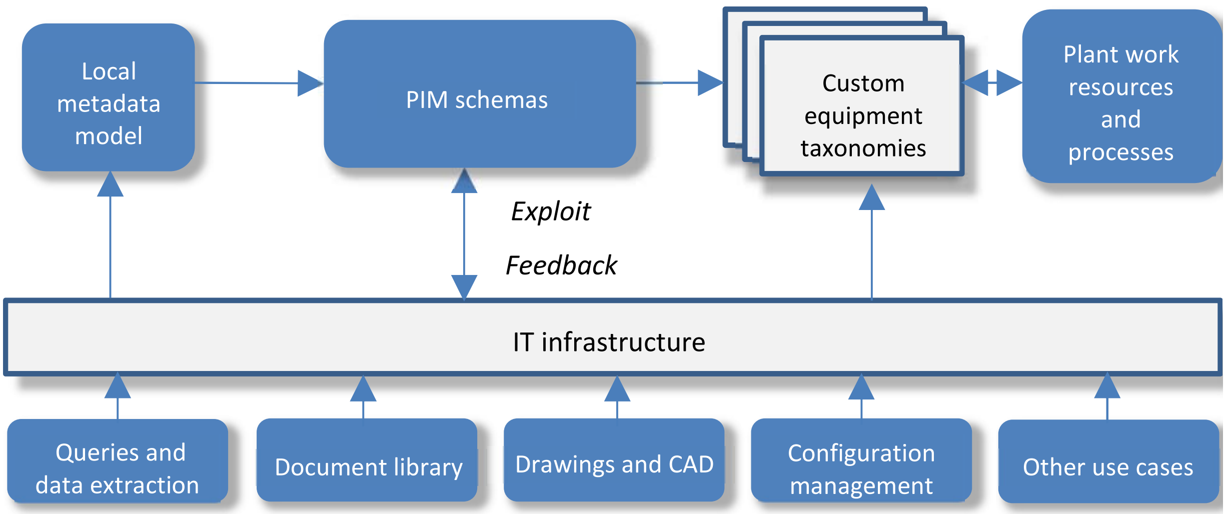


*FIG. 3. PIM architecture*

The next two subsections address the application of the concepts of PIM with respect to the NPP life cycle phases and key NPP processes.

### 2.2.1. Application of PIMs to design knowledge management

This section will explain how the implementation of PIMs is of central importance in the design knowledge management (DKM) process. DKM addresses the complex initial design process for NPPs and maintaining and revising this information and knowledge over time (i.e. throughout construction, commissioning, operation, modifications, and decommissioning). The application of DKM spans organizational boundaries, as, over a plant's life cycle many stakeholder organizations typically either contribute to the design of an NPP or are users of design information in order to carry out their works (e.g. plant maintenance and outage support). There is a need for clarity concerning who has overall responsibility for managing and maintaining DK through NPP life cycle. In this regard, specific functions of the design authority (DA) of the operating organization should be established as early as possible.

Effective DKM will ensure retention, availability and consistency between the initial design, licensing basis requirements, physical configuration, modernization of plant components and accumulated operating experience that are essential to the maintenance of design basis and configuration management. The design knowledge should be accessible and available to support plant safety throughout the NPP life cycle. However, effective DKM might not be realistically happening yet because of the existing organizational, technical, legal and other barriers hampering design knowledge capture, verification, integration, transfer and modification over the life cycle. A more realistic picture of the current state of the design knowledge transfer over the NPP life cycle is shown in Figure 4. As depicted, the level of design knowledge created and retained depends on the life cycle phase, and on how much design knowledge was captured and transferred - from previous phases of NPP's lifetime.

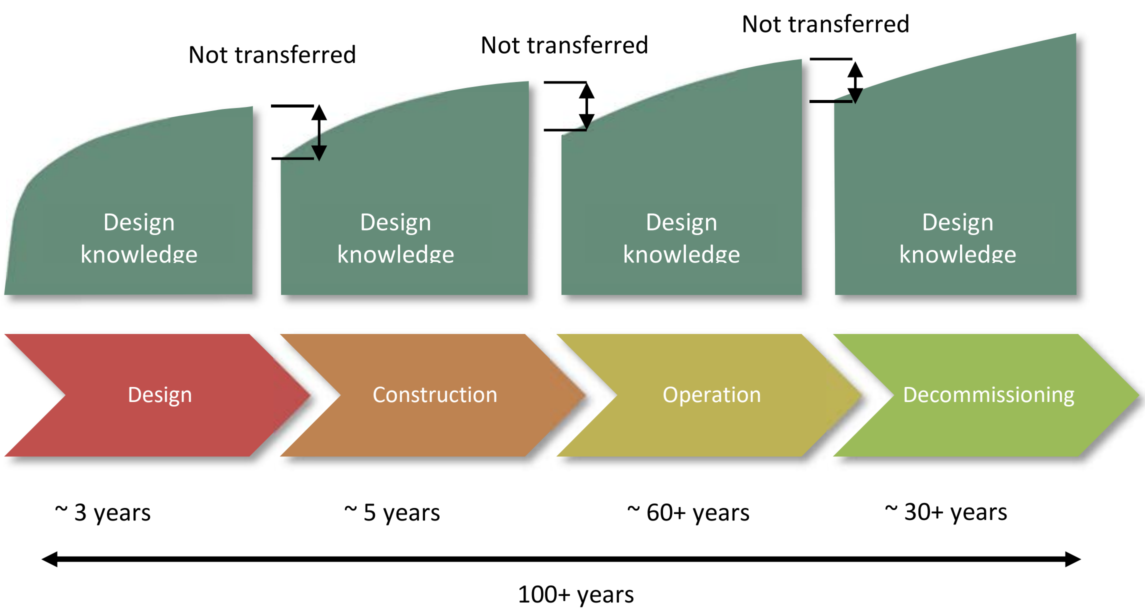


*FIG. 4. Design knowledge transfer over NPP life cycle*

DKM should be supported by modern information technology solutions to ensure that necessary design information will always be available as an essential input to decisions related to NPP safety, particularly to support design changes that are made over the entire lifetime of the NPP. As indicated previously, the selection of new IT solutions should include consideration for overall potential to support PIM concepts. The volume and complexity of design knowledge strongly indicates the need for technological solutions, and stakeholders involved in DKM should provide resources and/or be competent to apply, use and develop such solutions.

Proper DKM begins at the pre-design phase, as the more knowledge that can be captured at the point of creation, the better. DKM plays a critical role in knowledge management with respects to both the quantity and importance of the design information that is produced. The design information contains both tacit and explicit justification of a variety of requirements coming from several different stakeholders, e.g. the reactor designer, EPC companies, operating organization, the licensing authority and major suppliers. These requirements feed into specific design, procurement, construction and project management processes and can cover several domains such as:

- safety cases;
- license requirements;
- environmental requirements;
- operations & maintenance requirements;
- cost and planning; and
- decommissioning requirements and planning.

The satisfaction and subsequent demonstration of these requirements is the basis for the technical and physical configuration of the constructed plant, as well as for the contents of the information handover/turnover (H/T) from the supplier to the O/O. In order to prepare for the next phases of the NPP life cycle, the proper programme needs to be in place to transfer DKM information during the H/T process from the supplier to the O/O. It can be advantageous for the design authority to put in place the concept of the PIM early in the design process and ensure that all information required at H/T is clearly identified and fully captured.

From a design authority`s point of view, a DKM programme based on PIM should be implemented as early as possible through the integrated involvement of all responsible designers, starting from the conceptual design and basic design. This allows the capture of both tacit and explicit design knowledge to a greater degree, thus reducing knowledge loss. In addition, a DKM programme built on a PIM framework can help to capture the know-how and technical expertise of the responsible designer (e.g. the supplier). This approach also allows the re-use of key design knowledge in future projects by both the supplier and O/O. The DKM programme may contain the aspects described below.

#### *2.2.1.1. Coordination for design knowledge integrity*

The design of an NPP requires close cooperation between numerous engineering and technical disciplines and stakeholder organizations. Establishing the design authority function within the operating organization can be an effective means to maintain design knowledge integrity, as well as to maintain clear responsibility and a central decision point for all design changes across the NPP life cycle. To manage the design change process, information from all relevant disciplines is needed to support the design basis and other requirements of NPPs. In the past, such information was frequently stored in isolated databases and made effective collaboration difficult. The use of a common data dictionary providing a singular, unique definition of data concepts across disciplines, can bring consistency to these databases. In addition, a common dictionary can support data and information exchange with business partners and suppliers by using a semantic framework.

*2.2.1.2. Responsible designer as centre of design knowledge*

One of the main roles of responsible design entities is to manage the design knowledge. In order to have a better control of the design knowledge, the responsible designer, as the EPC for the NPP, can set up different activities, such as:

— Description of business processes and definitions, including which inputs/outputs are associated with each design activity. This effort will provide a better understanding of the design phase's organization that can be re-used for future projects. It can also be used by the responsible designer to develop and prepare the information model for H/T. In addition, the overall quality of information can be established and supported by the description of business processes and reference data sources within the PIM;
— Implementing a DKM programme can also be the appropriate occasion to transition from a document-centric environment to a knowledge-centric model. Examples of knowledge-centric approaches include structured documentation, text-based information repository (data-centric), or centralized data repositories in PLiM-type information systems that ensure positive version control and referential integrity of data relationships.

### 2.2.2. Application of PIMs for NPP life cycle management

A multitude of organizations are involved within and across the various phases during the NPP's life cycle, each one with its own methods and processes that create, capture and use knowledge. Generally, a significant portion of the knowledge created and used is explicitly captured in various documentation and information models that are specific to each organization's activities.

Over the NPP life cycle, organizations share, exchange, and transfer information. Thus, they need to agree on the scope and format of information to be shared, exchanged, and transferred. This process can be facilitated by the introduction of the K-PIM concepts that are described in Section 3. The following subsections further examine PIM considerations for each NPP life cycle phase.

*2.2.2.1.Pre-Design*

The pre-design phase normally spans the period from the NPP construction decision point, until the selection and engagement of the EPC contractor and/or reactor designer. Several events critical to the future development of a PIM take place during this time.

The knowledge and information gathered during this phase are both technical and institutional in nature, including scientific, regulatory and legal requirements, standards, and guidance. Once established, this knowledge and information will provide the basis for selection of the EPC contractor and reactor designer and provide the context for later design and construction processes. It is estimated that up to 70% or more of the basic knowledge that will guide the NPP through its life cycle is acquired during this period. Paradoxically, it is also the most vulnerable and at-risk period for losing knowledge, because in the past knowledge management processes making use of a PIM, IT systems or infrastructure for specifically identifying and collecting critical and knowledge have not been widely nor systematically considered. Any critical knowledge not transferred or explicitly captured during this phase of the NPP life cycle will likely need to be later either reconstructed or recovered from the EPC contractor, vendor, reactor designer or another commercial sources, usually at a significant cost.

For these reasons, it is never too early to establish a plan and preliminary activities such as training of responsible personnel, review of industry standards, and preliminary development of data schemas for a PIM. It is also important to carefully select enabling IT technologies, methods and processes for the knowledge capture and storage repository, to ensure that key knowledge from formal documents as well as unstructured sources, such as memoranda, discussions, e-mails, and research, is captured and remains accessible for later retrieval and use.

*2.2.2.2.Design*

The design phase plays a critical role in knowledge management in both the quantity and the importance of the information that is produced. During the design phase, the PIM provides the information infrastructure and framework to support obtaining and organizing necessary information. Project stakeholders then use this information in the design process to perform their specific tasks. Input data and requirements are developed for the "as-designed" NPP. A PIM for the as-designed data and requirements as-designed objects is then used to create the scope of the design documentation, configuration objects, calculations, and other design media. Since the PIM is a set of knowledge and data about the as-designed objects stored in electronic format by established rules, it contains the initial baseline information for engineering calculations, as well as supporting mathematical, computational, and simulation models.

The design information contains both the tacit and explicit justification of the satisfaction of a variety of requirements coming from several different stakeholders, such as the reactor vendor, EPC companies, suppliers and regulators. These requirements cover several domains that feed into specific design, procurement, construction and project management processes such as:

- license requirements;
- environmental requirements;
- operation and maintenance requirements; and
- cost and planning.

*2.2.2.3.Construction*

At the construction phase, the PIM provides the information infrastructure and framework to support obtaining the required information from each stakeholder related to their specific tasks, input data for requirements, as-designed, to be then joined by as-procured and as-built. The PIM contains refined and reviewed information for engineering calculations, updated by construction experience and field change requests.

At the construction phase, PIM is applied for:

- making of specific construction solutions;
- creation of high-quality construction documentation;
- estimating and building construction plans;
- purchasing of equipment and materials;
- other purposes related to the object;
- configuration management;
- requirements management and traceability;
- identification, control and management of design margins; and
- design change management.

PIM is used in specialized tasks, such as:

- visualization of the volume and arrangement of objects, checking for conflicts in the design 3D modelling;
- automatic receipt of plans, drawings, specifications, etc.;

- calculation of the quantities of materials and labor, bill of materials, requisitions;
- search related objects documentation such as design, requirements, as built, etc.;
- estimating and building plans, network schedules of construction and installation work;
- procurement, supply chain of equipment, materials;
- construction management;
- creating video and animation to familiarize staff with the location of objects at the NPP;
- identification of construction collision, 4D modelling;
- modelling of technological processes, construction process optimization, visualization;
- education and training of erecting teams, construction personnel; learning how to work with mechanisms and systems;
- allocation of equipment, materials to the WBS, construction work packages, schedules;
- labour and manpower calculations.

*2.2.2.4.Commissioning*

The NPP commissioning process is a complex and high-risk stage from a knowledge and data integrity viewpoint, given the significant knowledge transfer events between EPC, suppliers and O/O at this time. Knowledge capture and transfers of significance include, for example, the conduct and recording of acceptance testing data, and H/T of final design documents and packages for acceptance of the NPP.

It is during the testing, acceptance and commissioning phase that the EPC contractor will be transferring the bulk of the final, verified design information and knowledge for the NPP to the O/O. Unless a common information and knowledge transfer infrastructure, such as a PIM, has been put in place and has been utilized to capture design information and knowledge, an additional process (and repository) will likely be required. This process will need to translate and migrate the uploaded EPC contractor information and knowledge to the O/O's system, assuming the O/O has established such a design capture repository or system. The validation of EPC contractor information and knowledge can be very difficult without the implementation of a well-designed PIM. Typically, the contracts between the EPC contactor and O/O defer acceptance of final design information until the NPP has completed its first year of operation, particularly if a large number of design or document changes are expected.

*2.2.2.5.Operations and Maintenance*

When the O/O accepts full responsibility for NPP design, the O/O manages systems, structures, and components (SSCs) as part of the plant asset management. The design basis includes the defined service life and maintenance requirements throughout the operations phase as plant modifications, including those required by changes in regulations, are implemented. The performance and condition of components is observed, measured and recorded over the plant life cycle. A PIM is a suitable method to manage plant SSC life cycles based on industry-accepted criteria and parameters. Another factor that can hinder successful H/T is information interoperability from dissimilar IT systems without proper integration, particularly during the H/T process of plant data from EPC contractor, vendors and suppliers to the O/O. This can include IT applications that are provided from the manufacturer or equipment vendor that are required to be used as designed to ensure performance or warranty coverage. On other occasions, they are IT applications that, for technical, cost or management reasons, are not designated to be replaced. In this case, a PIM provides the ability to translate and collect data via synchronizing/replication or direct transfer. Both of these events offer opportunities for data normalization, which further enhances a PIM's ability to maintain an NPP's design basis and CM data repository by increasing the semantic value of, and reducing redundancy in, the data.

Also, any potential plant life extension-under consideration during the operations and maintenance life cycle phase, will greatly benefit from availability and accessibility to quality data[1].

PIM containing updated and reliable information allows users to efficiently solve the following tasks:

- Routine inspection of the current system state and parameters, equipment, and other NPP elements by means of on-line monitoring events of performance/non-performance of scheduled inspections by personnel, as well as on-line representation of current parameters and equipment condition values collected by the personnel during the walk down surveys;
- Planning and controlling of routine maintenance and repair measures: the joint use of PIM, colour labelling method, automated identification of equipment and mobile computing devices and integration with MRO (maintenance, repairs and operations) and project management information systems are advisable for solving those tasks;
- Engineering evaluations (i.e. strength calculations, hydrodynamics calculations, mean-time-between-failures calculation, etc.): it is to be performed with the use of certified calculating codes and current 3D engineering model integrated with operational data. This approach encourages transition from schedule preventive MRO to condition-based maintenance, which is considered more efficient;
- Integral reprocessing of the radiation information and fire protection data: structured data storage containing information on radiation and fire protection in NPP rooms are visualized in the 3D engineering model and can be used not only for the analytical reprocessing, but also for solving immediate tasks related to walk down surveys routing and repairs considering radiation dose rate tolerances for fire-fighting personnel, etc.;
- Information support of material science tasks: they are performed by means of storage, systematization, processing, analysis and visualizing NPP equipment and pipeline metal non-destructive inspection results;
- NPP safety analysis: the task foresees calculating complex indicators calculations on radiation safety, fire protection, technical safety and other areas and visualizing conditions according to the analysis areas on power unit 3D model. Complex indicators are to be calculated on basis of initial values resulted from systems and devices operation monitoring and accumulated in the information base. Using retrospective information makes it possible to evaluate time history of values changing;
- Training maintenance and operating personnel: it is performed with the use of interactive digital manuals, displaying materials, simulating models and tools developed on PIM basis;
- Planning and training measures on accidents and emergency situations preventing and response: the task is to be performed using trainer-simulators and simulating models developed on PIM bases.

*2.2.2.6.Decommissioning*

The design base of an NPP encompasses an extensive amount of information, which is needed during the decommissioning phase. A considerable amount of the NPP life cycle knowledge will be accumulated by this time, some of which has high potential for improving decisions during the decommissioning phase. Knowledge accumulated during the design and operational

[1] Quality data is data having an agreed upon quality level of validation, verification, and certification (Verification and Validation).

phases, which has importance for decommissioning, originates from various plant sources of a diverse nature. Some of this knowledge is explicit information resulting from measurements or modelling. Some of this information can be of great use in supporting decisions for access and storage during decommissioning. However, capturing and transferring all relevant information for decommissioning from the design and operational phase to decommissioning decision makers in an accessible and understandable way, requires that the information is, or can be, linked to a standardized PIM-based information system shared throughout the entire life cycle of the plant.

Some of the knowledge relevant for decommissioning may reside in the methods and procedures used during the NPP's construction. For instance, external contractors hired for decommissioning jobs must be trained and qualified on NPP safety procedures before work permits can be issued.

Finally, a good deal of the knowledge that is valuable for decommissioning may reside in tacit form, in the experience and skills of the people that have designed, operated and maintained the plant. This kind of knowledge is, for a number of reasons, very difficult to capture using traditional methods. The use of knowledge management tools combined with a suitably designed PIM can be of great benefit in capturing and maintaining this knowledge. This allows the capture of both tacit and explicit design knowledge, to a greater degree, thus reducing knowledge loss [6].

### 2.2.3. Application of PIMs for key NPP process

#### *2.2.3.1.Requirements management*

At the design phase, the requirements for the safety, and operational performance over the life cycle are established. These requirements will generally include regulatory requirements, legal requirements, scientific principles and industry standards. These requirements will then drive the development of a design basis and rationale for each SSC's normal operation, safety cases, life cycle maintainability and asset performance.

Because requirements may not necessarily address a specific SSC, an important feature of a PIM framework is that it supports the capturing and management of general requirements and design basis, apart from specific SSC references. It also needs to be data-centric, to permit the retention of requirements that are not document-based or must be maintained apart from a host document. In addition, the bulk of the requirements during the pre-design phase will come from knowledge sources such as correspondence, industry standards, and engineering documents. Such knowledge sources may not have a defined structure, may not lend themselves to storage in a repository, and as results are at risk of loss, over time. Thus, a process and content management system based on the concepts of a PIM should be in place from the beginning of the NPP development to ensure that early design knowledge is captured and organized for the intended applications.

#### *2.2.3.2.Configuration management*

Configuration management can be achieved in a number of different ways. However, one of the most effective ways of doing this is to utilize a PIM framework as the basis for the NPP information infrastructure. This is mainly because of the ability of the PIM to serve as a "single source of truth" to identify the relationships, status and version of SSC documents, and their corresponding design and licensing basis. This forms the key essentials of the CM "triangle" and verifies equilibrium. Such a capability depends primarily on a reliable database model that may be accessed easily and can interface and interoperate with other information utilized for the NPP. This forms a basis for transfer of design, operation and maintenance information as IT technologies evolve, or are replaced during the plant's life cycle. In addition, it would be ideal for similar-technology and like-minded NPPs to utilize an agreed PIM framework to exchange and use operating experience, lessons learned and maintenance information directly. This would reduce semantic issues when translating the information shared and exchanged between stakeholder organizations.

Utilizing PIMs can also improve the ability for NPP design knowledge to bridge the life cycle phases of plant design, construction, operation, LTO and decommissioning, as each phase in the plant life has its own knowledge and information requirements. Such information can often be mistakenly considered obsolete or irrelevant and thus not be available when needed for major plant modifications or steam generator replacement as well as decommissioning, unless such needs are carefully analyzed, and requirements identified on an on-going basis. Currently, the typical plant design lifetime is about 60 years, which is by far exceeding the working life of any plant staff. Thus, the content, integrity, corruption, misplacement or loss of such information is at risk without an effective repository.

#### *2.2.3.3.Margin management*

NPP operators and design engineering organizations, utilizing the configuration management system and design basis of SSCs, are required to periodically reassess, revise and maintain SSC safety and operational performance. This includes maintaining the design, safety and operating margins as the plant and its SSC change with age. Margins, over the life of an SSC, can change due to wear, physical or radiological damage, or as a result of changes to other SSCs, as well as changes in manufacturer or regulatory requirements. Any of these factors can contribute to a reduction in the margin of operation remaining until the safety or operating margin of the SSC is no longer considered acceptable, performance is severely degraded, or the SSC ultimately fails. The margin for a system in performing its design-basis function is normally made up of the cumulative margins of the components that apply to each safety case and accident scenario plus other margins added for reliability.

Given that, the margin for a component relies largely upon standardized equipment performance and condition data, as well as observed physical wear and degradation of the component function, margin management can thus benefit from a PIM to:

- quickly analyze, compare, track, update and standardize expected margins and expected generic margin changes across like components through appropriate semantic descriptions;
- review of utility, owner's group and other manufacturer operating experience;
- effectively share margin performance and change data from manufacturers and other O/Os with similar plants or SSC; and
- better understand overall industry operating experience, failure and reliability history.

#### *2.2.3.4.Handover/turnover*

For the purpose of this document, H/T means either the handover or the turnover of information; whichever one is applicable to the current business process at the time. H/T is defined as:

- Handover, from an O/O's perspective, is the transfer of "approved-for-use" information from an EPC contractor or supplier to the O/O for use in pre-operational readiness activities. Handover is also a continuous process between stakeholder organizations within and across the NPP life cycle phases to support their activities and milestones.

— Turnover, from an O/O's perspective, is the official transfer of "as-built" and final information from an EPC contractor or supplier to the O/O for use in the operation and maintenance of the plant. Turnover also occurs between stakeholder organizations for an official transfer of responsibility and ownership within and across the NPP life cycle phases.

A PIM can help to ensure required information is clearly identified and captured to share and exchange and transfer at all H/T points.

*2.2.3.5.Quality assurance and integrated management system*

Another benefit of PIM is that it acts as a quality assurance (QA) system for NPPs. By creating a well-understood PIM, auditor and regulator confidence should be increased. Quality controls, such as maintenance hold points, surveillances and component testing for handover or return to service, can be supported by PIM features such as standard equipment lists, requirements documents, procedures, specifications, test data and document references.

