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Approaches to Management of Requirement Specifications for Nuclear Facilities throughout Their Life Cycle

IAEA
International Atomic Energy Agency

APPROACHES TO MANAGEMENT OF REQUIREMENT SPECIFICATIONS FOR NUCLEAR FACILITIES THROUGHOUT THEIR LIFE CYCLE

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FOREWORD

The design and operational requirements of nuclear facilities such as nuclear power plants are specified and managed to ensure the safety and optimized operation of the facility. These requirements, and how they are managed, interpreted and used to support facility functions and activities are very important in all the life cycle phases of the facility, from design to decommissioning. Adherence to the requirements plays an important role in decisions related to safe, reliable and economical operation for almost all activities at the facility, including operation, maintenance, engineering, construction and procurement. Because the activities and functions of a nuclear facility undergo changes as it moves through the life cycle phases, knowledge of the design and operation requirements is always necessary. It is therefore important that these requirements be available to facility personnel in a form that is unambiguous, up-to-date, easy to find and use, and retrievable. The long life cycles of nuclear facilities and the complexities involved in the interactions of the large number of systems, structures and components provide challenges for the management of design and operational requirements.

The IAEA provides information on managing the knowledge related to the design of nuclear facilities in publications on topics such as the application of plant information models to support the management of design knowledge throughout the plant life cycle, and the management of design, manufacturing, construction and commissioning information and knowledge during new build projects. The present publication adds to this body of information with a focus on life cycle approaches to the management of specified design and technical requirements.

This publication analyses and provides new insights into the different approaches followed by the nuclear industry for the effective management of design and technical requirements, as well as information on developing a comprehensive requirement management programme in nuclear facilities. Although the information provided here is based on industry experience in developing such programmes for nuclear power plants, the principles and approaches presented can be used in all nuclear facilities, including research reactors, fuel manufacturing facilities, and fuel reprocessing and waste management facilities. The publication is expected to help newcomer countries to understand the importance of managing design and technical requirements early in the life cycle, and to help operating nuclear power plants and organizations to embrace new approaches of managing requirements using IT enabled applications.

The IAEA thanks all the experts who contributed to the production of this publication. The IAEA officer responsible for this publication was A. Ganesan of the Division of Planning, Information and Knowledge Management.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Issues related to the use of design knowledge were a significant factor influencing the 2011 Fukushima Daiichi NPP accident. Prior to the accident, no formal legal or regulatory requirements existed in Japan that required the comprehensive reassessment of the original site related design basis and site characteristics, either periodically or in response to new knowledge that might have been gained. This situation precluded periodic safety reassessment of the full range of external hazards that may affect plant safety under new conditions [1]. This led to a serious underestimate of the impact a tsunami could have on the Fukushima site.

The Agency has been working to develop guidance in the areas of plant information models and managing design knowledge over the life cycle of nuclear facilities. These two initiatives address the importance of design knowledge particularly for nuclear operating organizations. The design and technical requirements, which are a sub-set of design knowledge, are important information for nuclear facilities. The availability and use of detailed and unambiguous design and technical requirements support the establishment and operation of a safe and reliable nuclear facility.

Nuclear facilities, particularly NPPs, use complex technologies that cut across several engineering, scientific and technological disciplines. The design complexities of these facilities, along with their long life cycles (often close to 100 years) pose challenges to maintain and operate them to a high level of safety and reliability. Appropriate actions and decisions are required in almost all phases of a facility life cycle and knowledge related to the design and technical requirements are one of the important assets for successful performance.

1.2. OBJECTIVE

The objective of this publication is to address issues associated with traditional document centric approaches to managing the specifications of the design and technical requirements of nuclear facilities. This publication is expected to help Member States understand and implement improvements in facility RM being followed by the leading industry organizations. This publication also helps Member States embarking on new nuclear programmes to understand the methods and systems of RM currently applied in the nuclear sector.

This publication will be of benefit to those involved in the management of design and technical requirements associated with nuclear facilities, including:

- Vendors and designers of NPPs and other nuclear facilities;
- Design authority (DA) of operating organizations;
- Utility managers;
- Plant managers;
- Plant specialists (experts in nuclear safety, engineering changes, maintenance, radiological protection, environmental monitoring, modelling, emergency management, etc.);
- Staff responsible for the management of requirements;
- Staff involved in the design, maintenance modification, update of a systems, structures and components (SSCs);
- Regulators.

1.3. SCOPE

This publication aims to capture the importance of the specifications of the design and technical requirements and typical processes adopted by the industry to develop and manage them effectively over the life cycle of a nuclear facility. This publication highlights the roles and responsibilities of various stakeholders in the management and governance of the facility requirements as it moves through its various life cycle phases.

The requirements related to a nuclear facility such as a NPP go beyond the design elements of the facility. For example, there are technical requirements that have environmental, legal and financial aspects amongst others. Therefore, wherever the management of requirements is addressed in this publication, it implies both