When quality standards are to be reviewed and enforced with qualified suppliers and vendors, a PIM can help to prevent design knowledge transfer issues. PIMs provide a common platform and architecture for exchange of design information without the loss of key knowledge or data management and semantic issues. A PIM can help a subcontractor to better understand the "language" of the buyer and to deliver the service or materials that are needed. The goal of information interoperability is the key to information standards in most technical industries where information integrity and consistency becomes a bigger challenge as more subcontractor-based or outsourced work has become the norm. This is the major goal of the widely accepted ISO-15926 [5] for data interoperability standard as well.

Finally, the Integrated Management System (IMS) for NPPs must be able to resolve and relate the available information to processes, organization, interfaces and procedures within the NPP and externally with stakeholders to facilitate audits and corrective actions. The ability to enable these relationships depends upon common, standardized, well-understood and represented concepts that a PIM can provide.

## 2.3. PLANNING FOR PIM IMPLEMENTATION

### 2.3.1. General requirements

A PIM is a key element of the overall NPP knowledge infrastructure. The early establishment of a PIM ensures a high level of historical context and reference data capture, particularly in the early periods of an NPP project when many design decisions, processes and documents are generated. Without a PIM and given the potential inexperience of the project staff for new NPP projects, key knowledge and information may not be recognized, or simply get lost.

Additionally, at the beginning of a new build venture, organizations may, be faced with the challenge to overcome an existing or legacy organizational structure, processes and systems. PIM implementation can help both to identify and overcome these issues early in the project implementation.

### 2.3.2. Preparation for adopting a PIM

The cost and benefits of moving towards adopting a comprehensive PIM framework depends on the status and nature of the organization. The introduction of a PIM is not only applicable to O/O and EPC contractors at the beginning of a new build's life cycle, but also to all stakeholder organizations throughout the entire NPP life cycle. For example, a plant reaching the end of its operational life may need to develop a PIM framework to prepare for decommissioning. This can include understanding civil structures – the weight and volume of tons of concrete to be moved, the amount of steel, the scrap value of parts, the irradiation of machinery and the construction/deconstruction sequences. Such data may not necessarily be readily available. PIMs can also be used for design studies that ensure that main safety functions and supports functions, such as electric supply of heat, ventilation, and air condition (HVAC) are ensured even after deconstruction of systems, structure and certain components of the NPP.

In an operational NPP, it is possible that the operation and maintenance databases are not well-aligned, or have different key data identifiers, such as tag numbers or document IDs. Data may also be stored in unsearchable documents, causing delays in resolving issues.

It is, therefore, important to have a mechanism to evaluate the current business and IT environment that can be used to form a business case for investment in a PIM. This can be accomplished by using a PIM maturity matrix.

The PIM maturity matrix gives a visual indication of the maturity of a PIM in the current business and IT environment. Indicators can be used both within a team and over life cycle phases to indicate the barriers that exist between disciplines and phases.

PIM maturity maps utilized for self-assessment may be developed to suit. For example, an organization already in the operational phase may wish to evaluate its performance across disciplines, and their impact on the enterprise. See Appendix I for examples of PIM maturity self-assessment audit score cards.

### 2.3.3. People, culture and organizations

Developing PIM capability is not only a technical challenge, but also an opportunity to develop further knowledge, skills and competencies, governance and viewpoints to achieve a new way of working. The full business value of a PIM can only be realized by an integrated and systematic effort to consider technology, people, organization and governance issues related to its implementation. The people, processes and technology are usually identified with the KM strategy and principles. Governance is an additional factor to be considered, in order to ensure that all applicable safety and performance requirements and long-term business planning goals and targets are met.

In order to consider people first, an underlying cultural environment and work habits may be well embedded in most nuclear organizations. The younger generation of professionals have a different set of expectations than previous generations, particularly with regards to the availability and use of enabling technologies. Young technicians and engineers tend to be more comfortable with digital work environments and are expecting digital information to be readily available.

In many cases, it will not be sufficient to establish reliable and easily retrievable information, but it will also be necessary to convince the users of the reliability of the digital information, and the configuration management of the NPP. In addition, certain NPP safety processes do not permit decisions based solely on single-failure sources such as electronic data. Motivational measures that may help build a knowledge-oriented organizational culture may include the aspects described below.

*Leadership*

If managers and opinion leaders in the organization are aware of and can communicate the opportunities offered by using and maintaining a PIM, the likelihood of achieving effective and efficient use of a PIM to improve the organization’s way of working will increase. As in all areas of leadership, management needs to be motivated to set an example and employ the technology in their work.

*Training*

No new technical capability is fully embraced before it is mastered. No matter how easy to use it seems to be the software and information provided by the expert or developer, adequate training and instructions must be provided to the users. In this context, it is also beneficial that the instruction refers to the added value obtainable by the organization from acquiring this new capability.

*Intuitive user interfaces for adding, maintaining and retrieving information*

Plant information is only as valuable as it is accurate, and only improves decisions and actions in so far as it is used. Spending time on making interfaces relevant for the user's situation and intuitive to use will be important. Most 3D tools, while seemingly advanced and modern, are often regarded by infrequent users as difficult and cumbersome.

*Success visibility when achieving improved safety or efficiency using the tools*

In many cases, improved quality and easily accessible plant information would likely result in enhanced safety and improved organizational performance and efficiency. After an organizational learning-curve period, improvements should be achieved, and benefits become visible to both management and plant staff.

The value of PIM and the benefits/trade-offs need to be clearly communicated, otherwise there may be some resistance concerning the use of the PIM due to a lack of understanding of how it works, and which benefits can be achieved. Questions to ask when planning for PIM implementation may include:

- what is the underlying organizational culture (particularly with regard to IT systems) and how does it need to evolve?
- does the NPP currently rely on a certain individual or small group who "engineer" data in spreadsheet form?
- is a "document-centric" approach, where documents are repeatedly searched for design knowledge, considered sufficient, or should a "data-centric" approach to design data be implemented?
- how will PIM help specific jobs to coordinate with others?
- which training and communication strategies will be required?
- what management support and buy-in is there and is it strong enough to see the vision of a solution being implemented?
- can the owner rely on the type, quality and quantity of the information the contractors deliver, and what is their organizational and safety culture?

It is important for people to learn how this new approach will affect their work, the works of others and interactions with partner organizations. The organization's lessons learned and corrective action programme should be used both for early identification of changes needed in the PIM project and to aid future projects within the organization.

### 2.3.4. Processes and interfaces (internal and external)

Most organizations involved in the nuclear industry are heavily dependent on their processes to ensure the quality of activities performed. These processes are described and controlled through an integrated management system [7]. The IMS addresses both internal processes and those that involve interfaces with external organizations.

When moving to a data-centric PIM, affected processes need to be examined and updated. Questions such as the following should be posed:

— are processes written to produce documents instead of data?
— are the contracts written to produce and deliver only documents?
— will suppliers be willing and able to change?
— what is the data each process needs or relies upon that is produced by other processes?
— does the IMS have to be extended or revised to describe the supplier-customer aspects of data exchange?
— who will write/rewrite the required process descriptions and procedures?

Figure 5 shows the decision-making information model.

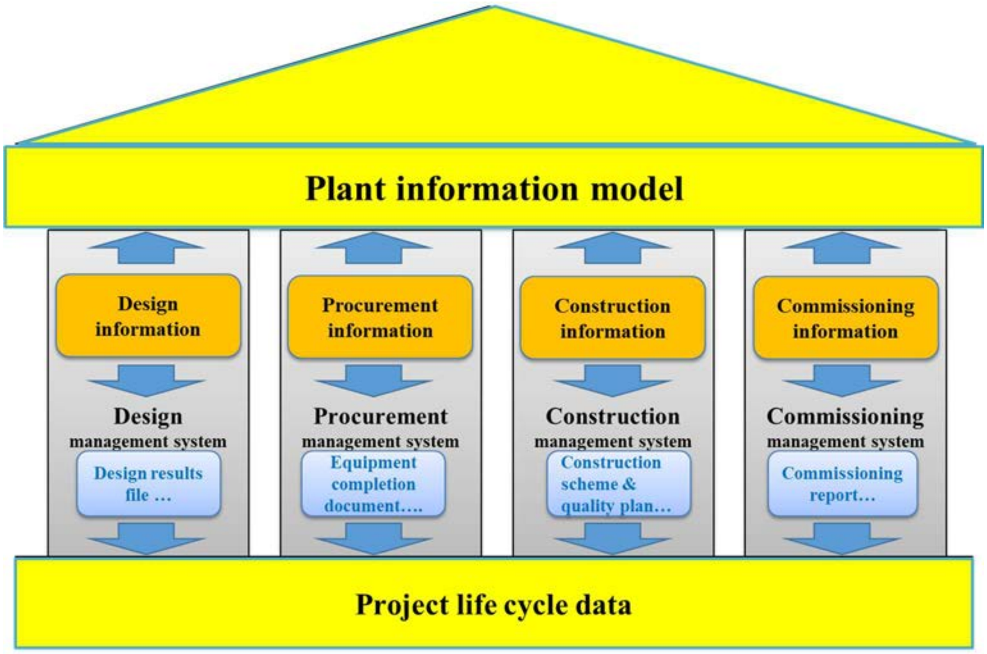


*FIG. 5. Inter connection in plant information model*

### 2.3.5. Technology and data sources

The technology solutions for utilizing the PIM should include the features described below.

*System Architecture*

The general IT architecture of the solution should utilize the PIM and allow interfacing and integration with a standard, defined data model. This integration should be achieved through methods of data integration, referential data or middleware data “translators”.

*Data migration and adapters*

Legacy data (data contained in applications developed before an integrated IT plan is implemented) may be integrated into production IT systems either directly or, if needed, after technical and semantic evaluation. With the support of a PIM, such information may be validated and retained, or disposed of as unreliable, duplicated or obsolete. This allows the ability to determine the best fit of any legacy data.

### 2.3.6. Integration with legacy systems and data

Legacy IT systems and applications are those developed before an enterprise IT system is fully implemented and deployed for an NPP organization. Normally, these IT systems and applications are developed by plant organizations to manage specific processes or reporting requirements, usually at a department or section level, without consideration of a PIM. This type of software may range from standard office applications, such as spreadsheets or word processors, to COTS departmental-level applications acquired and maintained by the organization.

Many of these legacy applications have been installed ad-hoc on personal computer platforms and are frequently not purchased or maintained by the IT department. This can cause interface and software life cycle problems, because these applications are isolated from the bulk of the plant operating environment. This limits the application and information as it cannot be updated or version-controlled by the IT department. Troubleshooting of software bugs or problems also becomes difficult, because the IT department is expected to repair and maintain software that they did not approve, purchase, deploy, or get trained on. It is also likely that such software does not fit into the NPP enterprise target architecture. The isolated information from such applications also creates risks regarding configuration management and NPP design decisions. As a result, for some legacy or specialized applications, a decision may be made to not integrate them into enterprise IT systems. The value of including any data from such applications into the PIM schemas should be evaluated on a case-basis.

The semantics and schema/dictionary for legacy applications are normally difficult to determine, as documentation, specifications and training for such applications may be brief or non-existent. If developed in-house, IT development procedures, documentation and software QA standards were likely not followed and the application, over time, becomes difficult to troubleshoot and repair. Most importantly, the data model for the legacy application is unlikely to have a validation process or follow any standards to aid in semantics, formatting or resolving data ambiguities. From an organizational viewpoint, such legacy applications also encourage isolated functional and process centres which do not communicate or integrate well with the plants enterprise IT systems.

As the NPP organization improves data quality by developing an enterprise IT system that allows the integration of COTS systems, data sharing and process integration with legacy applications becomes less common. Once the value of the data and processes contained in legacy applications is determined, an informed decision can be made to migrate or connect them in some manner with the enterprise system.

This connection may be made through:

- data sharing (distributed or off-board processing);
- process sharing (integration of applications);
- middleware (translation/bridge-ware); and
- absorption (migration of data and/or functionality and subsequent disposal of legacy data).

### 2.3.7. Interoperability across the NPP life cycle

Nuclear projects involve experienced organizations that routinely use CAE, CAD or other engineering tools. Each such organization has a specific IT system driven by its own business needs. The goal of information interoperability is to enable information exchange, regardless of how heterogeneous the IT systems are. In addition, information interoperability can help to bridge the gaps between specific country/international regulations or between different engineering cultures, such as EPC contractors, O/Os and suppliers.

Standardization initiatives have been launched over recent decades in order to facilitate information sharing and exchanges. These initiatives were limited in scope and in technical approaches. They resulted in the creation of standard file formats that are readable by different software platforms. Examples include Drawing eXchange Format (DXF) files for drawings, ISO STEP for exchange of 3D objects, and PDF files for documents. PIM frameworks deal with a finer level of detail and a broader scope; their goal is not only to share a specific genre of artefact, such as renderings or documents, but also to be able the share, exchange and transfer engineering and technical information throughout the life cycle of the asset. This has been the aim of the ISO 15926 [5] standard for more than 15 years. This standard specifies not just electronic compatibility, but also a semantic element and formatting consistency. However, these standards initiatives have not yet been sufficient to address all needs of the stakeholders involved over the life cycle of an NPP.

*2.3.7.1.Interoperability and flexibility of the IT architecture*

Another challenge of information interoperability is to bring flexibility to an existing IT architecture within an organization. Indeed, an NPP is a specific asset that is designed to operate up to 60 years (or more) and could require 10-20 years to be decommissioned. When design and development time is added, there is a need for information management in some form for up to 100 years, or even longer. Statutory requirements such as nuclear insurers and government record-keeping laws may even extend this period. For such a long period, maintaining the integrity of information is a major issue, because of the risk of digital and technical obsolescence. Compared to the lifetime of an NPP, the evolution of hardware and software solutions, file formats and computer infrastructure has been much faster. These should be updated with new version according to time schedules.

Reasons for maintaining such knowledge are diverse, including:

- records need to be managed for legal as well as technical reasons;
- modifications need to be tracked for license compliance and configuration management purposes;
- information is necessary to support long term operations (LTO) and the decommissioning phase.

To manage the risk of losing design knowledge, specific knowledge management procedures and processes need to be put in place to maintain this information, and to ensure it is accessible in the long term using non-proprietary formats [7]. The NPP organization should have a long-term strategy to review IT systems and platforms with the objective of managing technology evolution and obsolescence, in order that knowledge and information are preserved in an accessible, PIM-compliant format for its entire life cycle.

## 2.4. BENEFITS AND LIMITATIONS OF CURRENT PIM PRACTICES

### 2.4.1. General benefits

PIM benefits are generally divided into two groups, namely safety and economic aspects. From a safety perspective, a PIM framework helps to:

- facilitate the ability to seamlessly exchange/transfer design and design knowledge information throughout the entire plant life cycle;

— improve collaboration between organizations in an understandable, logical, traceable, reproducible and manageable way between O/Os and contractors, and among a fleet of standard designs;
— navigate, interpret, coherently compile and rapidly access massive amounts of information from documents, requirements, and CAD data accumulated over decades of the NPP life cycle;
— streamline and improve the quality of H/T processes.

From an economic perspective, a PIM framework helps to:

— lower design and construction costs and time;
— increase the quality and reliability of data used to support higher efficiency in engineering, maintenance activities, plant processes and programmes;
— streamline change control and decision making among stakeholders.

### 2.4.2. Specific benefit values

An analysis of international experience, published in various industry sources, supports the fact that 3D engineering models and PIM frameworks provide value at operating NPPs. A summary of the analysis results is given in Appendix I of this document.

### 2.4.3. Limitations of current PIM practices

The entire life cycle of an NPP requires the participation of a broad range of stakeholder organizations such as: EPC contractors, O/Os, regulators, TSOs, R&D organizations, trade organizations, and government ministries. While all stakeholders acknowledge the overall need for safe, reliable design and operation of the NPP, they still balance their own priorities, agendas and requirements against the common, theoretical benefits of confirmation management design knowledge management and the PIM. The main stakeholders in this chain often may have competing strategic, legal, and commercial requirements to find a common ground for nuclear knowledge sharing and collaboration.

A PIM not only enables better sharing and exchange of design and construction information and knowledge from the principal EPC contractor or designer, but also from subcontractors. These include design and construction sub-contractors and material and parts suppliers. All of these stakeholders have their own reasons for deciding whether or not to share information and knowledge, and for determining how much, and for how long such information and knowledge may be available.

Some key limitations are:

— Most current concepts of a PIM solution are unique to a given organization or consortium business environment. These PIM solutions consist of multiple, complex IT software systems that have been stitched together by means of translators, software tools and application program interfaces (APIs). Some of these complex IT software solutions constitute a de-facto PIM by themselves. These concepts of a PIM solution work fine (or at least meet requirements) within a particular business environment. However, the IT software should be modified in a timely manner to interoperate with or share, exchange, or transfer data to other business environments within or across the NPP life cycle phases. This kind of environment in particular creates dependencies between the IT systems that can cause difficulties in case of commercial upgrades or replacements and will necessitate dedicated IT support;

— Current concepts of PIM practices are improving NPP design knowledge. However, these are rather focused on design and construction of NPPs, than on the knowledge preservation and transfer of the complete NPP design across the NPP life cycle phases;
— Many industry standard initiatives, such as ISO 15926, building information modelling (BIM) [5] and other similar ISO standards initiatives already include PIM concepts. Many industry groups that are working to improve and update these standardization initiatives, are primarily working within their own agenda, plan and goals. However, some of these groups are starting to work together, through both formal and informal agreements, toward a harmonized framework.

## 3. CONCEPTS OF A KNOWLEDGE-CENTRIC PLANT INFORMATION MODEL

### 3.1. INTRODUCTION TO THE K-PIM CONCEPT

#### 3.1.1. Data, information and knowledge

In the field of information science, the terms of data, information and knowledge are closely related. Nevertheless, there are significant differences between these terms especially in their ability to support decision-making. Data, information and knowledge can be represented as a pyramid, a hierarchy that rank those concepts (Fig. 6).

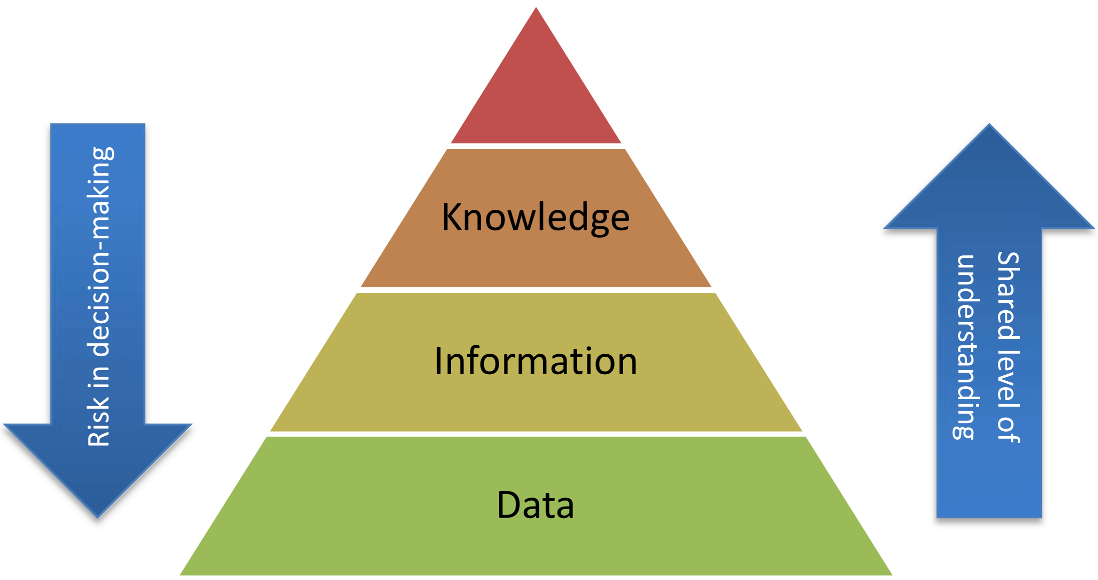


*FIG. 6. Knowledge hierarchy, level of understanding and related risk in making decisions*

At the bottom of this pyramid there is data. Data can take the form of symbols, figures or facts that represent or describe events, objects or phenomena that are not structured in any way. Data can be processed, structured and linked together in such a way that it becomes interpretable, readable, and provides an accurate description of the object or the phenomenon studied. This is information. Finally, knowledge is when information is sufficiently contextualized to reach an exhaustive and unambiguous understanding of the description.

Consequently, if decisions are based on knowledge rather than on information, they are likely to result in less risk. Furthermore, the completeness and the clarity of the description associated with the knowledge to be managed make it easier to share and understand.

### 3.1.2. PIM versus K-PIM

The development of NPP projects utilizing PIM-based solutions and architectures have given way to new opportunities in managing unforeseen and more complex business cases throughout the NPP life cycle. The rising complexity in NPP design, NPP project operations, extended enterprise organizations, regulatory requirements and client oversight have fueled the need to be able to quickly and effectively make decisions and solve sophisticated problems as the industry's business cases become more knowledge intensive.

Section 3.1.1 explained the distinction between information and knowledge. Regarding information modelling in the context of NPP and design basis management, PIMs manipulate information that is:

- structured according to data models;
- populated through software application that process data;
- interlinked with each other to provide an explicit description of the plant.

As a result, since the design basis is managed at the information level, PIMs maintain a technological framework to accurately describe the NPP, for instance to support information handover from the EPC contractor to the operator. Yet, lessons learned from the handover process show that a PIM is primarily, a static description of a plant at a given time, that does not necessarily contain enough explanation to understand the context – for example about the link between what was constructed and initial design requirements.

For the same reason that there is a difference between information and knowledge, there is a contrast between information management and knowledge management for which one of the complex aspects is to capture and manage the contextual environment of the information handled. Indeed, the context can be tacit, difficult to formalize or fragmented, and disseminated in documents or in the minds of subject matter experts. In some cases, it can consist of:

- a precise semantic description of the environment (further described in section 3.2.1.);
- the traceability of evolution of this information over time (see section 3.2.5.);
- the experience or insights around the production or the understanding of this information that reflects the know-how.

These new challenges in leveraging plant information utilize data produced and stored in compliance within a PIM schema, but in addition, also require harvesting the otherwise implicit knowledge that goes into the design, construction and operations of an NPP.

Figure 7 shows that, by enriching the PIM model with a knowledge-based framework, the resulting information model could not only store the design of the plant (systems, structures and components) but also capture the semantic significance and underlying knowledge for the basic design, detailed design, licensing, procurement, construction, commissioning, operations and decommissioning. This knowledge-centric plant information model (K-PIM) could be leveraged as a modern and efficient approach to better support, manage and transfer design knowledge and to provide a highly integrated and complete source of information for stakeholders within and across the NPP life cycle. Thus, the management information system (MIS) and PIM evolve into the K-PIM.

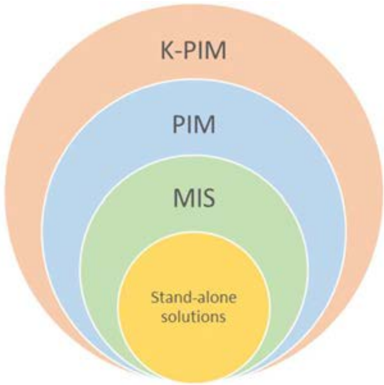


*FIG. 7. K-PIM evolves from the non-integrated NPP applications, through the MIS and PIM*

A K-PIM is a semantically organized set of information describing plant structures, systems and components, incorporating relationships and rules within a knowledge framework that collectively forms enriched representations of the plant that provide shared knowledge services and resources over its life cycle.

Consequently, a K-PIM may be a PIM, enriched with knowledge resources that incorporate semantics and knowledge services over the whole life cycle of a plant.

None of the current PIM practices represented by the PIM scenarios are based on best practices or industry standards that fully represent this working definition of K-PIM, as currently none exist. K-PIM design and design knowledge information is not being effectively communicated, understood or efficiently shared, exchanged or transferred within and across all NPP life cycle phases.

Nonetheless, increased awareness of the need to greatly improve knowledge harvesting and sharing (particularly during the design phase) as well as recent advancements in computer technologies and the development of new industry standards provide an opportunity to radically improve knowledge capture, integration and seamless transfer between stakeholders.

## 3.2. THE NEED FOR K-PIM

The K-PIM concept is driven by the need for a standard that enables interoperability and capture of both information and knowledge for the exchange and better utilization of NPP design and operating experience throughout the plant's life cycle.

Figure 8 describes the initial scope and complexity of the K-PIM, which is determined by the requirements for an architecture that utilizes a core knowledge framework and supports the different business needs of these stakeholder organizations. This core can be augmented by customized NPP requirements for knowledge capture. When the K-PIM concept is extended to the industry as a whole, a synergy is achieved that encourages a cooperation essential to nuclear knowledge capture, evaluation, utilization and management by all actors and organizations of the NPP life cycle. The objective is a resulting K-PIM that maximizes data integrity, completeness and semantic intelligence that no single organization could have achieved alone. An infrastructure and framework as K-PIM, when deployed across the nuclear industry, could also streamline nuclear knowledge creation, opportunities for innovation, verification, and acceptance and accuracy, resulting in significant NPP safety and financial benefits.

K-PIM is a tool for managing knowledge related to design. A key component for successful implementation of a K-PIM is the ability to capture the data, information and knowledge regarding the design basis of the NPP. The ongoing risk of loss, misinterpretation or inconsistency of design knowledge creates the need for the K-PIM infrastructure to ensure the integrity and validation of an NPP's design basis by essentially supporting effective decision-making and the achievement of plant safety and economics.

K-PIM is a modern information technology solution with a knowledge-centric interoperability infrastructure and framework underpinning successful DKM within and transfer across all NPP life cycle phases. This would not only provide more sustainable NPP designs and design knowledge, but would also facilitate information sharing, exchange and transfer at H/T. Heterogeneous organizations would have a standard vocabulary to establish pre-negotiated semantics, formats and quality standards for information.

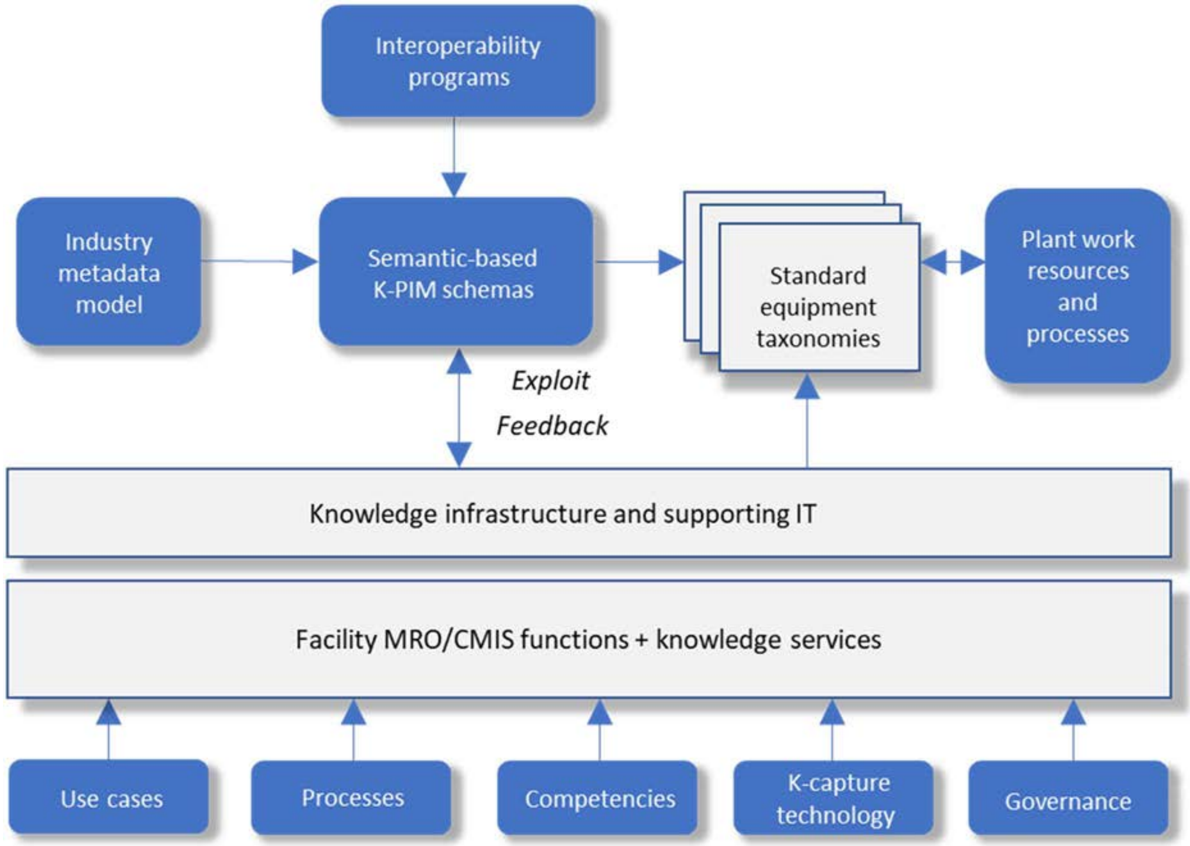


*FIG. 8. PIM with K-PIM knowledge services*

### 3.2.1. Semantic organization

Semantic organization and representation are the keys to establishing a knowledge-centric PIM model.

#### *3.2.1.1. Semantic understanding*

In linguistics, semantics is a sub-discipline, which focuses on the study of meaning. In informatics, semantic technologies are methods which aim at making a machine "understand" the meaning of what is originally presented to them. This can be a string of characters or other tokens such as images or sounds.

Semantic technologies form the basis for the semantic world wide web, or "web". The term "semantic web" was intended for a web of data that could be processed by machines. It marks the transition from the web of documents to the web of not only numerical but any data entity in general. This data is described and referred to in a way similar to referencing documents on the web.

Concepts are the basic building blocks for modelling a domain of knowledge. Such a model is generically referred to as knowledge organization system (KOS). It includes a broad range of term lists, taxonomies, thesauri and ontologies. KOSs vary in functional purpose and semantic expressivity. Standardization of KOSs by the World Web Consortium (W3C) standards [8] allows its full power to be exploited by interlinking and utilizing them to build comprehensive knowledge networks which form the foundation for developing knowledge-based applications.

*3.2.1.2.Controlled vocabularies and knowledge models*

A common language is not only essential for communication on interorganizational and individual levels, it is indispensable for the interoperability of systems. Only by defining concepts that are understood by the systems involved, can data be exchanged and related to each other. A common language may be specified as a vocabulary or a thesaurus, containing all the concepts describing a given knowledge area. The Simple Knowledge Organization System (SKOS) standard is well suited to formalize the vocabulary, structuring it in a hierarchical way by broader/narrower relationships, and adding attributes such as definitions, examples and notes.

A controlled vocabulary provides the necessary basis for developing a comprehensive model of the knowledge domain. Such a model describes the structure of the domain, i.e., its concepts as well as concept attributes and interrelations, and is referred to as an “ontology” or a “scheme”. In order to communicate with each other, all systems must share the same ontologies. An illustrative example is the communication between two databases, which must utilize the same structure or, at least, a mapping between ontologies and database schemes for being able to exchange data.

For the development of the knowledge model, existing ontologies can be reused. Such ontologies may exist within the organization or be taken from external sources such as the reference data library defined for the process industry in ISO 15926 [5].

Finally, the ontology will be populated with instances. All instances of a class inherit the attributes and relations assigned to the concept. For example, the concept “Pump” may contain the attributes “component ID” and “nominal flow rate”. A possible sub-concept might be defined as “Feedwater pump”, which inherits the attribute definitions of “Pump”. A specific feedwater pump might then be assigned to the concept of “Feedwater pump”, which specifies its component ID and the numerical value of flow rate. The integral of ontology and instances constitutes the knowledge base for the domain.

*3.2.1.3.Semantic interoperability*

The concept of information interoperability can better be understood in contrast to integration. Integration refers to a process where formerly distinct data sources and their representation models are being merged into one newly consolidated data source. The concept of information interoperability is defined by a structural separation of knowledge sources and their representation models. This allows connectivity and interactivity between these sources by deliberately defined overlaps in the representation model.

A knowledge model constructed according to semantic principles and realized by web standards can be published to the internet and linked to other sources by conforming to the principles of linked data, which describe best practices for exposing, sharing and connecting distributed data across the web. Linking can either be internal or external to organizational boundaries.

*3.2.1.4.System to system interoperability*

The mechanisms described in the previous section outline the theoretical foundations for semantic interoperability. Their application for designing specific systems with these mechanisms may be complex but follows these basic ideas. With respect to K-PIM, its system-to-system interoperability needs to recognize that a K-PIM is not a purely technical system, it operates in an environment that is embedded in social and economic structures. These aspects are particularly important when regarding the whole of the system life cycle, from design to operation to decommission including information H/T between phases. The various stakeholders involved, such as designers, developers, technicians and end-users in various fields (e.g. administration, management, design, and plant operations), must also be considered. Growth in computer, network, and wireless capabilities, coupled with more powerful software applications, have made it possible to apply knowledge-centric information technologies in all phases of an NPP life cycle. This growth is creating the potential for effectively streamlining historically fragmented operations. Semantic technologies provide the "glue" to link these otherwise isolated data, information and documents together.

*3.2.1.5.Infrastructure*

KOSs, in particular knowledge models, are fundamental for the semantic organization of the K-PIM and the utilization of semantic technologies. The development, maintenance and integration of KOSs and applications require an appropriate infrastructure. For developing and maintaining vocabularies and knowledge models and for enhancing them by linking to other sources, a tool is needed for managing the KOSs and for providing the data to other systems in the K-PIM environment. Data repositories that are aware of semantics are desirable as they can be interconnected with little effort. However, legacy systems such as large relational databases must be considered, which usually require translation or middleware to provide interfaces to the native database query language. In addition, the integration of systems into the K-PIM, e.g. 3D visualizations, user interfaces, reporting systems and many more, will be simplified by the ability to handle knowledge models.

### 3.2.2. Inter-organizational common language

The worldwide nuclear new build programme has highlighted the need to effectively and efficiently share, exchange, and transfer design and design knowledge information from and to O/O organizations. Less often considered, but equally important, is the need also to effectively and efficiently share, exchange, and transfer design and design knowledge information from reactor designer/nuclear supply steam system (NSSS) vendors to EPC contractors, and suppliers. If effective and efficient sharing, exchange, and transfer of design and design knowledge information does not occur from reactor designer to EPC contractor, it is impossible for the complete transfer to occur from the EPC to the O/O. Similarly, the same need may arise in operational plants, when two or more power plants are brought together through a merger or acquisition, or even within single plants between engineering, operations, and maintenance. This also applies to individual-to-individual communication or tool-to-tool migration of data with a given organization.

The K-PIM provides a common language through which interaction and sharing of information and knowledge can be managed. Thus, the controlled vocabularies and knowledge models described previously not only provide the basis for communication between technical systems, but also become the reference for the communication between and within organizations and people.

### 3.2.3. Knowledge-centric information interoperability across the NPP life cycle

The deployment strategy of a K-PIM approach may depend on the complexity of the organizations involved in the NPP life cycle, the supported knowledge-oriented business cases and the nature of the legacy systems to be integrated. In all cases the establishment of a common information system between the partner organizations requires the implementation of a knowledge-centric information interoperability layer.

Figure 9 below represents four organizations corresponding to a specific life cycle phase of an NPP: design, construction, operation and maintenance, and decommissioning. Each of these four life cycle phases has its own set of distinct processes that create, manage and share information within their organizations. Typically, these domains of information are based on local PIM models.

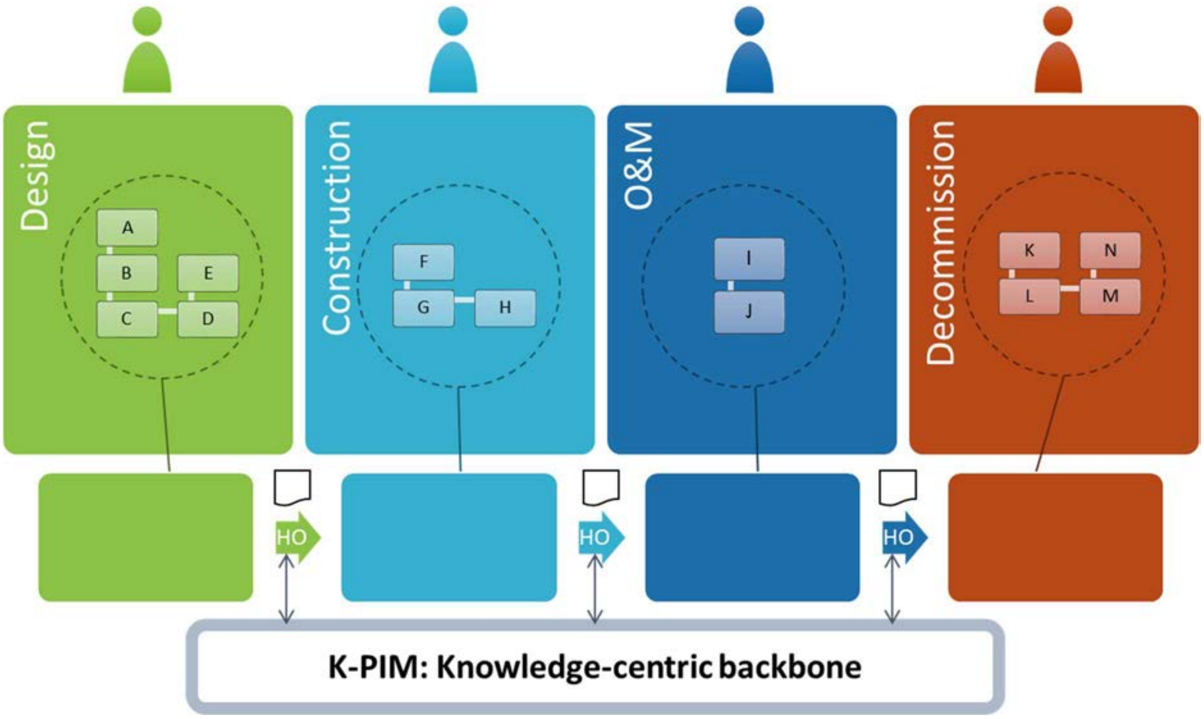


*FIG. 9. K-PIM as a knowledge-centric information interoperability layer (HO = handover)*

At some point, NPP organizations must share, exchange and transfer information within and across life cycle phases, and thus must agree on a scope and a format of information to transfer. In early K-PIM implementations, the K-PIM would function as a knowledge-centric backbone for information interoperability across these organizations. Different organizational concepts of a PIM within and across each NPP life cycle phase would be harmonized and translated or mapped to the K-PIM knowledge-centric information interoperability layer which spans all life cycle phases and acts as a guide for the content of the K-PIM for each phase. This schema is typically suited for organizations strongly dependent on legacy systems and willing to maintain a conservative approach in sharing and protecting the information they manage and store.

The K-PIM can support a higher level of interoperability while preserving stakeholder intellectual property. This method would, however, still require complex translators, software tools and APIs for this higher-level of interoperability within and across all plant life cycle phases.

As K-PIM implementation becomes more accepted, adopted, and used, the K-PIM could then evolve into a more knowledge-centric unified model, as shown in Figure 10 below.

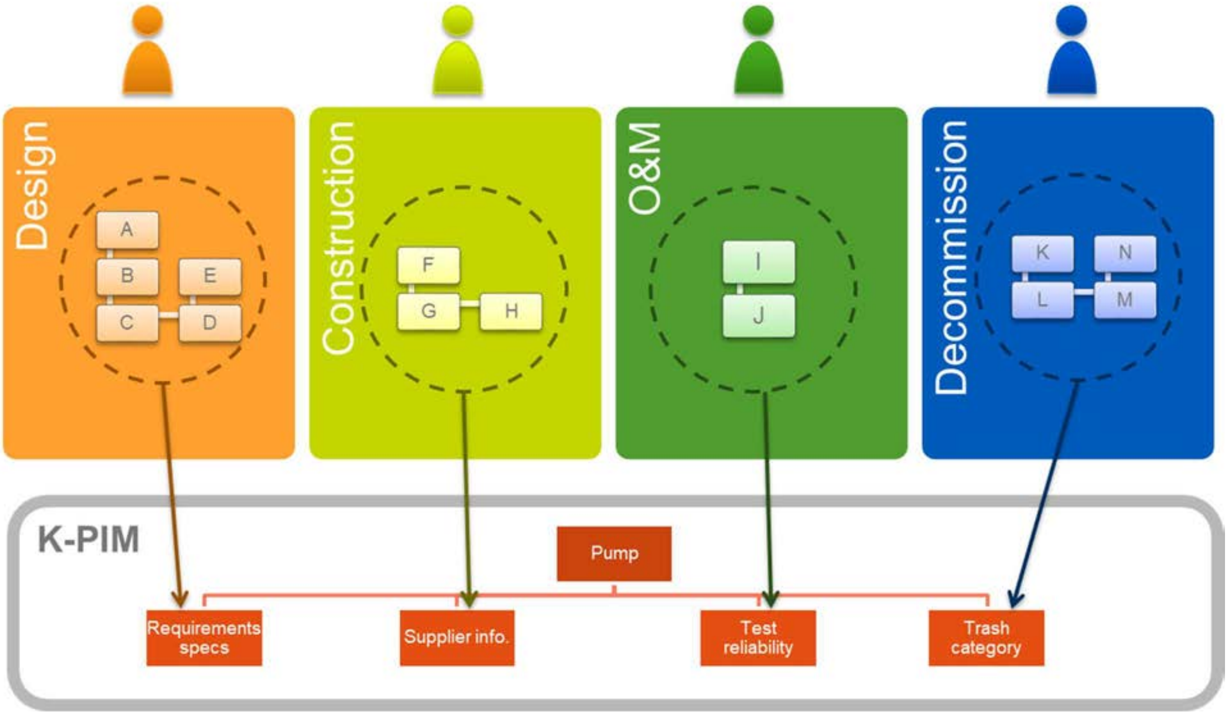


*FIG. 10. K-PIM as a knowledge-centric unified model*

In this scenario, K-PIM becomes a de-facto knowledge-centric common language exchange and interoperability method, without the need for many complex translators, software tools and APIs. The added value of the K-PIM approach in terms of data interoperability and exchange, life cycle management support and sophisticated, knowledge-based services is maximized.

### 3.2.4. Process-oriented knowledge-centric frameworks

Knowledge-centric frameworks are needed to support key NPP processes. They will help ensure continuity and sustainability of design and design knowledge information sharing, exchange, and transfer within and across the NPP life cycle phases as well as support the creation of knowledge-driven services.

Processes driving the knowledge-centric approach may include:

— design knowledge management;
— requirements management;
— configuration management;
— margin management;
— information life cycle management;
— information handover/turnover;
— asset management (equipment reliability);
— performance monitoring information management;
— supply chain management for inventory control.

Knowledge management provides a basic infrastructure for the capture, preservation, sharing and training of both explicit (recorded) and tacit (expert and personal experience) knowledge. When added to the more data-oriented PIM, knowledge management elements can permit the PIM to span the life cycle of the NPP and service as a design knowledge transfer environment.

Examples of what might constitute characteristics of knowledge-centric frameworks include:

*Structural framework characteristics*

- Terms and definitions of all artefacts (objects, attributes, relationships, etc.);
- Properties of objects and relationships (property definitions, types, ranges, rules, conversion properties);
- Object named relationships (relationships names and definitions, cardinalities, rules);
- Object hierarchies (type groups, classification taxonomies).

*Semantic framework characteristics*

- Object properties inheritance rules;
- Plant process and physical relationships and rules (integration and control (I&C), hydrodynamics, structural physics, neutronics, etc.);
- Life cycle properties and rules (as-required, as-designed, as-procured, as-built, as-operated, etc.);
- Management properties and rules (milestones, maturity, owner, user, related activities, work and task management, versioning, configuration, etc.);
- Business properties (business methods, procedures tools and practices, applied industrial norms and standards, business rules and best practices, etc.);
- Security and intellectual property.

### 3.2.5. Design knowledge rationale and traceability

Design knowledge is more than knowing what the plant consists of. Design knowledge captures and preserves the why and how in major NPP decisions with information traceability. In current operating NPPs and most new NPP practices today, this is described in the context of qualified documents. As a result, the understanding of the NPP design is still buried in documents and/or maintained as tacit knowledge of subject matter experts (SMEs) and experienced knowledge workers. No one group of SMEs or experienced knowledge workers has neither a complete understanding of all aspects of the design, nor can they fully describe the what, when, where, who, why and how of all the required information for designing and operating an NPP. With the ongoing need to better understand the design and licensing basis and to address regulator concerns, many design changes are made throughout an NPP's life cycle.

These design changes are then captured or documented in many different formats including e-mails exchanges, correspondence, request for information, request for additional information, engineering reports, regulator reports design basis documents, and web meeting recordings. These captured documents are typically neither related to each other nor to the license or design basis information.

Recovering and capturing design traceability is an indispensable step in forming a knowledge-oriented information system covering the life cycle of the plant. It is mainly characterized with named relationships for the what, when, where, who, why and how. Figure 11 shows how the DKM traceability framework connects the volumes of information being produced within and across the NPP life cycle that can constitute a major hurdle in deploying knowledge-oriented services.

The following are some examples of business cases where DKM, provided by the deployment of a K-PIM, may improve reliability, completeness, and efficiency of supported NPP processes:

- A mechanical engineer is changing a calculation based on a design change and can filter on the "design input to" type named relationship and look downstream to determine if any other calculations or supporting design information may be impacted by the change of the calculation;
- Alternatively, filtering on "design input from" type named relationships and looking upstream to identify what information objects i.e. calculations, specifications, commitments or design requirements are the design inputs to this calculation. Of course, the filter can also be set to "all" to see all identified named relationships to the calculation both upstream and downstream;
- A licensing engineer is evaluating a regulatory requirement change and can filter on "mandatory compliance to" or "non-mandatory compliance to" type named relationship and look downstream to determine what the impacts are to commitments, design requirements, design/operational, maintenance documents, procedures and of course what structures, systems, and components are specifically impacted;
- A component or procurement engineer is performing an equivalency evaluation for replacement of a pressure-reducing orifice (RO) with a different model which has some design features different from the presently installed RO. As this RO is safety-related, the engineer first wants to know if this change will require a license amendment change. During design safety screening, the engineer uses the named relationship filter to easily identify and access the flow calculation. He can identify whether there is a technical specification change required.

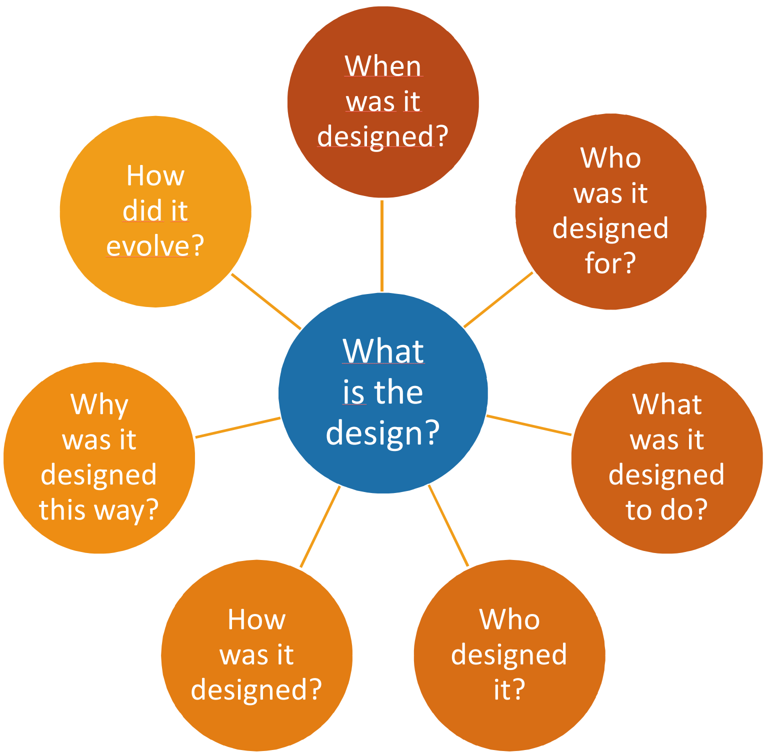


*FIG. 11. Tracing the physical asset back to its origins*

### 3.2.6. Knowledge-based services

Most current information retrieval practices involve opening up a document (electronic or hardcopy) to read and review the data stored in it as the actual information in knowledge is filtered through the readers own understanding of the subject matter. When related information is identified, the user must consult the document and search again in order to retrieve the identified pieces of data, information or documents, often relying on past tacit knowledge to locate it. This process then typically involves the user searching the specific data or information found, and/or copying and pasting the specific data or information from the original document. This process is performed repeatedly until the user has determined all required data, information or documents necessary to support the work that needs to be done.

This process of retrieval, interpretation and concatenation of scattered data can benefit from a semantic based K-PIM implemented in the IT solution. If the data and documents were to reference back to a K-PIM this would provide structures, definitions and mapped relationships between the bits of data and hence facilitate the users' ability to navigate through it. But K-PIM demands significant cost and effort of nuclear engineering works.

Figure 12 provides an example of a K-PIM named relationship traceability framework that is external to documents. The requirements and traceability management process is shown from the named relationships connecting the requirements to the design and operating information that fulfils the requirement to the installed information that validates that the installed asset meets the requirement.

Named relationships, or pre-staged cross-references, business, life cycle, and maturity knowledge could additionally be provided if a K-PIM were to be implemented. By connecting relevant associations of information objects with knowledge-centric named relationships, new knowledge-based services could be built in order to shift the human oriented search-filter-extract methodology to a more automated, reliable computer assisted approach to navigating and compiling information.

Some of these knowledge-based services may include:

- semantically rich query search engines;
- cross referenced business, surveillance, cost and maturity indicators;
- single-source-of-truth quick access information portals and repositories;
- intelligent impact analysis tools;
- risk informed and knowledge driven decision-making tools;
- advanced simulation and CAD services;
- knowledge hand-over staging areas;
- knowledge based security and IP management and protection;
- operations and maintenance /asset management support services;
- support for periodic safety review and preliminary safety analysis report.

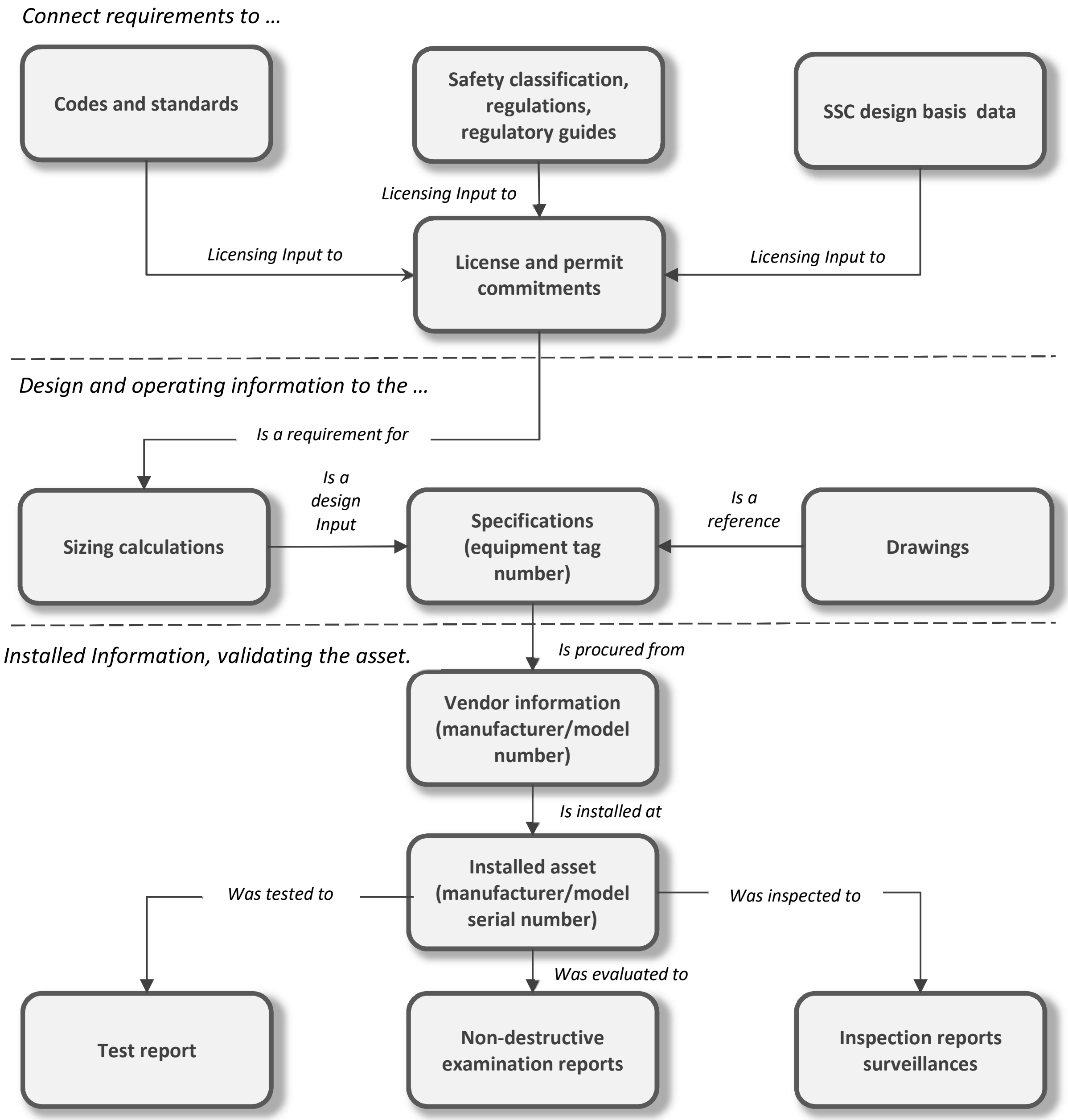


*FIG. 12. Example of a K-PIM named relationships traceability framework*

### 3.2.7. Improvements in information handover/turnover

Lack of H/T standards leads to ambiguity when interpreting H/T information content, functional requirements and information quality. The K-PIM, once developed, could be used to produce a semantically organized best practice information H/T specification that could then be used to develop the information H/T section of NPP procurement documents. This would be leveraging K-PIM as a modern and efficient knowledge-centric approach to help ensure better support, manage and transfer NPP design and design knowledge information within and across all NPP life cycle phases.

## 3.3. DEVELOPMENT OBJECTIVES FOR K-PIM

### 3.3.1. Specific K-PIM benefits

The K-PIM, as an evolution of the PIM concept described in Section 2, has specific benefits including:

- knowledge capture and retention;
- ability to interface with knowledge portal- and Wiki-based knowledge management tools;
- extending PIM as a useful information tool throughout the NPP life cycle;
- preserving design knowledge and providing infrastructure for design transfer;
- providing means for formal information exchange among EPC contractors, suppliers and O/Os.

### 3.3.2. Key industry steps for the development of K-PIMs

These steps aim to:

- develop a knowledge-centric common language framework to leverage, use, adopt or harmonize with internationally accepted standards and other industry group initiatives where it is practical and makes sense to do so;
- develop knowledge-centric process frameworks;
- develop object model structures with minimum property sets; for example:
  - location objects;
  - requirements objects;
  - document objects;
  - equipment objects (including bill of material parts and stock);
  - procured (manufacture/model) objects;
  - installed objects;
  - organization roles objects;
  - program objects;
  - object property sets for object maturity and property inheritance;
  - drill down on property sets for each object to expand the entire life cycle.
- develop a traceable, interconnected objects framework, defining the named relationships and specific relationship rules between objects in object model structures;
- document the model in a detailed data dictionary and develop an implementation plan;
- create a structure for a K-PIM model and develop an online K-PIM demonstration model (preferably based on industry standards);
- create a semantically organized framework for exchange and H/T representation of documents and data, which can be downloaded from the online K-PIM demonstration model in multiple consumable outputs.

## 3.4. BENEFITS, BUSINESS DRIVERS AND CHALENGES FOR K-PIM

### 3.4.1. General benefits

#### *3.4.1.1. Standard information H/T representation*

Standard information H/T representation can be leveraged for NPP procurement contracts. The general benefits are as follows:

- Providing a common language between reactor vendors, EPC contractors, suppliers and O/Os to facilitate information sharing, exchange and transfer;
- Ensuring that sustainable H/T of quality information occurs throughout NPP life cycle, thus reducing information H/T periods and improving acceptance;
- Ensuring that O/O and H/T needs are known and addressed by suppliers;
- Ensuring that the O/O has confidence that H/T information is correct, complete and meets quality expectations;
- Providing for electronic exchange of H/T information, reducing the need for rework, retyping and verification, validation and certification (V, V&C);
- Providing better integration, interaction and interoperability of information.

*3.4.1.2. Build regulator and public confidence*

Adopting K-PIM will build regulator and, indirectly, public confidence by demonstrating that suppliers and O/Os are working in a consistent and effective way through the NPP life cycle.

*3.4.1.3. NPP design and design knowledge transfer*

NPP design and design knowledge are captured, understandable and traceable from suppliers to the O/O across all NPP life cycle phases, and therefore:

- reduces risk of design knowledge loss;
- ensures the integrity of supply chain knowledge transfer;
- harvests and repatriates legacy and orphan design knowledge data;
- design intent will be traceable and consistently interpreted, trusted and maintained across the NPP life cycle resulting in:
  - better support and management of NPP design and design knowledge;
  - understanding the creation process for information and its context;
  - increased safety;
  - improved efficiency.

*3.4.1.4. Design and licensing information*

Knowledge can be captured from the beginning of the design process and can be enriched over the time. K-PIM can help to:

- improve ability to verify contractor and supplier qualifications;
- preserve knowledge and design basis of the designer's decision process (the what, when, where, who, how and why) for the entire span on the NPP life cycle;
- undo SME silos by providing interpretable and ready-to-use information to all users;
- streamline design review and verification processes;
- realize new NPP improvements in management of sub-contractors due to common language and better understanding of O/O needs and expectations;
- mitigate the risk of a design basis reconstitution;
- support long term operation.

### 3.4.2. Business and safety drivers

Drivers for developing and implementing K-PIM for NPPs include the following:

*3.4.2.1. Increased Safety*

K-PIM is a key to meeting the design basis and safety cases for NPPs by providing an engineering knowledge-centric infrastructure. This ensures that design criteria, technical specifications and license requirements are satisfied in a traceable and demonstrable manner at any point of the life cycle. K-PIM can be leveraged to prove safe NPP operation, including procedures, audits, maintenance cycles and other measures of plant integrity, through documents, records, data, and design and configuration management.

Regulatory safety drivers in K-PIM are defined by safety and license compliance and will, therefore, center around the ability of the license holder to continually demonstrate that plant performance and controls are within the safety envelope that the regulator has established. In certain countries, the regulator enables the licensee to construct a plant and operate it once construction is complete if certain standards identified in the licensing process are satisfied. In this context, the regulator will benefit from an active role in the design and construction process: K-PIM can help to raise the confidence of the regulator, aided by communication with the EPC contractor and O/O as the design and construction progress.

*3.4.2.2. Technology developments*

O/Os rely on technology, and also have very specific ways of doing business, particularly with their suppliers and regulators. New technology implementation needs to be justified, not only based on cost, but also for its beneficial impact on processes and organizational work culture.

One of the major improvements to design efficiency and knowledge capture is related to further development of 2D, 3D models and supporting data applications. This can entail that:

— the designer organization has developed the digital 2D, 3D design project and, as a result of their activities, is in a position to deliver to the general contractor or owner a 2D, 3D design model. However, there is a challenge here as most EPCs typically do no maintain the 3D model as-build in a nuclear quality process;
— 2D, 3D design models can also be actualized, or back-fit with as-built design data, both during construction and after completion of construction by means of laser scanning technology;
— based on the actualized model, a 2D, 3D engineering model can be developed for the purposes of the NPP operation, retrofitting and decommissioning;
— integration technology helps to complete the design model with data of adjoining systems, thus supporting operational tasks solving.

For equipment identification and tagging, the bar coding/radio frequency identification provides automatized identification of K-PIM objects using mobile devices and facilitates the immediate capture of complete information about an element from consolidated repository, which significantly reduces efforts to search and collect information.

*3.4.2.3. O/O autonomy during operation and maintenance*

The O/O, for strategic business and efficiency reasons, will ideally want to assume the maximum autonomy in design and maintenance of the NPP once the operation phase begins. Those reasons include to:

— reduce business dependence on an external entity that the O/O does not control and whose future existence and/or interest in the nuclear business area aren’t guaranteed;
— reduce costs.

*3.4.2.4. Support long term operation beyond design lifetime*

K-PIM implementation for O/O organizations can be critical to the safety and viability of long-term operation of the NPP. The cost and effort of acquiring legacy design knowledge from the EPC contractor and suppliers after plant operation commences and/or outside of contractual agreements can be immense. Failure to obtain this data can significantly limit the ability to affect design changes in response to  changes and amendments regulatory requirements and license, to modernize the NPP as technology evolves address obsolescence and performance issues and ensure life extension safe operating in the long term , may impede NPP long term operation

*3.4.2.5.Social and economic drivers*

Social and economic drivers may be:

- Gaining awareness and understanding of K-PIM usability over NPP life cycle;
- Growing requirements for economics and efficiency of operation, plus retrofitting and rehabilitation processes coupled with strict compliance with operational safety requirements;
- Growing need to demonstrate to the public the safe operation of NPPs.

*3.4.2.6.Staffing levels*

Staffing economies can be realized through reductions in engineering research and information retrieval requirements through the use of K-PIM and 3D virtual plant models. Configuration management requirements in performing engineering changes may be better performed, more accurately executed and may be verified, validated, and certified with fewer personnel hours expended.

*3.4.2.7.Business drivers for EPC contractors*

EPC contractor business models can vary according to the experience, resources and nuclear legacy of the potential O/O organizations. These can range anywhere from complete O/O control over project progress and design knowledge, with the EPC contractor acting merely as a pure vendor, up to turnkey and build-operate-transfer (BOT), build–own–operate–transfer (BOOT) delivery models, where the EPC and its suppliers have total control over design, construction and even operation of the project. K-PIM can provide flexibility for the EPC contractor to adapt to various industrial organizations and delivery models.

*3.4.2.8. Business drivers for TSOs*

Technical service organizations (TSO) are suppliers of knowledge. They frequently represent the origin of much of the design knowledge that ultimately is represented in the NPP design basis. The major goals of a TSO in utilizing a K-PIM would be ease of access to, and better understanding of EPC contractor, regulator and O/O design semantics to better connect with their clients to reduce terminology differences and misunderstandings.

*3.4.2.9.Business drivers for software vendors*

Software developers and vendors that offer both custom and COTS software for the nuclear power industry could benefit from a standardized K-PIM framework. This standardization would reduce software customization for each NPP and result in commonality and compatibility for applications and data. It would also serve a more organic purpose of supporting the core K-PIM concept of a common infrastructure and ecosystem that would be deployed across the full design process for NPPs.

This could cause the software vendor to be the provider of choice for more nuclear clients and leveraging possibilities for software service level agreements (SLAs), business process consulting, and other collateral business opportunities. Meanwhile, the industry as a whole could conceivably get the framework of a K-PIM integrated into a software product utilized in daily plant design, construction and operation. This could, in turn facilitate the sharing of information and knowledge with their customer base, supply chain organizations, the regulator and other key stakeholders.

*3.4.2.10. Business drivers for technology communities and owners groups*

Nuclear technology owner groups, such as Pressurized Water Reactor Owner Group (PWROG), Boiling Water Reactor Owner Group (BWROG) and CANDU Owners Group (COG), have a great deal to gain by adopting the K-PIM and its implementation. By leveraging experiences from the technology users or owners in the group, specific K-PIM applications for their technology may be developed.

### 3.4.3. Challenges

This section identifies some challenges for development and implementation of K-PIM concepts.

*3.4.3.1.Establishment of a K-PIM framework*

The definition of a common language is an exercise that can be challenging because of various aspects, e.g.:

- cultural and language differences among Member States;
- the variety of types of stakeholders of the nuclear sector including EPC contractors, O/O, suppliers, software vendors, regulators, TSOs, R&D organizations;
- the convergence process might be lengthy and necessitate the involvement of subject matter experts from a variety of organizations and countries.

Similar initiatives have already been launched in other industrial sectors, such as oil and gas, and construction. Annex I identifies standards and consortium approaches that propose methodologies and reference data that could be relevant for an NPP K-PIM. However, if the intent is to develop a framework that is shared and utilized by the main stakeholder organizations in the nuclear sector, their involvement in the definition process is critical. In particular, convincing and encouraging EPC contractors, suppliers and software vendors to participate in such initiative could be difficult.

For instance, EPC contractors may have business goals that conflict with the O/O concerning design control and ongoing plant operation support. The EPC contractor would ideally like to leverage its position as the NPP designer and builder, in order to ensure an ongoing design, supply and services relationship and have a revenue stream with the O/O throughout the NPP life cycle. Thus, the EPC contractor does not have incentives to share design knowledge with the O/O or other parties beyond contractual or statutory requirements. This becomes most apparent when the time comes to negotiate H/T of design knowledge, which is one of the key purposes of the K-PIM. In addition to the subjective feelings of freely giving up IP and knowledge, it is almost certain that EPC contractors (and major suppliers) will view the K-PIM, if they participate, as an added effort and expense to be borne as an overhead cost to the company. Thus, it may be difficult to convince an EPC contractor of the value of updating, maintaining and migrating legacy data to the K-PIM.  as long as there is no clear return in investment from their effort.

Software vendors may have similar conflicts as EPC contractors regarding their involvement in a K-PIM approach because its implementation may mean that these clients become less dependent on the vendors' solutions. Nevertheless, this is also an opportunity for evolution of business models, for instance:

— EPC contractors and their suppliers might see the benefit of a common language for better information exchange with their equipment suppliers, through the definition of shared exchange templates;
— EPC contractors might promote knowledge management services in their contracts while focusing on their core business;
— Software vendors might move from solution providers to service providers.

A realistic graded approach might be to develop a high-level schema representing a first step of reference data and to demonstrate the feasibility and the benefits of such an implementation.

*3.4.3.2. Contractual aspects and intellectual property*

The main sub-contractors and suppliers to the nuclear industry may have many of the same business and technical objectives as the EPC contractors. Main suppliers may have concerns about long-term business and revenue strategies, the cost of preparing and transferring design materials, and IP and trade-secret sharing and restrictions.

Some O/Os attempt to circumvent, or at least mitigate, such a situation by making separate contracts with the sub-contractor or third-party supplier, and this is in some cases successful. However, the O/O immediately assumes greater safety and financial risk when the EPC is not included in the supply chain to assume acceptance, liability or warranty for the NPP components or design involved.

The involvement of a major technology supplier for K-PIM adoption must therefore be made on a case-by-case basis. After a careful assessment of the potential benefits and shortcomings, the adoption of a K-PIM can be made. Findings influencing the implementation can be the lack of design knowledge access from other sources, willingness to participate, and the ability of the participating EPC to be the preferred or sole provider of design knowledge and insights into K-PIM requirements.

Another challenge to address is the protection of IP rights of the stakeholders so that proprietary critical knowledge and trade-secrets are not shared with a competitor. K-PIM should enable the management of sensitive information, which will increase the confidence of the stakeholders and facilitate their involvement.

*3.4.3.3. Maintenance of a K-PIM over the plant's lifetime*

The knowledge of the NPP O/O will evolve continuously over the lifetime of the NPP. Consequently, the K-PIM, as a technical infrastructure, and the knowledge it contains should be seen as an asset and should be managed and maintained properly. A dedicated staff should be in charge of the maintenance and operation of the K-PIM. The staff should also be in charge of evolution of the K-PIM for integration and application of new technologies (e.g. laser scanning, mobility) or mitigation of the risk of digital obsolescence or loss of design knowledge.

The use of documented standards for storage and structure of knowledge will support its persistence throughout the plant's life cycle.

*3.4.3.4.Knowledge-centric paradigm: a change of culture*

Moving from a document-centric paradigm towards an environment where the knowledge is properly formalized, captured, updated and exchanged represent a new way of working and a major change that must be reflected in the organization and in its processes. Indeed, the challenge is to apply knowledge management and the update of K-PIM information over the lifetime of the NPP.

Knowledge producers will have to spend time to capture and to document its evolution. In return, they will spend less time to access and understand information produced by others.

## 4. CONCLUSIONS

NPPs currently being designed or constructed, as well as operating NPPs whose information management practices are leveraging the concepts of a PIM framework, can expect significant benefits and value in design quality and DKM sharing, exchange and transfer. These benefits and values are unique to each NPP project. Each of this new NPP build environment requires the continued improvement in strengthening and maintaining the effective management of design basis knowledge and information. The risk of knowledge loss needs to be identified and mitigated, in order to maintain the integrity and validation of NPP design basis. This is essential to support an effective knowledge-based decision-making process and the achievement of plant safety, performance and viable economics.

The concept of a knowledge-centric PIM creates numerous benefits and business drivers, as presented in this document. It provides a strong technical and managerial case for industry development of a comprehensive K-PIM. The K-PIM is the evolutionary solution to providing the industry with a practical, standardized and portable information and knowledge repository, providing the common knowledge infrastructure that provides for understanding and sharing of critical nuclear experience.

The PIM concept is important to both newcomer and experienced Member States. Both new-build and operating NPPs will benefit from the effective support for the management of design knowledge loss risk and the on-going need to ensure the integrity and validation of NPP design knowledge. This is essential to support effective decision-making and the ultimate achievement of both plant safety and economics.

Both newcomer and experienced Member States planning a new build NPP could benefit from leveraging the K-PIM principles through the development of a EPC to O/O handover/turnover specification to be included as part of new NPP procurement contract, thereby ensuring the transfer of critical design data and knowledge upon transition to the operating phase.

New NPPs currently under design or construction as well as operating NPPs whose information management practices are leveraging the concepts of plant a PIM, would greatly benefit from this development. As they continuously make improvements to their information management practices and processes, a K-PIM can capture and store the information.

Operating NPPs would benefit from K-PIM development to leverage knowledge on plant asset management for long-term operation. This involves major equipment replacement, and eventually planning for decommissioning, during a time when much original design knowledge has been lost or compromised due to staff turnover, design loss and other long-term knowledge issues.

Some challenges remain to be addressed in order to implement a K-PIM framework, including setting the foundation of a common language, intellectual property protection, contractual issues, technical maintenance over the NPP's lifetime or the organizational change of culture to a knowledge-centric paradigm.

PIM in form of an engineering data management system is the core for creating an integrated informational foundation for making process-related, engineering and management decisions during plant operation and decommissioning. Data consolidation in a single information storage increases efficiency and ensures transparency and safety of plant operation.

# APPENDIX I. BENEFITS VALUES OF CURRENT PIM PRACTICES

## I.1. SPECIFIC BENEFIT VALUES

International experience has confirmed the efficiency of PIM applications for the design, construction and operation in complex industries: NPPs, oil and gas plants, refineries, and others. Unfortunately, information modelling technologies and PIM are sometimes confused with 3D modelling applied during the design stage. These technologies are very useful, but the principal result of the deployment of a PIM is a positive economic effect on construction and, even more so, for operation of the plant. The PIM application during the life cycle can give an overall benefit exceeding 10% of a final cost of the NPP project.

For example, investments in PIM applications can be returned with dramatic reductions in piping and component collisions discovered during the design and engineering stage. The final correction cost of such collisions alone can exceed the total cost of the application of these technologies for construction or modernization.

An analysis of IAEA publications and international experience published in various industry sources supports the fact that a PIM provides significant value for operating NPPs. A summary of the analysis' results is given in the Tables 1- 4.

TABLE 1. PIM VALUE DURING THE DESIGN PHASE OF THE NPP UNIT LIFE CYCLE

| Improvement | Means of improvement | Value range |
|---|---|---|
| Faster production of design documentation;<br><br>Improvement of the quality | Automated mechanisms for generating design documentation, including drawings and specifications based on information saturated 3D model. | 5-10% |
| Reduction of time needed for reconstruction and upgrade of an NPP | Designer has access to the PIM reflecting the actual NPP integrated information;<br><br>Lowering number of modifications in the detailed documentation. | 15-30% |

TABLE 2. PIM VALUE DURING THE CONSTRUCTION PHASE OF THE NPP UNIT LIFE CYCLE

| Improvement | Means of improvement | Value range |
|---|---|---|
| Increase of construction work quality | Construction workers have access to PIM including 3D model; | 5-10% |
| | Precise planning of construction works with a PIM. | |
| Reduction of rework and materials used | More precise planning of procurement based on PIM data; | 5-10% |
| | Decrease errors during on-site works with the help of visual display of information during pre-job briefing. | |
| Reduction of equipment and personnel downtime | Detailed planning of construction works based on a PIM with business indicators of current resource load for equipment and personnel. | 15-25% |
| Increase in productivity of workers | Access to detailed and up-to-date information about the constructed plant; | 10-20% |
| | Planning and forming detailed work packages based on PIM data. | |
| Reduction of costs of handover and commissioning | Commissioning and handover based on the delivery of datasets in an accurate, well-organized, non-redundant format; | 20-50% |
| | Reusing and leveraging the engineering design basis by building solutions for managing project execution, systems completion and operations on top of this virtual plant asset, rather than in separate stand-alone systems, can further reduce costs and provide better quality information as a basis for these work processes. | |

TABLE 3. PIM VALUE DURING THE OPERATION PHASE OF THE NPP UNIT LIFE CYCLE

| Improvement | Means of improvement | Value range |
|---|---|---|
| Reduction of equipment failures | The operating personnel have complete engineering information available, thus indirectly providing improved maintenance; | 2-5% |
| | Performing engineering evaluations with the use of actual operating engineering models enable to predict and prevent failures. | |
| Reduction of downtime during shutdown | PIM-based detailed scheduling and optimization of critical installation or maintenance activities (e.g. for limited access or high radiation areas; | 20-50% |
| | Preparatory training a pre-job briefing of the personnel with the use of PIM (3D engineering models); | |
| | Improved unplanned corrective maintenance through high quality engineering evaluations with the use of precise and comprehensive PIM. | |
| Reduction of cost of complex maintenance and repair operations | Detect, anticipate and correct collisions and clashes (introduction of equipment, lack of space to perform activities and others) prior to work commencement; | 15-20% |
| | Optimize personnel work and mitigate risks in their activities; | |
| | Train next generation of operating personnel. | |
| Reduction of maintenance personnel costs; | Decrease number of required maintenance workers due to optimized planning; | 15-25% |

| Improvement | Means of improvement | Value range |
|---|---|---|
| Reduction of training time | Optimized training of operating and maintenance personnel with the use of PIM prior to performance of complex operations. | 50-80% |

TABLE 4. GENERAL BENEFITS OF APPLICATION OF PIM THROUGHOUT NPP LIFE CYCLE

| Improvement | Means of improvement | Value range |
|---|---|---|
| Change management | Trace, document and publish history of change for specific NPP SSC back to its origin;<br><br>Improved impact analysis of modifications based on reliable and up-to-date SSC information;<br><br>Ensure correct procurement, implementation, maintenance and inspection of SSC changes. | 5-20% |
| Information search | PIM supports immediate access to detailed and relevant information about specific NPP elements. Search by criteria can be performed on process diagrams, electrical schemes, on 3D model data, by parameter values, or in plant breakdown structure or in geographical breakdown structures. | 10-40% |
| Reduction in training costs and time | Application of modern visualization tools such as intellectual 2D or 3D models facilitates delivery of information to learners. | 30-50% |
| Reduction of IT costs | Integration of existing information systems via a common PIM;<br><br>Minimize the amount of duplication of information in existing information systems and databases. | 10-20% |

## I.2. SOURCES OF IMPROVEMENT OF NPP OPERATION MANAGEMENT

The IAEA has developed a significant number of recommendations related to application of information technologies, in particular PIMs, for the NPP operation phase. These include publications for ageing management for NPPs (IAEA NS-G-2.12) [9], data collection and record keeping for management of NPP ageing (IAEA 50-P-3) [10], information technology impact on NPP documentation (IAEA-TECDOC-1284) [11] and others.

Creation of a PIM with detailed engineering information on the NPP (including as-designed, as-built, operation, diagnostic and test data, and maintenance modernization) and support during the NPP life cycle (supported by NPP personnel and data updates), is one of the key factors for the realization of efficient and cost-effective operation of the plant.

More than 40% of all operational failures are caused by deficiencies in management and the organization of NPP operation (see Table 5). The root causes of failures and their development are:

- insufficient analysis and lack of measures to change P&ID drawings, design of equipment or components, and technical solutions for the implementation stage;
- deficiencies in operational documentation which does not contain detailed or step-by-step instructions for execution of works, or poor quality of instructions with deficiencies in description of sequence of installation maintenance within the normal operation mode, as well as personnel actions during accidents or failures;
- untimely changes in operational (repair) documentation while making changes in design of equipment and components;
- untimely or premature replacement of components;
- insufficient analysis, and changes in maintenance and repair instructions for NPP maintenance personnel;
- insufficient analysis and plant programmes for monitoring of fault diagnosis and repair of malfunction equipment;
- insufficient training of operational and maintenance personnel, resulting in requirements for job procedures and service instructions for equipment not being met;
- poor quality control of fixed equipment condition when conducting planned maintenance, repair works or planned walk-downs and inspections;
- insufficient measures for work safety and underestimation of hazards when working on operating equipment;
- poor use of job-order system;
- deficiencies of the organization in coordination of personnel and insufficient supervision;
- ergonomics of technology and organization of the workplace not well understood.

NPP inefficiencies related to these causes lead to underproduction of power generation, and consequently to the financial losses arising from reduced delivery of electricity to consumers. The PIM-based compensatory measures to resolve the above-mentioned issues are shown in Table 5.

TABLE 5. FAILURES RELATED TO NPP OPERATION MANAGEMENT ISSUES

| Cause of failures | Share in total number of failures caused by operation management issues | Compensatory measures |
|---|---|---|
| Incomplete operation documentation and unavailability of manufacturing documentation | 25-30% | Outdated or missing operational documentation can create many obstructions in cases when the documentation is necessary. Establishment of a centralized repository constituted of up-to-date operating, engineering and process documentation supported by appropriate procedures to update the whole NPP PIM data could minimize occurrence of these problems by a factor of ten. |
| Failures of control procedure at NPP | 5-10% | PIM facilitates access to specific operating information (in many cases access to this information was otherwise impossible) both for regulating authorities (even if paper-based procedures remain the reference) and for equipment manufacturers. Comprehensive information about every equipment or current and planned actions is accessible at any time. The accessibility of information will significantly simplify and accelerate control procedures and simultaneously will allow for increasing completeness and timeliness of actions on unit performance control. This enables anticipated decisions based on real-time data. |
| Untimely decisions or missed opportunities during operation, maintenance, long-term operation | 10-30% | Greater accessibility to information and ability to analyze complex situation through the PIM will allow NPP personnel to prepare better technical solutions, to carry them out in a timely manner, and promptly control results of actions taken. In addition, the PIM will report immediate information on current status to external experts and to manufacturers of equipment, or to the K-PIM knowledge base.<br><br>On-condition repair is considered to be the most effective method of NPP maintenance to reduce costs and is directly related to assessment of actual equipment life characteristics. The calculations are based on power unit configuration and topology data contained in the PIM. |

| Cause of failures | Share in total number of failures caused by operation management issues | Compensatory measures |
|---|---|---|
| Quality problems of maintenance, repair, overhaul, installing, and adjusting performed by NPP personnel | 5-25% | PIM is used for more comprehensive training of future MRO personnel to perform their tasks. Besides oral and formal instructions, personnel can explore MRO in a virtual space beforehand for pre-job briefings, make basic measurements, evaluate equipment state and features, and plan operation algorithms. PIM enables integration of comments from dedicated experts, to assess need for spare parts, and to calculate repair personnel dose rates more precisely. Using PIM mobile applications by personnel will allow them to have access to the data base, diagrams and 3D-model on site which should significantly improve the performance. All these measures directly contribute to shortening equipment downtime at repair and maintenance operations and, if applied properly, should significantly increase total NPP production. |
| Insufficient personnel training level | 15-45% | Application of a PIM makes it possible to study issues related to specific NPP equipment visually and in detail. A PIM can be used for preparing a new or enhancing existing personnel training courses that will improve the quality of personnel training and will also be useful to create operational manuals when solving regular tasks of current operation. |

## I.3. RETURN ON INVESTMENT

Through facilitating quick access to documents, data and available parameters of NPP equipment for stakeholders involved in NPP services, the application of a PIM (including 3D engineering models, control instruments for repair, retrofitting and margin management of the NPP), when used properly, will make it possible to:

- shorten the time needed for decision-making;
- avoid conflicts in organizational procedures;
- gather all possible data beforehand for studying complex situations;
- ensure the personnel is sufficiently trained for the job.

All this creates a synergistic effect from other aspects of PIM implementation and helps to increase safety, adequacy, and timeliness of actions taken for operation, repair, and retrofitting of NPP equipment, without loss of time. It also helps in making the best decision on the basis of significantly more complete information. This will decrease operating and maintenance cost.

This section provides a justification for investment in PIM implementation based on the following reference data:

- 454 commercial reactors are in operation in the World in 2018 for a total net electrical power of 400285 MWe and a total production of 2488 TWh in 2017;
- in 2017, estimated unplanned outages caused a loss in production of 163595 GWh (this estimation was calculated from the actual production, load factor and unplanned capability factor);
- in 2017 an average capability factor for a 1000MWe PWR was 78%.

The following hypothesis is formulated by levelized cost of electricity (LCOE) for nuclear generation: 0.04 USD/kWh.

TABLE 6. ASSESSMENT OF THE YEARLY COST OF UNPLANNED OUTAGE FOR AN NPP IN OPERATION

| | Yearly production (TWh) | Yearly loss in production due to unplanned outage (TWh) | Yearly cost of unplanned outage (in millions of USD) |
|---|---|---|---|
| total (454 units) | 2488 | 163.595 | 4907 |
| average (per unit) | 5.48 | 0.360 | 10.8 |

Hence the underproduction cost due to failures is $10.8M for one NPP unit. Section II.2 indicates that application of PIM may reduce number of relevant failures up to 40%. Taking into account the most optimistic forecast (reduction of the failures by 40%), the application of PIM could generate $4.3M of savings per year for each NPP regarding reduction of failures only.

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# ANNEX I. LESSONS LEARNED FROM OTHER INDUSTRIES RELATED TO DEVELOPMENT OF AN NPP K-PIM

## I-1. INTRODUCTION

The purpose of this Annex is to raise awareness in the nuclear industry on what other industries have done to support the implementation of PIM and K-PIM principles for their plants/facilities.

Over the past few decades, automotive and aerospace industries have made fundamental changes in their practices and processes that have increased the productivity of these sectors, improved cooperation between stakeholders, and reduce costs. This transformation has been possible through technological improvements combined with development of standards for exchange of information. These standards have enabled a high level of integration and knowledge sharing among the supply chain stakeholders.

There are no comparable standards available for NPPs. Lessons learned from these and other industries highlight the challenges to establish a common framework for support information and knowledge exchange and capture, as well as to agree on sets of reference data. Among these challenges are engagement of subject matter experts and sponsorship of the leading companies in the supply chain.

Whereas the automotive and aerospace industries differ from nuclear in terms of scale, disciplines involved or production series, oil & gas, building or process industries have also engaged a similar digital transformation of their practices and have defined standards. These standards propose exchange schema, technical frameworks and high-level reference data such as taxonomies or ontologies. In addition, other actors such as industrial consortiums enrich this ecosystem by providing additional sources of reference data.

The purpose of this appendix is to list and assess the maturity of this ecosystem in order to raise awareness of the nuclear industry on what can be re-used to support the implementation of PIM and K-PIM principles.

Section I.2 contains:

- a short introduction to relevant standards and a study of the business drivers that lead to their development;
- a study of technical frameworks available, and their potential application to the nuclear industry;
- an analysis of reference data available that covers:
  - their applicability for the nuclear industry;
  - their compliance with K-PIM principles related to life cycle management and knowledge management;

Then, section I.3 provides and explains an interaction map between ISO committees, standards and related consortiums.

## I-2. ANALYSIS OF OIL&GAS AND CONSTRUCTION INDUSTRY STANDARDS RELATED TO PIM AND K-PIM PRINCIPLES

### I-2.1. Oil and gas standards – ISO 15926

The purpose of ISO 15926 is to facilitate integration of data to support the life cycle activities and processes of process plants. ISO 15926 is based on a generic, conceptual data model for computer representation of technical information about process plants described in ISO 15926-

2:2003 [1]. This conceptual data model defines high-level information classes and is the foundation for information exchange. The data model is designed to be used in conjunction with reference data. ISO 15926 proposes technological solutions for management, capture, publication or exchange of technical information based on semantic standards. In addition, other parts of ISO 15926 propose sets of generic reference data that can take the form of taxonomies or ontologies.

Currently, ISO 15926 is used to facilitate information exchange between the stakeholders of a new built process plant project, and especially to streamline the handover of information from the designer to the operator. More recently, this framework has been deployed on brownfield projects to support the refurbishment of plants.

The development of collaboration and harmonization practices in the oil and gas industry has been encouraged by several factors:

- Implementation of additional regulatory standards since the Gulf of Mexico oil spill in 2010;
- Shift in the business organization through the definition of Architect Engineer (AE) entities responsible for the integration and the delivery of turnkey projects;
- Increased maturity with regards to intellectual property in collaborative environments.

### I-2.2. Building information modelling

Similarly, in the construction industry, the BIM initiative aims at improving the construction process and cooperation between the stakeholders. BIM scope includes life cycle and multi-discipline modelling of objects related to construction of objects. The BIM approach is led by the buildingSMART International Consortium [2]. This Consortium has the role of initiator of standards as well facilitator and promoter of BIM practices in the construction industry.

BIM is an interconnected network based on standards including:

- ISO 12006-3 [3], which specifies a language-independent taxonomy data model that can be used to store or provide information about construction works based on dictionaries;
- ISO 16739 [4], which contains the industry foundation classes (IFC) schema, a file format that describes components of a building and that facilitates interoperability in the construction industry;
- ISO 29481 [5], which defines a methodology to formalize an information delivery manual (IDM), which, for example, model the processes of information exchange including the interactions between stakeholders.

Some countries impose a level of BIM-compliance for the stakeholders involved in publicly funded projects. BIM principles are evolving fast in order to more efficiently support the construction of large infrastructure projects and buildings. On some projects, BIM data can be re-used during the operation and maintenance phases.

### I-2.3. Supporting standards and concepts

#### *I-2.3.1. W3C standards*

The World Wide Web Consortium (W3C) [6] is an international community aimed at developing web standards to lead the web to its full potential. In the field of semantic technologies, the work of W3C can be summarized by the following diagram (Figure I-1).

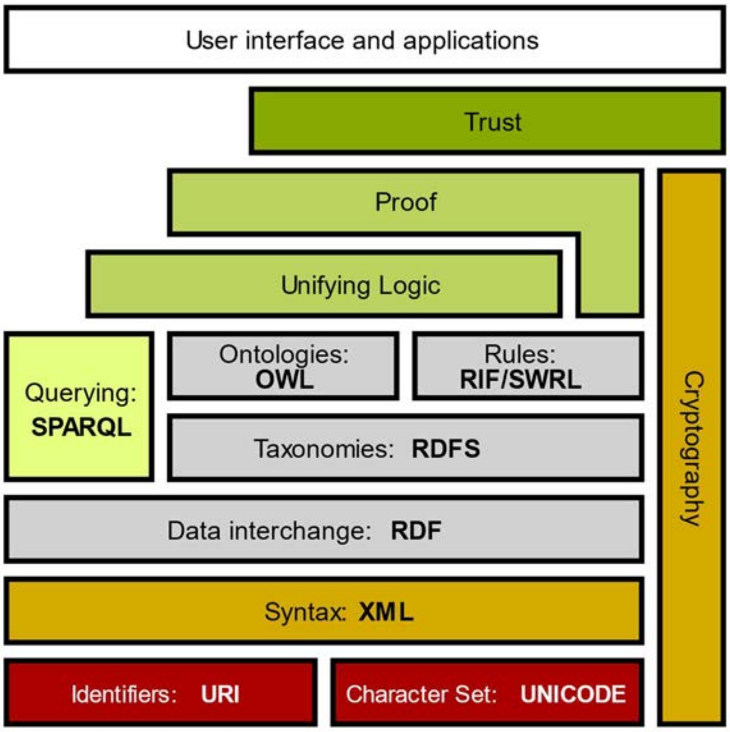


*FIG. I-1. Semantic web stack (Reproduced courtesy of [7])*

*Legend:*

*RDF: resource description framework*
*RIF: rule interchange format*
*OWL: web ontology language*
*SPARQL: sparql protocol and RDF query language*
*XML: extensible markup language*

W3C has published the resource description framework (RDF) standard that formalize "triples". A triple is a linking structure that forms a directed, labelled graph, where the edges represent the named link between two resources represented by the graph nodes. Each element of the triple is uniquely identified through a unique reference identifier (URI). See Figure I-2 and Figure I-3.

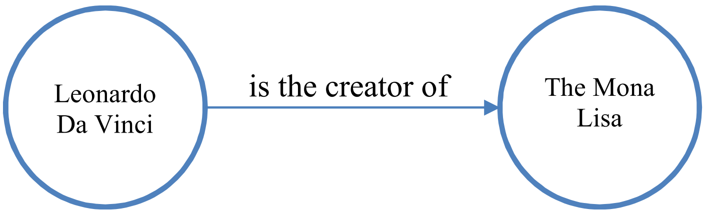


*FIG. I-2. Illustration of the RDF triple concept*

A named graph is key concept of semantic web architecture in which a set of triples is identified using a unique URI and that can contain metadata about those triples.

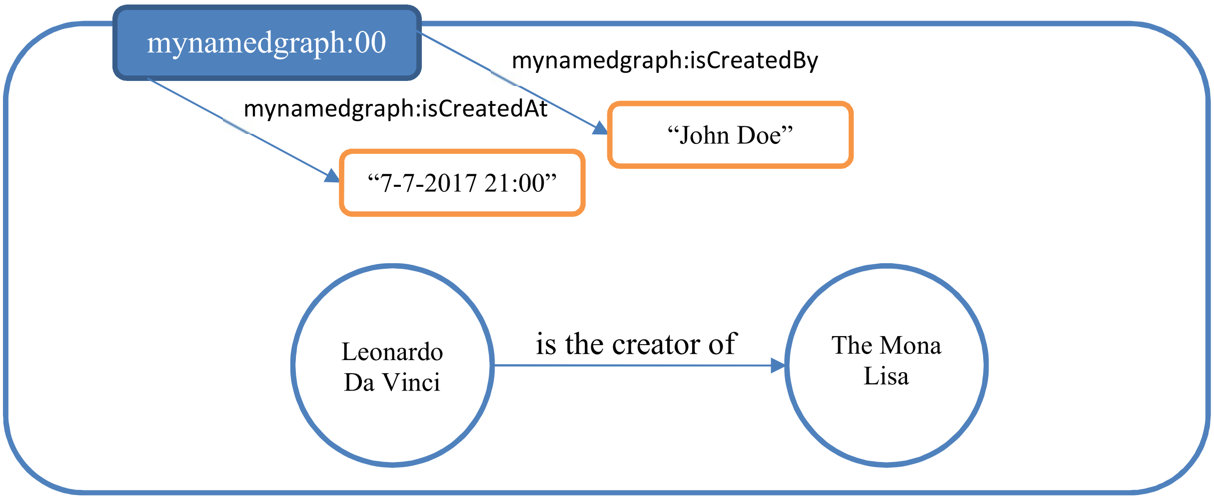


*FIG. I-3. Illustration of the named graph concept*

W3C has also introduced the concept of Linked Data to enable the link between those graphs with data published and URI-identified on the web through hyperlinks. These hyperlinks connect all Linked Data into a single global data graph, similar to the hyperlinks on the classic web that connect all HTML documents into a single global information space.

#### *I-2.3.2. Other relevant supporting standards*

ISO 8000 [8] describes the features and defines the requirements for the data quality and portability of enterprise master data. This standard is similar to ISO 9001 that defines the quality rules and processes for management of the quality of documents. ISO 14721 [9] defines the reference model for an open archival information system (OAIS) in order to preserve information over time.

### I-2.4. Reference data

#### *I-2.4.1. Reference data in construction and oil & gas industries*

This generic reference data is particularly important to raise awareness of stakeholders and to support them in the implementation of a common language for information and knowledge sharing. Reference data can take the form of taxonomies or ontologies with specific scopes of coverage, such as sources of reference data and relationships models proposed in the following international standards:

— ISO/TS 15926-3 [10] specifies a reference data library for geometry and topology;
— ISO/TS 15926-4 [11] contains an initial set of reference data library for physical objects, activities, properties and other reference data necessary to record information about process plants and oil and gas production facilities. It contains definitions as well as classification relationships between reference data items;
— ISO/TEC/IEEE [12] and ISO/TS 15926-11 [13] define an initial set of relationships to support integration of systems engineering principles. Those relationships can model:
  - systems engineering statements such as the breakdown structures composition or the formalization of requirements, interfaces or risks applicable to an item;
  - metadata about the system engineering statements that describe traceability, maturity, status of information or rationale for design changes.

As stated previously, what is proposed in these standards is high-level data that might not be sufficiently detailed to be directly utilized in industrial projects. In some cases, industrial consortiums and member organizations such as POSC Caesar Association (PCA) for the oil and gas industry or buildingSMART for the construction sector, propose extensions or additional sources of reference data with a lower level of consensus but more business value. Those consortiums play the role of incubator and accelerator in the development and implementation of standards in their industry. Their work might be integrated in standards in the future. Work done by these consortiums includes:

- PCA proposes extension of the reference data library as defined in ISO/TS 15926-4. This library is published publicly on a reference data service;
- USPI (United States Prescribing Information)-CFIHOS (Capital Facilities Information Hand Over Specification) proposes its own extension of ISO/TS 15926-4 and has developed a tool to manage it;
- BuildingSMART manages the BuildingSMART Data Dictionary, which is an ISO 12006-3 based ontology for the construction industry.

#### *I-2.4.2. Applicability of construction and oil & gas industry data to the nuclear sector*

Currently, there are no comparable standard available in the nuclear industry. Nonetheless, concerning the modelling of components and business objects:

- ISO 15926 provides descriptions of process plant components including piping, HVAC, mechanical, electrical, I&C, fire protection and chemistry;
- BIM provides elements related to construction and in particular regarding architecture, civil and structural engineering.

Consequently, these two sources could already model a significant part of the information and knowledge managed in the nuclear sector and could be used to initiate the construction of a nuclear report definition language (RDL). However, some aspects or disciplines are not modeled, including nuclear safety, radiation protection, and descriptions of nuclear specific components or properties.

Finally, the relationships defined in the previous section about ISO/TS 15926-11 relate to the need for design knowledge rationale and traceability in a K-PIM. These relationships might be used as a foundation for the development of a knowledge-centric model that would enable management of knowledge throughout the life cycle of an NPP.

### I-2.5. Applicability of technical frameworks to K-PIM principles

To ensure interoperability of information, both ISO 15926 and BIM define semantic layers for understanding and description of concepts. For instance, the conceptual framework proposed by ISO 15926-2 contains about 200 interlinked core-classes. This framework may be generic enough to be suitable to manage NPP information at the PIM level.

Although the purpose of this meta-model is to be computer-readable and to provide a layer of abstraction, the evolution of semantic technology offers new perspectives to facilitate the understanding, the capture and the publication of knowledge by and for humans.

For instance, ISO/TS 15926-11 proposes a technological implementation that transcribes ISO 15926-2 concepts into a human-readable format under the form of triples and named graphs. This framework leverages the use of different standards in order to promote a common language for knowledge capture and exchange, including:

- data formalized according to ISO 8000 recommendation, to ensure its integrity and reliability;

— systems engineering principles as defined in ISO 15288, which enable tracing the evolution of information over the life cycle and its contextualization;
— the semantic (i.e. the grammar of the common language) of information exchanged specified by ISO 15926-2 (computer-oriented language) or in ISO/TS 15926-11 (natural language);
— the technical terms that define the objects related to information exchange listed in the RDL (ISO/TS 15926-4), which can be related to Linked Data;
— the storage of information in RDF stores;
— exchange of information done according to schema, for instance with XML files;
— the process of information exchange, which can be formalized according to IDM (ISO 29481).

The implementation of a comparable technical framework for the nuclear industry would demonstrate the feasibility of the K-PIM principles for NPPs.

## I-3. INITIAL INTERACTION MAP BETWEEN ISO COMMITTEES, STANDARDS AND RELATED CONSORTIUMS IN THE NUCLEAR SECTOR

Based on the standards listed above, Figure I-4 provides an interaction map between standardization committees, consortiums and other nuclear initiatives.

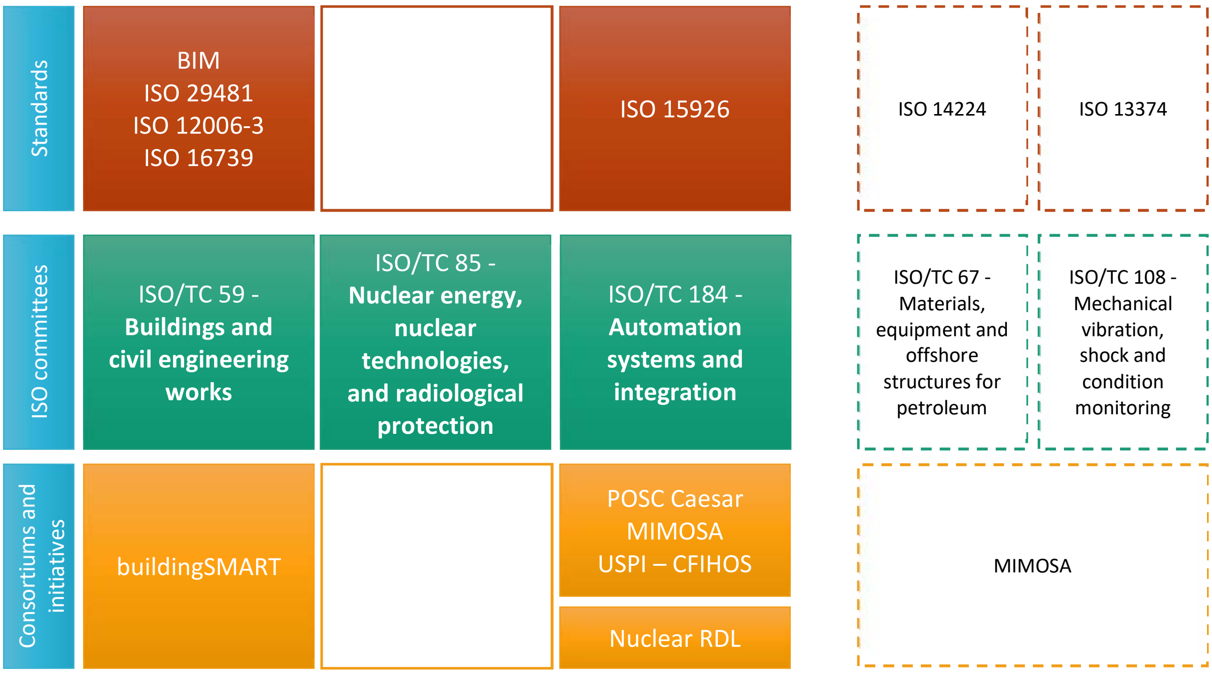


FIG. I-4. Interaction map between ISO committees, standards and consortiums

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# ANNEX II. CASE STUDIES ON DESIGN, CONSTRUCTION MANAGEMENT AND OPERATION OF COMPLEX ENGINEERING FACILITIES BASED ON PIM-TECHNOLOGIES[2]

## II-1. BACKGROUND

Rosatom State Corporation Engineering Division JSC "ASE" (is one of the global companies in nuclear power plant engineering and construction. ASE has implemented the design and construction projects of NPPs using Multi-D technologies.

## II-2. PRECONDITIONS FOR IMPLEMENTATION OF PIM-DESIGN TECHNOLOGY IN ASE GROUP OF COMPANIES

The approach to the life cycle management based on BIM and PIM technologies are the “best practices” among foreign technological companies and often considered to be the basis for their innovation. The implementation of PIM technology during NPP design phase was a premise driven by industry requirements and the company’s own development initiatives. The ASE customers for NPP design in both domestic and foreign markets were no longer satisfied with projects based on preliminary stipulated terms. At some point in time, it became evident at that the company applied separate software solutions at the designing and construction stages than the NPP customers, a separate tool of calendar network planning, etc. At the same time, it had to operate the large bulk of data that generally referred to the NPP.

The leaders of the industry took the decision to implement information modelling technologies and data management systems in the VVER project in order to integrate all NPP stages into the uniform digital model accomplished by clearly specified business-processes.

The Multi-D platform engineering data management system (EDMS) developed on the basis of PIM-designing technologies allows both projects designing and engineering as well as complex data management for all components of NPP (immediately from the power unit design in 3D format, procurement and supply of real equipment, deadline, resource and cost management during NPP construction up to data verification and project requirements management). Multi-D platform EDMS has passed all the necessary tests including the full scope of regulations and procedures that allow to work in this system and has been put into commercial.

## II-3. IMPLEMENTATION AND DEVELOPMENT OF IT-TECHNOLOGIES, METHODOLOGY AND STADARDIZATION OF APPLIED TECHNOLOGIES

### II-3.1. Concepts of PIMs

The adaptation of the information system started with the choice of the IT-platform that would enable consolidation of the project engineering information to use it at all life cycle stages of designed facilities. The selected platform was the integration system SmartPlantEnterprise, that offers an integrated solution consolidating the following programme modules:

— SmartPlant P&ID (SP P&ID) – creation of functional process diagrams;
— SmartPlant 3D (SP3D) – complex 3D designing system;
— SmartPlantElectrical (SPE) – designing electric supply systems;
— SmartPlantInstrumentation (SPI) – designing automation systems;

[2] The IAEA neither endorses the software and technology described, nor does the IAEA promote or favour any technologies.

- SmartPlantReview (SPR) – visualization of complex 3D model including connection with the calendar network planning and development of complex PPM;
- SmartPlantReferenceDataBase (SPRD) – design catalogues generation and management system;
- SmartPlantFoundation (SPF) – engineering data and document management system, central software complex module SmartPlantEnterprise.

The core of the information system is the Multi-D EDMS platform of the designed facility. The platform provides the means for the collection, structured storage and submission of technical information to the user, as well as the transfer of information between various system modules, that allows to:

- form the information NPP model as a hierarchical organized facility system applying the adopted project power unit decomposition structure;
- ensure smart interface between engineering data of various project disciplines;
- ensure possibility to connect the model objects to various types of documentation;
- retain the history of data changes about model objects;
- ensure submission of the navigation medium for prompt retrieval of technical information and documents based on the coding and classification system;
- ensure computer-aid to business processes;
- ensure variation management;
- ensure visual (without programming) development of route charts, that specify the life cycle and processing procedures for various types of documents.

As part of adjusting NPP project engineering data management systems, the following technical, organizational and methodological work for their immediate adjustment was carried out:

- standards of application as part of equipment classification and coding system projects, equipment components and their location based on KKS [3] (Kraftwerk-Kennzeichensystem), as well as materials coding on the basis of modulation and coding scheme (MCS) coding system were developed;
- unique system of project documentation coding on the basis of IEC 61355-1 “classification and designation of documents for plants, systems and equipment were developed. Part 1: rules and classification tables” [1];
- principles of project documentation from the information model were generated and standardized. Based on these principles, the procedure of project documentation package generation and management was developed;
- a series of standards to draw up the project documentation obtained from the information model with account of specific features of all software systems applied during generation of the information model were developed;
- a package of methodical documents has been developed to adjust all modules of the complex information project system, detailed module users guides and user manuals; and
- training an information support is organized for design project participants in the generated information medium of the project.

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[3] The identification system for power stations (KKS) serves to identify plants, section of plants and items of equipment in any type of power station according to task, type and location. The guideline considers the format of code, contents of data characters, special rules, the assignment of system codes to mechanical equipment and measuring circuits, special rules for civil engineering, and special rules for electrical control and instrumentation engineering.

The basis for generating a 3D-model of the power unit are diagram solutions including the technological, electrical part of the project and I&C. The up-to-date information medium represent the diagram solutions as smart documents with the database describing design solutions with the possible transmission of the required information into the engineering data management module.

The module of P&ID diagrams ensures designing and representation of functional systems and process diagrams, including equipment, pipelines, valves, and points of I&C connections, and ensures connection of the process diagrams with the 3D project model to ensure that the diagram and spatial designing are aligned.

The centralized knowledge base is adjusted including rules of transmission and comparison of relevant P&I element attributes values - diagrams to check that the data are introduced correctly, and routine operations are ruled out, i.e. the same value is introduced for several elements. The rules ensure validation of the data throughout the whole designing phase and allow to make automatic updating should one element be changed, which spares significantly designers' time and improves the quality of designing.

Layout solutions were developed in the 3D designing module, i.e. SmartPlant 3D. As part of development of the project, the basic functional features of this module was significantly extended and supplemented and finally resulted in the unique software product that allowed to implement the complex 3D-designing in all project disciplines and to obtain the working documentation immediately from the 3D-model.

In order to enhance quality of the 3D-designing, the organizational and technical procedure for collision management in 3D design was developed that enabled to check collisions for not only physical elements, but for various spaces such as evacuation paths, transport equipment relocation paths, spaces for servicing of various equipment, pipeline and ventilation ducts isolation. The procedure for obtaining regular reports were developed for existing model collisions, a procedure for designers' work was developed as well for the elimination of the collisions.

Another important updating of the standard 3D functional module was the adjusted procedure of the project rooms management. This functionality allowed to mark the rooms of all buildings of the unchangeable project part and to create a complete list of the properties of these rooms (marking the premise, name, level of ionizing radiation, explosion and fire hazard category, grade of servicing, heat input, etc.) obtained from the different project modules and to set connections of the room with all project items that are hosted in its space. This information is necessary throughout the whole power unit life cycle for rooms management and servicing and for the management of equipment and mechanisms located in specific power unit rooms.

### II-3.2. An integrated information management system

As part of the information model implementation tasks, great effort was put together by all project members into creating a unique integrated information management system for the power unit. The integration of all project-related information into a single environment significantly improved the quality of the design works, the development of technical and layout solutions, and the creation of a comprehensive information model of the unchangeable parts of the design, which would be ready for replication at different sites of NPP construction.

The unified information space (UIS) is a collection of information systems and the IS interfaces and databases operating on the basis of common principles and rules that provide information communication of the project participants, as well as meeting their information needs. Due to the high complexity of engineering processes there is a constant need in applying tools that provide support for engineering processes. The architecture of a typical industrial UIS reflects activities of the engineering company at the next stages of NPP construction:

- Design;
- Construction;
- Commissioning.

UIS components may be divided into the following classes according to their functional purpose:

Project management system:

- Business analysis for NPP construction project;
- Calendar and network planning;
- United schedule (coordination of schedules of construction, engineering, procurement and supplies);
- Project management portal (information management system);
- Requirement management;
- Chain of assistance (decision-making in the NPP construction project);
- Electronic document flow for NPP construction project with the customer.

Systems and applications supporting project through business-processes:

- Keeping the company's documentation electronic archives;
- Budget estimation;
- Design process management;
- Electronic document flow for NPP construction project inside the project unit;
- Procurement and supply management systems;
- Agreement of technical specifications;
- Equipment and materials management system;
- Warehousing.

Construction management systems:

- Multi-D-modelling;
- Design and survey, construction and structure erection management (certificates of performed work, need of design unit, topical planning);
- Recording of personnel working hours in NPP construction projects with the help of RFID-cards;
- Generation and recording of weekly/daily tasks.

Reference and corporate systems:

- Equipment and materials electronic catalogue;
- Electronic catalogue of regulatory reference information;
- Electronic document flow;
- Personnel management.

Enterprise management systems:

- NPP construction projects abroad;
- Information security management based on ISO/IEC 27002 - Information Security Foundation (ISFS) standards [2];
- Cost management.

Currently, all information about the object design is stored in the unified information space (UIS), which was built based on the PIM-design technologies. It forms the basis for project management, combining more than 20 systems responsible for the implementation of various processes within the design and construction of complex engineering objects (design, construction, procurement, cost management, etc.).

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[2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Information Security Foundation (ISFS) Certification Program, ISO/IEC 27002, ISO, Geneva (2013)

# ANNEX III. A LIFE CYCLE APPROACH TO NPP INFORMATION MODELING IN THE FRENCH NUCLEAR INDUSTRY[4]

## III-1. EDF ORGANIZATION

Électricité de France S.A. (EDF) is France's main electricity generation and distribution utility largely owned by the French government. The company operates a diverse portfolio of generation capacity using nuclear power, coal and gas, and its operations include electricity generation, from engineering to distribution, as well as power plant design, construction and dismantling, energy trading and transport. EDF manages the country's 58 power reactors in addition, EDF is involved in the development of the EPR (Evolutionary Power Reactor), as well as in the design and construction of five EPR units in France (Flamanville), China (Taishan) and in the UK (Hinkley Point).

## III-2. CURRENT STATE OF PLANT INFORMATION AND THE DESIGN INFORMATION MANAGEMENT

Given its divers implication in NPP life cycle phases and its significant nuclear fleet, EDF's Nuclear Division has a long experience in developing sophisticated IT solutions aimed at managing technical data frameworks for plant design, construction, operation and maintenance. The group has developed a variety of tools in design and asset information management. The examples EDF exhibits are two cases which had major information modeling components during their development phase:

— CAD 2000: plant design information management backbone solution aimed towards supporting the design of new EPR units;
— SDIN: nuclear asset management solution, aimed towards optimizing fleet management performance in operation and maintenance phase.

These tools are detailed in the following paragraphs.

### III-2.1. CAD 2000 initiative

Following the last wave of nuclear plant construction in France, there was a need to adapt design processes in terms of information management in order to drive the transition from the former N4 model to the new EPR generation of nuclear reactors. MUDU (Modèle Unifié de Données Utilisateurs or Unified Business Data Model) is a project that meets the expectations of EDF's nuclear engineering division in supporting the design of new nuclear developments. MUDU is an information modeling approach whose main objective is to standardize engineering practices by defining business processes through a shared language for every discipline during the detailed design phase.

In order to achieve its objectives MUDU focuses on modeling:

— the structure of technical data: The aim is to describe in a unique and consistent way the 900 business objects used in the design activities. The data structures are defined by the combined use of dictionaries and catalogues. Dictionaries list and define the concepts (e.g. types of characteristics, functional relationships, equipment, etc.), which assure a uniqueness of information. A catalogue gathers together specific data frameworks for every item used in a single CAD application in order to capture the appropriate

[4] The IAEA neither endorses the software and technology described, nor does the IAEA promote or favour any technologies.

engineering knowledge. These data frameworks condition the creation of engineering data in the CAD core (see FIG. III-1.);

— the SME knowledge management: EDF stores and manages the expertise acquired by its SMEs after over 50 years as a nuclear plant designer and operator.

In relation to the engineering processes and activities over the life cycle, the design phase has been divided into macro-activities, activities and actions. For each activity, a description of the data inputs/outputs has been formulated to enable their association with the applicable design and regulatory requirements, engineering processes, business planning and procedural rules (regulatory documents, industrial standards, EDF procedures, etc.). Consequently, it was possible to link data production and project planning.

The CAD 2000 is a software suite that utilizes the MUDU standardized concepts and the common repository approach. It contains about 20 in-house and off-the-shelf CAD solutions that support various design engineering tasks. The tools support the process of creating, modifying and managing information related to engineering objects according to the data frameworks defined in MUDU.

Figure III-1. details the general CAD2000 architecture: MUDU specifies the data frameworks for each type of business objects. Every instance of a business object is created and modified by the CAD 2000 tools and is stored in the common repository: the CAD core. The information stored in the CAD core uses the data pattern defined in MUDU and can be modified in the different CAD 2000 tools.

Some of the end-results of this approach are a more efficient collaborative workspace and increased digital data quality thanks to reduced information discrepancies between tools as information is centralized in a repository accessible to every stakeholder. Moreover, MUDU introduces a common language between all disciplines involved in design engineering that ensures unified concepts and definitions. Finally, MUDU houses business knowledge of EDF's subject matter experts. This knowledge is injected into the engineering processes and formalized business rules to ease implementation of design activities and better guarantee design quality.

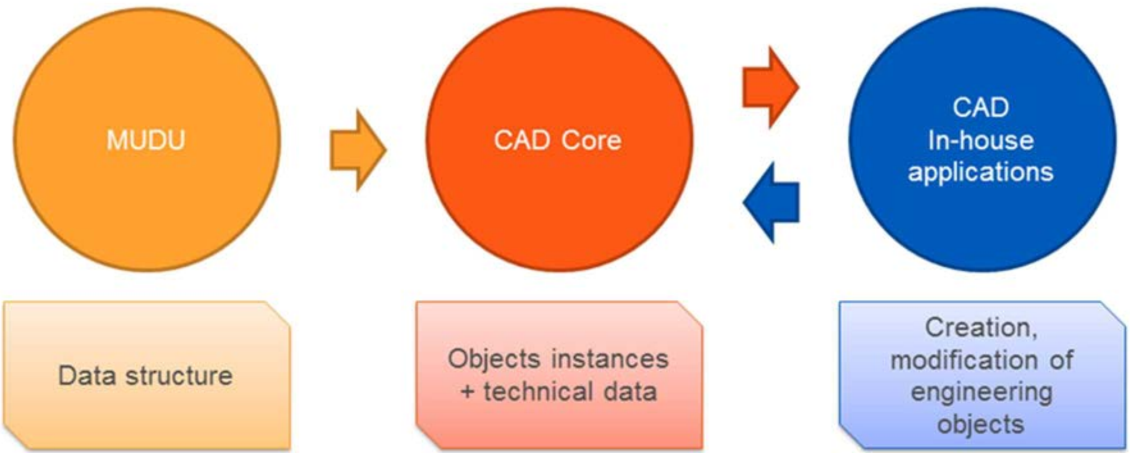


*FIG. III-1. Integration of MUDU data structure in the CAD 2000 environment*

### III-2.2. Service design for innovation project

Service design for innovation (SDIN) designates a program developed by EDF in order to renovate its nuclear asset information system for operation and maintenance phases. SDIN is a central technical component in the industrial management of the 58-unit reactor fleet in France. The initialization of this program was driven by the following goals:

- Reinforce the production and safety performance of the fleet;
- Support the activities concerning lifetime extension of reactors beyond 40 years;
- Facilitate the incorporation of lesson learnt and plant modification following the Fukushima events;
- Standardize operation & maintenance procedures across the different nuclear sites;
- Secure and accelerate access to O/O information and documents via a user-friendly interface.

SDIN is based on an integrated set of well-tried commercial software that fulfills the six following functions described in Figure III-2.


*FIG. III-2. SDIN: scope of the business functions*

Concurrently with the integration of new tools, a large effort was made to revamp the work processes: standardization of practices throughout the different sites, rationalization of maintenance activities, and integration of lessons learnt. These efforts resulted in the development of a nuclear management model, a key element of the SDIN project.

A dedicated team of subject matter experts, IT architects and asset management software specialists has captured the operation and maintenance activities into one shared activity model. This nuclear management model is divided into processes, sub-processes and activities which all trace back to a single O/O information data model shared by all 58 reactors.

Diagrams represent the sequence of sub-processes for a given a process, the succession of activities for a given sub-process, business intelligence indicators as well as input and output information exchanges. Every activity is associated with a type of business actor (organization, discipline, level of hierarchy) who is responsible for carrying out the task. An additional architecture layer of modeling provides insight on the IT tool that is used for each activity.

## III-3. ISSUES AND CHALLENGES TO PLANT INFORMATION MANAGEMENT

The current state of PIM at EDF can be illustrated by the CAD2000 and SDIN approaches that focus on two different phases of the NPP life cycle. From an organizational perspective, it involves two different departments of EDF, with different goals and expectations. In addition to the differences in terms of work processes and cultures, these two entities of EDF have their own responsibilities to preservation of engineering information and configuration management.

CAD2000 covers the design phase during which EDF as an architect-engineer has to justify and document the design choices and ensure the conformance between what is built and the facility configuration information. The key challenges and issues to be addressed during this crucial phase in the NPP life cycle are tracing design specifications back to the original functional requirements, ensuring data uniqueness and reliability, easing access to all data and documents and being able to provide a coherent set of information for handover once the NPP is built.

On the other hand, during the operation phase, the plant has to perform as efficiently as possible while complying with the licensing base safety standards. Plant configuration management calls for a continuous monitoring of any discrepancies between the physical plant configuration and the design basis; a tedious and costly task which SDIN aims to facilitate by providing support to daily maintenance and operations activities on a plant, integrating process and change feedback back into the fleet, unifying the data models for all reactors, and by easing access to design and maintenance data and documents.

As a consequence, there are potential opportunities in adopting an integrated strategy taking into account business needs of each stakeholder both from the engineering-construction and O/O points of view. One of these opportunities is to leverage new information technologies during the handover phase.

The handover of information from the design engineering division to the nuclear production division is challenging as it represents a huge amount of data (documents, drawings, 3D models, maintenance procedures, operating rules and procedures). The nuclear production teams have to interpret this information and transfer it into their IT system in order to be able to operate and maintain the plant safely and efficiently. This step of rekeying information can lead to errors, inconsistencies or misinterpretation.

One way to mitigate this risk of misinterpretation is to capture the design knowledge and document the design choices in a structured manner (see Figure III-3.). Tracing the answers to the following question is essential to build an efficient source of knowledge:

- Who was it designed for?
- What was it designed to do?
- Who designed it?
- How was it designed?
- Why was it designed this way?
- How did it evolve?
- When was it designed?

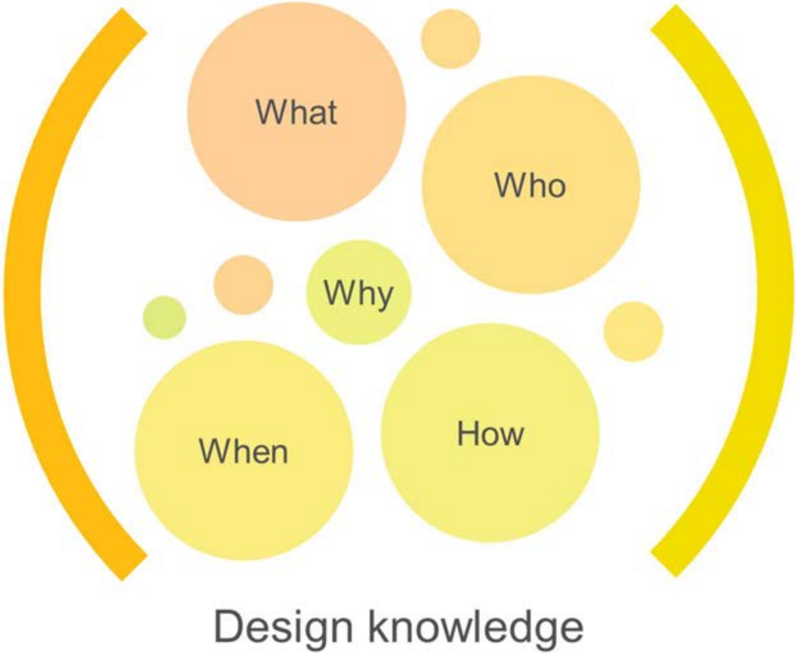


*FIG. III-3. Principles of design knowledge capture*

## III-4. TECHNOLOGIES AND APPROACHES TO PLANT INFORMATION MANAGEMENT

The plant life cycle management (PLiM) project has been launched by the EDF's nuclear engineering division in 2012. Its aim is to optimize its business strategy concerning plant information management of new reactors. The PLiM strategy is based on a digital duplicate of the plant that is able to collect, record, and classify all technical data produced along the life cycle of the NPP from design to decommissioning, and makes it possible to define and trace the history of SSC and equipment. The underlying information model is meant to ensure a high level of traceability of all information as it is consistently created, validated, modified and handed over.

Designing, building and operating a new reactor are complex tasks that require the collaboration of many stakeholders over a hundred-year timeframe. The goal of the PLiM project is to share these structured and organized data in a single secured database:

- internally, among the different engineering divisions;
- externally, with partners, suppliers and nuclear regulatory authorities;
- over time, with future generation of workers.

The main expected end-results are an unprecedented level of traceability and access to information and an efficient collaborative workspace particularly during the design phase.

The PLiM project builds on EDF's experience with previous IT projects, such as CAD200 and SDIN, and benefits from information modeling experience during both the engineering-construction and operation-maintenance phases of EDF's commercial unit fleet (see Figure III-4).

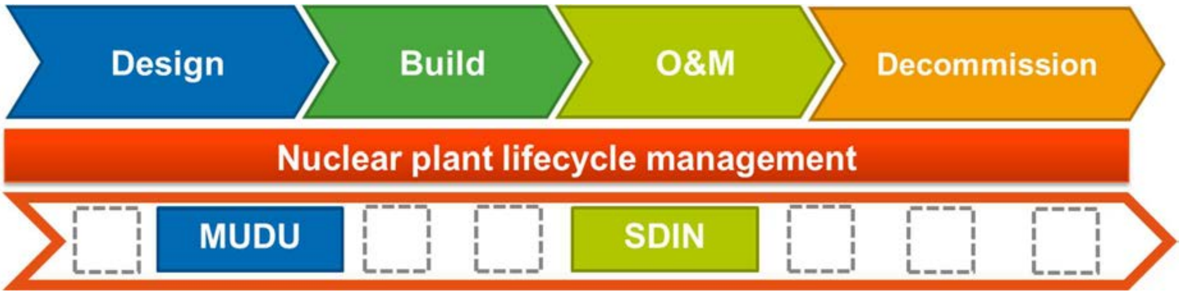


*FIG. III-4. Scope of the PLiM project – Integration of experiences related to previous IT projects*

EDF promotes a holistic approach that encompasses the previous business needs and sets the foundation of a unified methodology leveraged by PLiM tools. This approach consists of four layers that jointly cover business processes, data and architecture aspects, and capture business knowledge in a structured and re-usable manner (see Figure III-5).

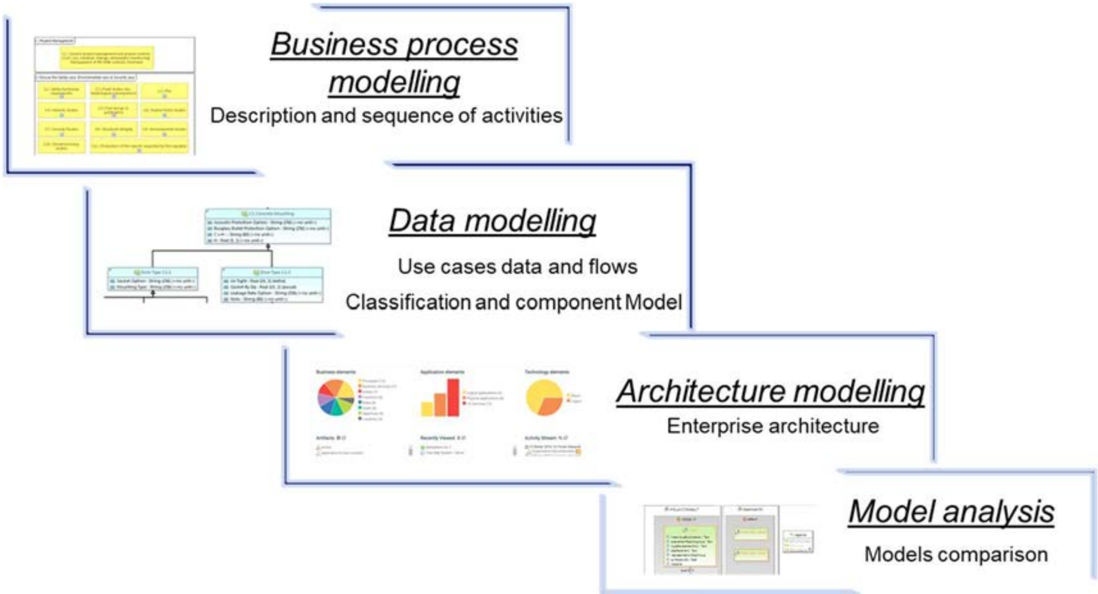


*FIG. III-5. Scope of the PLiM project – Integration of experiences related to previous IT projects*

## III-5. BENEFITS AND OPPORTUNITIES FOR IMPROVEMENT WITH APPLICATION OF THE PIMS AND COMPLEMENTARY TECHNOLOGIES

The nuclear PLiM's information modeling approach will support future construction projects of the group. These new projects are opportunities to apply new concepts related to PIMs. The information modeling approach can, therefore, take into account and facilitate the:

- application of systems engineering principles (ISO 15288) [1]: facilitate the management of complex systems by decomposing the product in breakdown structures, and by separating the requirements from the architecture of the solution. Information models provide a framework to develop optimal, multi-disciplinary solutions in a progressive manner;
- configuration management: ensure the consistency between what is required by the stakeholder and architects, what is designed by the engineers and what is procured, installed and operated on site during the lifetime of the plant;

- traceability of engineering hypotheses and impact analysis of design modifications: improve productivity by keeping track of changes in the plant digital configuration and by performing impact analysis, margin management and interface identification directly in the IS. Decision makers will base their judgment on reliable digital information. Document based CM will evolve to a digital CM philosophy providing a real-time image of the plant and conformance to requirements;
- requirement management: describe all the safety and performance requirements in data objects so that complex networks of dependencies and impacting links may be traced back to the design, physical equipment and documents;
- optimization of the construction schedule: detail the dependencies between the different construction activities to optimize construction sequence and avoid clashes through 4D simulations;
- transition to data centric paradigm;
- defining efficient IT tools: vault and manage subject matter experts' knowledge in a tool independent data structure which is flexible enough to adapt to different business contexts and IT infrastructures for different projects and evolving IT tools within existing projects.

## III-6. AVAILABLE STANDARDS AND GUIDES IN THE AREA AS WELL AS THOSE UNDER PREPARATION AND PLANNING

The PLiM aims at enabling collaborative work between stakeholders that will define, create, trace and store massive amount of information over 100 years period. As a consequence, it is necessary to use interoperability standards to assure the conservation, access and sharing of the information over time. In particular, EDF is carefully monitoring the evolutions of ISO 15926 [2] and is working on building a nuclear reference data library (RDL) that could be suitable for the nuclear industry.

EDF is also aware of the crucial role of neutral file formats in order to safeguard and access data over the years. The EPRI report (EPRI, 2009) [3], gives a good overview of the problem and recommends the use of neutral format such as PDF or xml. EDF is also involved in other initiatives for the definition of neutral 3D geometry (Web3D).

## III-7. MAJOR ACHIEVEMENTS AND LESSONS LEARNT

Based on EDF experience in the data modeling domain, implementation of large-scale IT projects go hand in hand with an evolution of the engineering processes. To succeed in this task, it is necessary to involve SMEs as early as possible in the solution development process; not only in the specification of the tools themselves but also in the information modeling process.

In addition, the nuclear industry as a whole (reactor vendors, construction industry, and equipment suppliers) has to come to together in order to establish and promote industry standards that will be able to create a more collaborative global workspace.

## REFERENCES TO ANNEX III


[1] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Systems and software engineering - System life cycle processes, ISO 15288:2015, ISO, Geneva (2015).

[2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Industrial automation systems and integration - Integration of life-cycle data for process plants including oil and gas production facilities - Part 2: Data model, ISO 15926-2 :2003, ISO, Geneva (2003)

[3] ELECTRIC POWER RESEARCH INSTITUTE, Advanced Nuclear Technology: New Nuclear Power Plant Information Handover Guide, 1019221, EPRI, Palo Alto, CA (2009).

# ANNEX IV. PLANT INFORMATION MODEL FOR STEAM GENERATOR REPLACEMENT AND LTO ACTIVITIES OF KRSKO NPP[5]

## IV-1. HISTORY

The Krsko Nuclear power plant began construction in 1974, as a joint venture of two republics of the former Yugoslavia, Slovenia and Croatia. The electrical generation is split 50/50 to each country. The plant is a Westinghouse Model 60 Pressurized Water Reactor (PWR) built by Gilbert Associates/WorleyParsons and provides about 40% of Slovenia's electricity demand. The original design power rating was 630 MWe. Commissioned in 1982, the NPP conducted a design basis reconstitution (DBE) in 1991 and replaced steam generators in 2000, resulting in an uprate to 705 MWe. The NPP is currently approved to operate on an LTO license until 2030 [1].

For the first ten years of plant operation, the Krsko NPP relied almost exclusively on outsourced and contract support for maintenance and engineering changes. The plant had no on-site engineering organization, and the principal maintenance managers acted as project management for outsourced contractor-based work performed for engineering changes or major outage work. Outages and major technical surveillances were almost completely managed and staffed by the nuclear steam supply system (NSSS) vendor, Westinghouse.

## IV-2. TIMELINE

The Krsko NPP life cycle has followed four phases that are typical of most NPP projects, even if the times are longer for some phases. In Figure IV-1 below, the most apparent difference from typical NPPs is the extended turn-key operation period (nearly 10 years), prior to the O/O taking more control of the plant maintenance and engineering. It was at the beginning of this period that the creation of the Krsko management information system (MIS) took place and the on-site engineering organization was established. In addition, in year 2000 of the O/O operation, the Steam Generators were replaced after 2 years engineering review, preparation and procurement cycle. The last phase in includes the application for license extension and LTO.

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[5] The IAEA neither endorses the software and technology described, nor does the IAEA promote or favour any technologies.

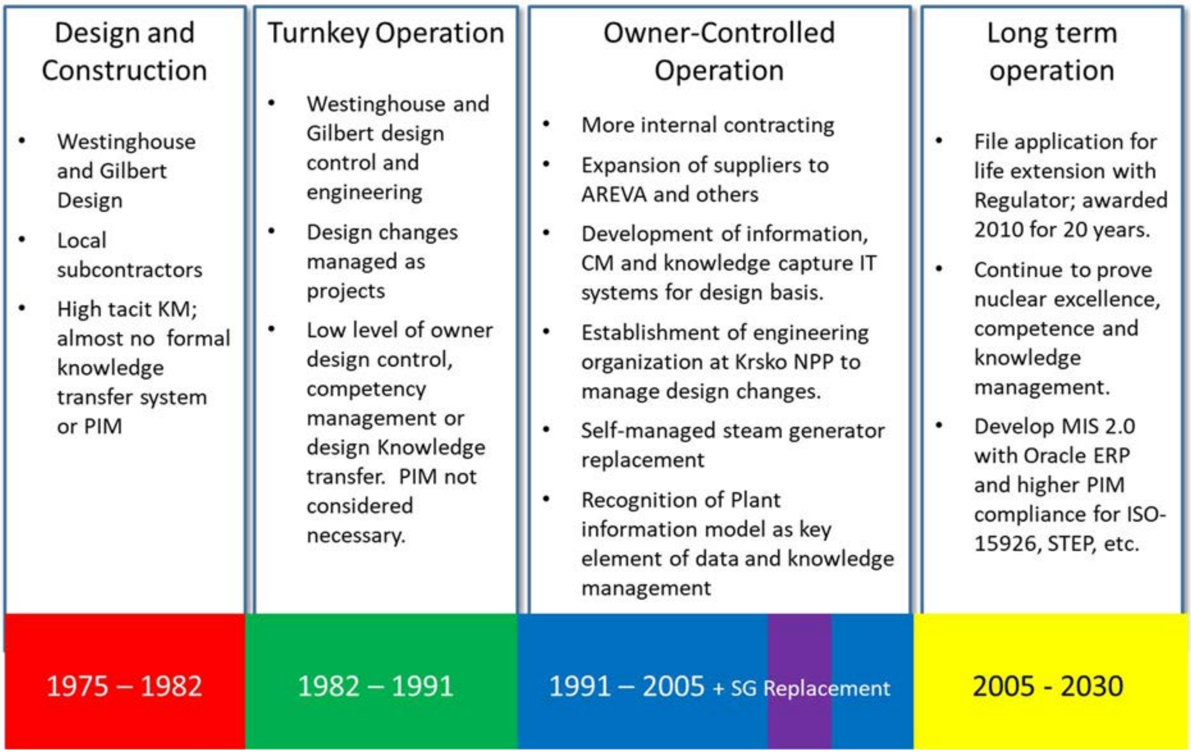


*FIG. IV-1. The Krsko NPP Life cycle*

## IV-3. KRSKO MIS

As part of the Krsko Plant MIS and general design knowledge consolidation efforts, a data dictionary and standard schema development was undertaken by the IT department at NPP Krsko in the early 1990's to establish standards for semantics and relationships of engineering and operational data. The intention of the Krsko MIS and supporting data base was not to be a true design-knowledge transfer infrastructure or to attempt to standardize data schemas or taxonomies over organizational boundaries but was nonetheless created for a number of the same reasons. For that matter, the NPP Krsko MIS may be viewed as typical first step to ultimately establishing a true PIM. The Krsko MIS was nominally intended to perform the following tasks:

— Support the self-management of maintenance, repair and minor plant modifications in a maintenance, repair, overhaul-based environment;
— Develop a design changes system for an internal design engineering organization, to replace the previous outsourced contract-and-design model;
— Establish a solution for tracking NPP design basis and requirements, equipment identification and data, and document control in support of configuration management programs;
— Meet regulatory compliance for procedure index, document control, design basis library, design requirements, task action tracking, etc.;
— Audit general data quality and configuration through engineering review of MIS input.

## IV-4. KRSKO MIS/PIM AND DEVELOPING A K-PIM

While not representing a fully implemented K-PIM, the Krsko MIS as a PIM has established a basis for development of a K-PIM, and has in fact accomplished several of the goals that support the concept of a fully developed K-PIM, including:

— communication with an EPC and/or major vendors in a common semantic framework;
— maintaining an accurate and timely configuration of the NPP in order to better support LTO and major works, such as the steam generator replacement;
— better prove integrity of design basis, requirements tracking, task tracking and margin management to the regulator and NPP management board;
— discourage and reduce dependence on local, legacy database and non-data repositories (such as spreadsheets and paper files).

Krsko NPP began to review IT requirements, architecture, and path forward, the concept of a PIM in the mid-1990's following the development of the original MIS system. Figure IV-2 describes some of the MIS areas considered important to meet the PIM goals for increased independence in maintenance and operations.


*FIG. IV-2. Krsko MIS/PIM Taxonomy*

## IV-5. KRSKO NPP STEAM GENERATOR REPLACEMENT AND MIS/PIM

The steam generator replacement project in 1997-2000 was the first major test of the improvements in organization, staff loading and knowledge management for the plant, as well as the performance and accuracy of the MIS as a true PIM.

The replacement of the Krsko NPP steam generators in 2000, after about 18 years of power operation, was an engineering effort that rivalled the complexity of constructing the original plant, in the sense that virtually every component, system, design basis and supporting calculation had to be re-verified and/or modified as appropriate for impact analysis to the plant. It was a true test of the MIS, PIM and CM program results. The new steam generators were larger and more efficient and would result in a power uprate of approximately 10%-15%. This would create considerable impact on basic plant performance parameters and margins, including heat balance, steam capacity, reactor power and turbine capacity.

These considerations are in addition to the massive steam generator tube-plugging that had progressed during the operation of the plant. Heat balance and generation were lost through the previous years of plugging an increasing number of the steam generator heat-transfer tube bundles as they began to stress fracture and split open over plant life during the 1980's and

90's. The Westinghouse-supplied steam generators used in the Krsko NPP had a history of degraded performance and were generally replaced by most affected NPPs after 20-25 years.

The Krsko NPP had already plugged the regulator-approved design maximum of 18% of the total tube inventory and had requested an extension to 25% to continue operation. Plugging the tubes, while preventing migration of primary coolant inventory into the secondary steam cycle and ultimately the turbine-generator and the atmosphere, also reduced the available heat exchange surface area in the steam generators, with a corresponding loss of heat load and consequently, generated power.

## IV-6. OUTCOME FOR KRSKO MIS AND PIM

The engineering effort took place over a period of about 24 months, including building the new steam generators. The steam generators were exchanged, old for new, during an extended refueling outage that lasted 63 days, at a total project cost of about USD 120M. The plant was then successfully restarted and, after heat-up and power ascension testing, was returned to service at a new capacity of 705 MWe, increased from the nominal rating of 630 MWe, and far above the degraded output of little over 520 MWe output available just before the replacement of the steam generators. General results for the impact and benefits of a PIM-based MIS for the project:

— The engineers, external contractors and NPP Krsko management all agreed that this performance and level of success in such a short time frame would not have been possible, or even thinkable, without the high quality and reliability of the MIS, CM data and the overall PIM-enhanced knowledge management and design basis knowledge programs at NPP Krsko;
— The scope and quality of the MIS/PIM, the coordination of external vendors and the in-house maintenance, along with the engineering preparation, permitted the steam generators to be removed and exchanged during what amounted to an extended refueling outage of 62 days total duration;
— The research and preparation for the steam generator replacement added to, and increased the existing quality of, the existing MIS, CM and overall knowledge management content of the MIS, as it represented virtually a full-plant walk-down and design basis review and analysis.

The system engineer program produced a large amount of plant condition, operating experience and status knowledge which was then entered into the MIS, to commence and encourage the development and transition of the MIS from PIM to true K-PIM.

## REFERENCES TO ANNEX IV

[1] NUCLEAR POWER IN SLOVENIA, https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/slovenia.aspx

# ANNEX V. THE PLANT INFORMATION MANAGEMENT AND APPLICATION OF THE PLANT INFORMATION MODELS[6]

## V-1. SHORT INFO ABOUT ORGANIZATION

The NEOLANT group of companies offers comprehensive engineering and IT support for power generation industries, particularly in the nuclear and fossil fuel sectors. PIM technologies are among the IT solutions NEOLANT develops and implements in support of the life cycle management of power generation facilities.

Modern engineering information technologies enable efficient change management and nuclear power unit configuration management, on the basis of a solution developed by NEOLANT NPP Units Decommissioning Database information system, which uses 3D engineering information models of nuclear power units (Figure V-1). The information system concept includes a nuclear power unit information model in form of an engineering data management system (Figure V-2.) to collect and store engineering information and documents and interfaces on the basis of a 3D plant model (e.g. of a nuclear power plant, the Joint Institute for Nuclear Research, any other nuclear facility) to search for information and to display it.

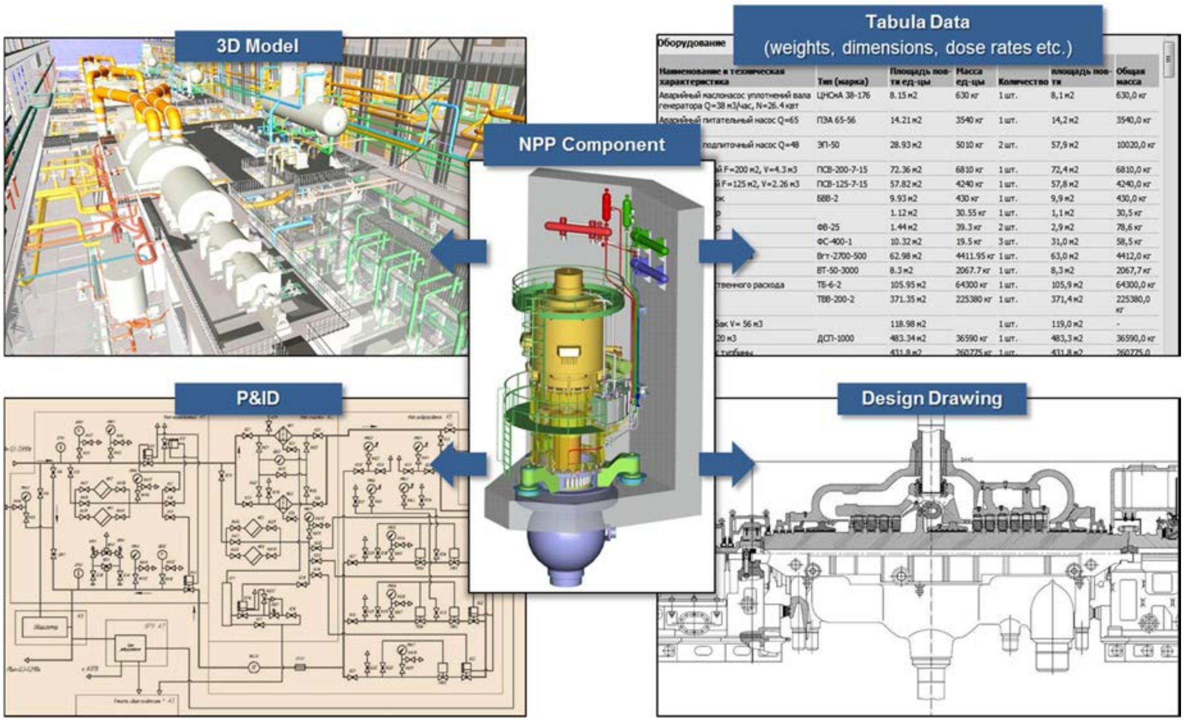


*FIG. V-1. Information system for engineering data management based on 3D models (reproduced courtesy of NEOLANT)*

[6] The IAEA neither endorses the software and technology described, nor does the IAEA promote or favour any technologies.

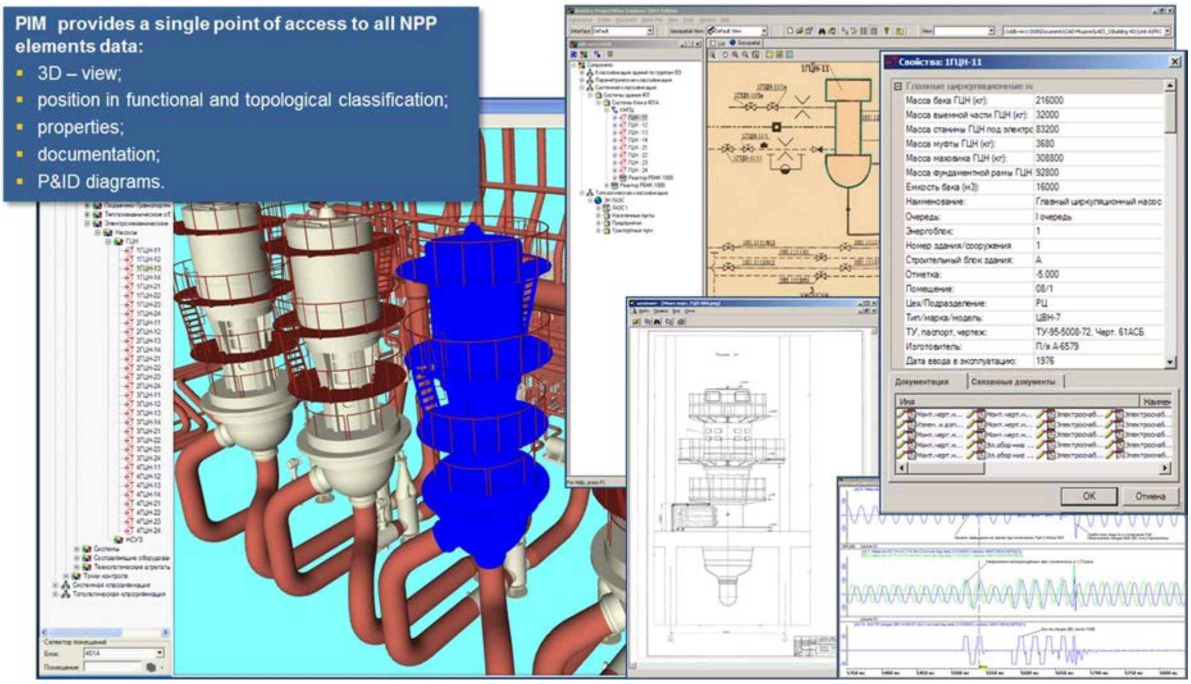


*FIG. V-2. Interface element of the "NPP Units Decommissioning Database" Information System, enabling access to different types of information through the 3D model (Reproduced courtesy of NEOLANT)*

PIMs were built in exact accordance with available paper-based documents. In cases when some drawings had been lost or not kept up to date after refurbishment or rearrangement, laser scanning technologies were applied in order to collect precise and detailed spatial as-built information.

PIMs created by NEOLANT are being used as a basis for implementation of the NPP Units Decommissioning Database information system for specific nuclear power plants based on PLiM platforms, which are harmonized with the platforms currently used by the general designers of those plants.

## V-2. ISSUES AND CHALLENGES TO PIM

Managing engineering data for an industrial facility, including integration and maintenance of all engineering and technical data, ensuring fast and convenient access to that information and its analysis, proves to be necessary in order to perform the following tasks:

— to increase economic efficiency of the plant during its life cycle, including the decommissioning stage;
— to ensure strict adherence to industrial safety requirements, radiation safety requirements (in case of nuclear facilities) and environmental safety requirements during operation including refurbishment and restoration projects, and decommissioning.

While performing aforementioned tasks, one faces a range of challenges, including:

— an enormous amount of information describing the plant configuration; for instance, at the time of a nuclear power unit start-up, the amount of technical information reached up to 2600 volumes, classified into 15 main sections and 70 subsections; the total manpower effort of 20 or more organizations involved in creation of technical design documentation was typically close to 1,160,000 man-hours. A large amount of data is also generated during the plant operation phase. The total effort of the engineering personnel at a nuclear power plant spent on searching for paper-based information may reach several dozens of days per staff member per year.

- complexity of engineering procedures, step-by-step commissioning and significant geographical distribution of industrial infrastructure: for instance, a nuclear power plant includes several sites, located at a distance from each other, each consisting of various buildings and structures. Each of such buildings or structures itself is a complex plant facility, supporting special functions of energy generation and/or ensuring process safety at the nuclear power plant. As a general rule, informational support of plant and infrastructure operations is based on so called "patchwork" automation. In such a case, specialized operational IT systems use isolated data storages dedicated to particular tasks of the central office and functions of the operator. The particular system usage efficiency depends heavily on the quality of the data that has been put into the system, particularly with respect to the data correctness, integrity, completeness, and consistency. Databases of legacy information systems lack spatial representation of systems and equipment, which complicates data search and analysis;
- high importance of plant refurbishment projects: in case of nuclear power facilities, design and engineering projects at such life cycle phases as lifetime extension and decommissioning are characterized by special importance and responsibility. In order to be able to develop high-quality refurbishment, lifetime extension and decommissioning projects, the general designer needs to know the current operational state of a particular plant.

## V-3. TECHNOLOGIES AND APPROACHES TO PIM

Creation of an integrated database with all technical engineering information concerning the nuclear power plant (design, construction, operation, diagnosing, maintenance, and refurbishment) and maintenance of this database throughout the whole plant life cycle (ensuring a high level of adoption by all plant employees and permanent updating) are key factors for an efficient implementation of nuclear power unit life cycle management. The optimal way of creating and maintaining such a database implies application of information technologies such as 3D CAD systems, digital document workflow systems, web-portals, etc.

Modern CAD tools allow not only to design an industrial plant, prepare a complete set of construction documentation ("main product"), but also create a useful "byproduct" – an engineering information model of the plant. In terms of information technologies, an engineering model created with modern CAD tools is a database with engineering information necessary for efficient plant management during regular phases of operation, maintenance and repairs. Using it as a foundation and employing de-facto standard commercial database management software allows to create an information model that can be used as a basis for making decisions concerning engineering issues and processes as well as for managing economic aspects.

During the "pre-digital-modeling" era, a design process of an industrial plants ended in creation of a set of documents in form of drawings, cost estimates, explanatory notes, etc. (design, construction, commissioning documentation) as hard copy paper sheets of various sizes. Those documents performed at least two functions: they served as a storage place of information about the plant and as a reference and guidance toolbox for construction workers, equipment installers, supervisors and inspectors of various levels.

If design and engineering companies apply some of the modern CAD tools, the design process results in a database that includes information about the plant geometry (3D), materials, piping and instrumentation diagrams (P&IDs) and control paths, power supply schematics, equipment lists, suppliers of materials and equipment.

Data source unification – information model in the form of engineering data management system – and open API allow NPP experts and general designers to receive comprehensive information on an NPP element from various integrated ISs through 3D engineering models and visualize operating data on 3D models (Figure V-3). This ensures better understanding of an NPP equipment current integrated state, promotes rapid decision making, considers operating features at designing and planning renewals and repairs.

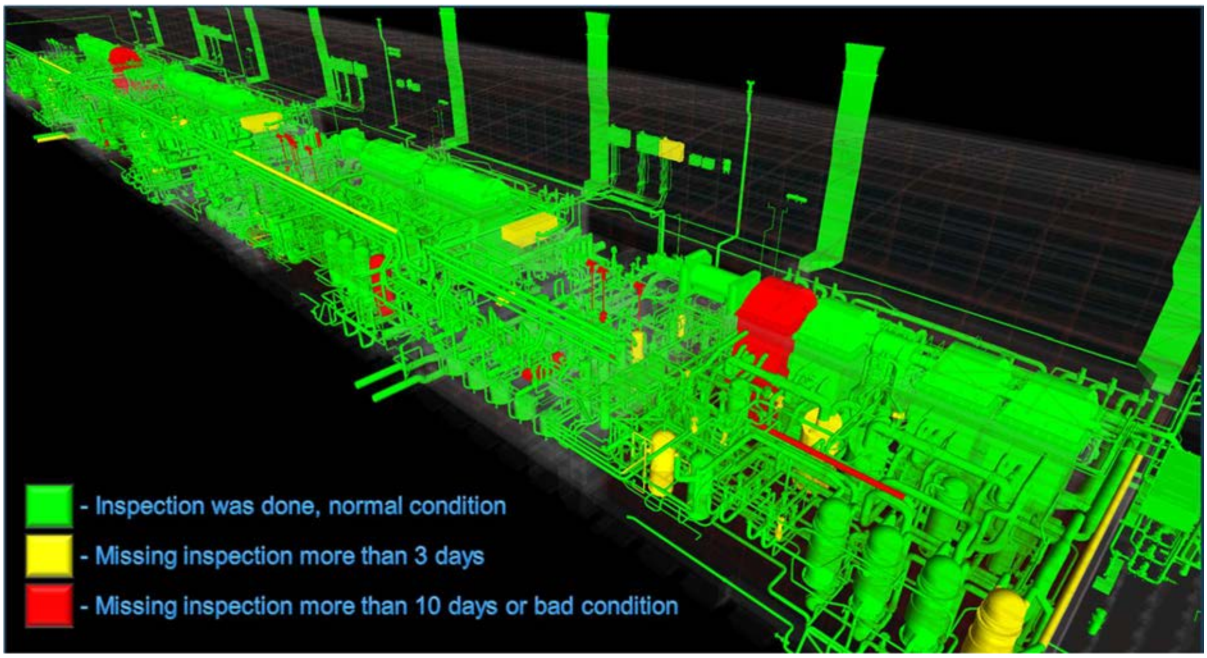


*FIG. V-3. Color-marked information about equipment state defined by inspections (reproduced courtesy of NEOLANT)*

### V-3.1. Lifetime characteristics management

At present, special commission entities are being established in Concern Rosenergoatom NPPs to assess equipment residual lifetime. The commissions consist of NPP and operator representatives, NPP general designer, chief designer, equipment manufacturer and other specialized organizations representatives. The commissions manage the development, drawing up and implementation of an inspection program, assessment of technical conditions, equipment and pipelines residual lifetime and issue technical decision on ability and conditions of further equipment operation continuation. As well as implementing diagnostic itself and evaluating residual lifetime using existing techniques, experts of the above listed entities are forced to arrange some preparing operations including searching and analyzing technical documentation.

Using an information model with integrated diagnostic systems for basic equipment and plant monitoring systems, such as computer-aided pipeline leak detection system, pumping machinery vibration-based diagnostics system, etc. (Figure V-4), makes it possible to solve basic tasks of lifetime characteristics management.

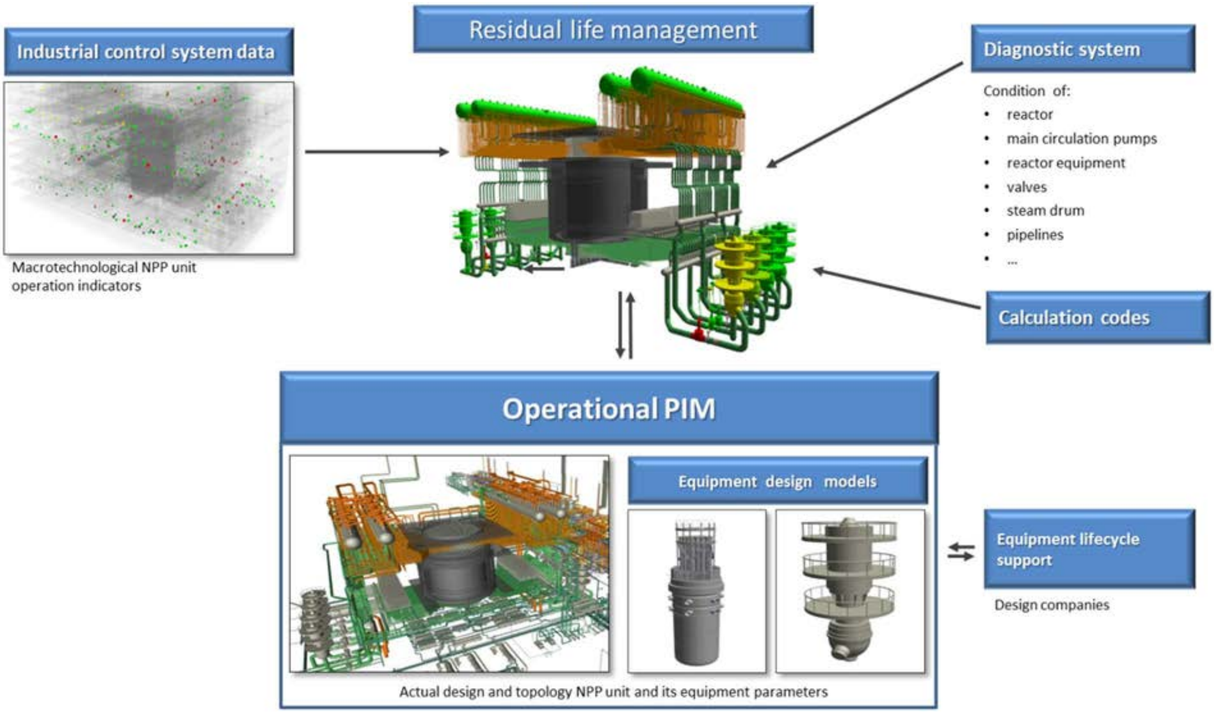


*FIG.V-4. Residual lifetime management (reproduced courtesy of NEOLANT)*

### V-3.2. Radiation safety

An NPP executes different types of radiation monitoring: standard computer-aided systems, manual dose rate detection, personal dose rate detection, etc. However, a common structured radiation information repository, that integrates all types of radiation monitoring in NPP rooms and provides experts with a clear representation of the results, is not available in the majority of NPPs.

The updated radiological information is visualized in a 3D NPP model (Figure V-5). A point displayed on the 3D model can be a point of manual measurement or location of an automated monitoring system detector. When referring to this point, the PIM user will be redirected to the whole array of information on the location under control, thus making it possible to draw trend lines, select data and support other tools.

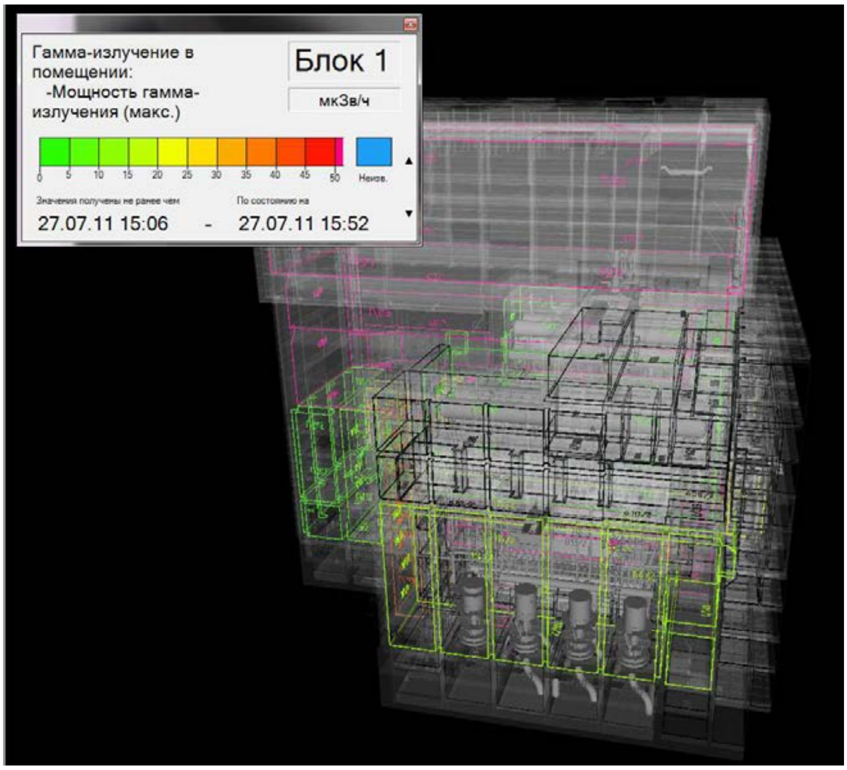


*FIG. V-5. Displaying current radiological data on Leningrad NPP 3D model (reproduced courtesy of NEOLANT)*

### V-3.3. Simulation modeling of complex repair works

Information models, integrated with computer-aided identification technology and the facility's MRO system, are capable to efficiently backup, in digital format, the planning and implementation of planned and condition-based preventive maintenance measures and repairs of NPP elements. Possible areas of application are to:

- visualize on 3D model timetables regular preventive repair work and general overhauls on the power unit;
- plan details and optimize sequence of complex repair activities on certain areas based on the 3rd – 5th levels timetables;
- demonstrate for maintenance personnel an approved detailed plan of works execution in visual format by means of a 3D engineering model on the working place;
- display for maintenance personnel sequence of assembling-disassembling, parts replacement, and preventive works implementation by means of interactive technical manual on the working place;
- provide access on the working place to required technical and engineering information about units under repair and preventive maintenance (design documents, data on equipment and its elements, etc.) in electronic form.

In the last two options, the computer-aided identification is used to identify units under repair on the working place aimed at receiving access to detailed work execution plans, interactive technical manuals on assembling-disassembling elements and other essential repair information. It is possible to use the computer-aided identification technology for registering the work execution fact and managing the work sequence.

### V-3.4. Training simulators, staff training

Information models provide the basis for implementation of advanced techniques for operating, maintenance and engineering NPP personnel training.

Training tools and simulation models based on 3D engineering models make it possible to create virtual user-directed computer simulation of a process procedure or complex repair/assembling/disassembling operation. The systems allow users to manage procedures and operations through interaction with control elements of simulated virtual control desks, manipulate virtual personnel mockups (avatars) and technical means (lifting and transporting machineries, robotics, scaffolding, etc.).

Use of training tools and simulation models during repair works provides the possibility to optimize them through manipulation with operations sequence and scope. Example use of PIM for personnel training is a system developed at Novovoronezh NPP Training Center: “Software and Hardware Complex of Virtual Reality in Novovoronezh NPP” (Figures V-6 and V-7).

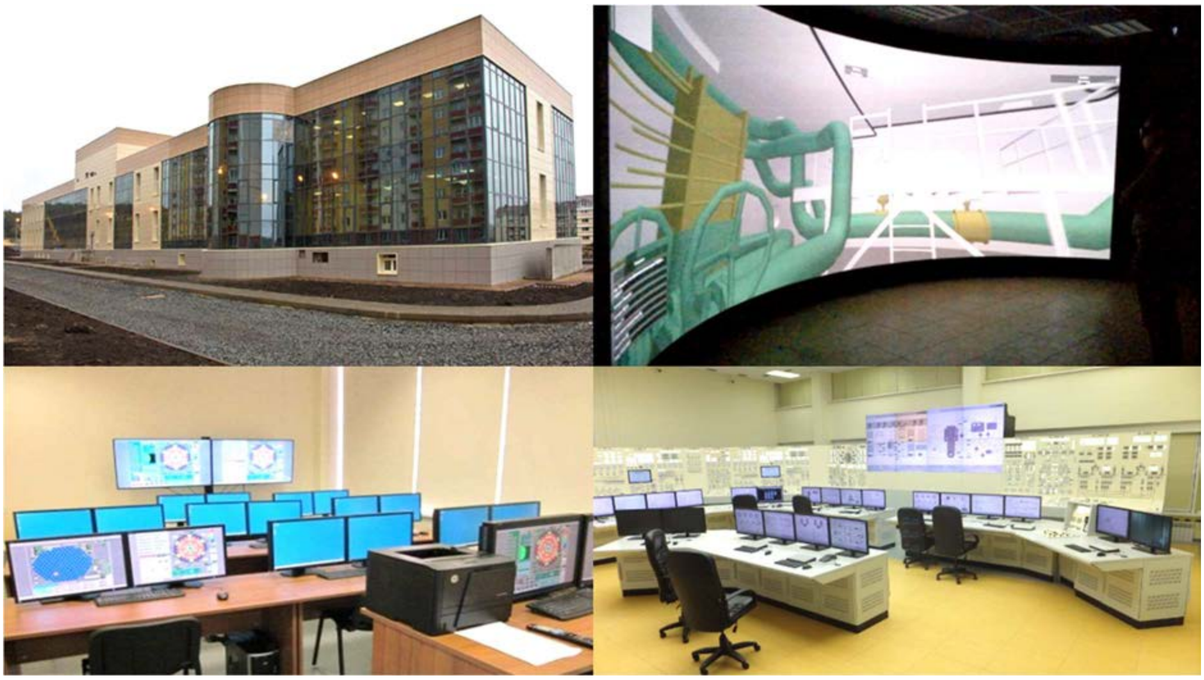

*FIG. V-6. Software and hardware complex of virtual reality in Novovoronezh NPP (reproduced courtesy of NEOLANT)*

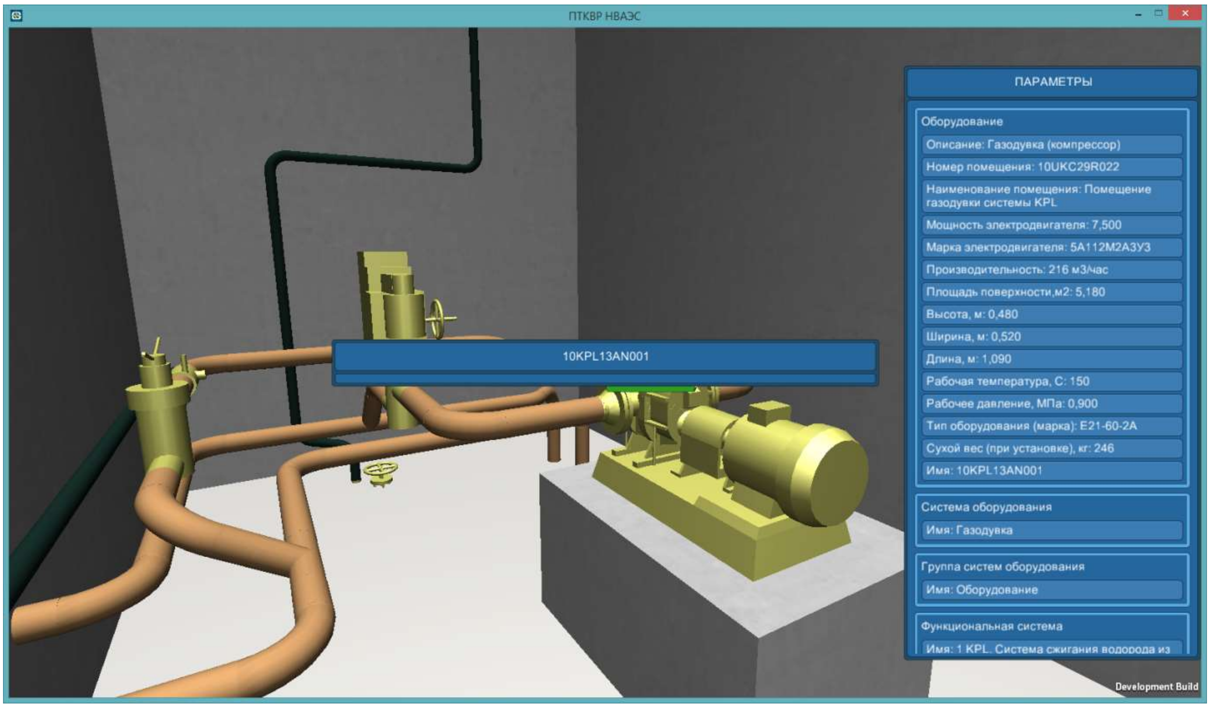


*FIG. V-7. Displaying equipment date in SHCVR (reproduced courtesy of NEOLANT)*

## ABBREVIATIONS

| | |
|---|---|
| 2D | Two dimensional |
| 3D | Three dimensional |
| 4D | Four dimensional |
| 5D | Five dimensional |
| API | Application program interface |
| BIM | Building information model |
| CAD | Computer-aided design |
| CAE | Computer-aided engineering |
| CIM | Common information model |
| CM | Configuration management |
| COTS | Commercial off-the-shelf |
| DKM | Design knowledge management |
| EPC | Engineering procurement construction |
| H/T | Handover/turnover |
| K-PIM | Knowledge-centric plant information model |
| I&C | Integration and control |
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| IT | Information technology |
| MIS | Management information system |
| MRO | Maintenance, repairs and operations |
| NKM | Nuclear knowledge management |
| NIST | National Institute of Standards and Technology (USA) |
| NPP | Nuclear power plant |
| O/O | Owner/operator |
| PIM | Plant information model |
| PLiM | Plant life cycle management |
| SSC | Systems, structures, components |

## CONTRIBUTORS TO DRAFTING AND REVIEW

| | |
|---|---|
| ADAMS, R. | International Atomic Energy Agency |
| BERAHA, D. | International Atomic Energy Agency |
| BOTHA, G. | International Atomic Energy Agency |
| DE-GROSBOIS, J. | International Atomic Energy Agency |
| DOROBIN, D. | JSC “NEOLANT”, Russian Federation |
| FREELAND, K. | PowerKnowledge Energy Systems, USA |
| GANESAN, A. | International Atomic Energy Agency |
| GLADYSHEV, M. | International Atomic Energy Agency |
| GOICOECHEA, J. | Empresarios Agrupados, Spain |
| GOVGASSIAN, G. | EDF, France |
| KAMARA, A. | International Atomic Energy Agency |
| KANG, K. | International Atomic Energy Agency |
| KOLOMIIETS, V. | International Atomic Energy Agency |
| KONONOV, V. | JSC “NEOLANT”, Russian Federation |
| OVANES, M. | International Atomic Energy Agency |
| PAUGAM, T. | EDF, France |
| RENUART, R. | Renuart Consulting, USA |
| SELIVERSTOV, A. | JSC Atomenergoproekt, Russian Federation |
| SZŐKE, I. | Institute for Energy Technology, Norway |
| TIKHONOVSKY, V. | JSC “NEOLANT”, Russian Federation |
| WAKEMAN, M. | NewNuclearData.com, UK |

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Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
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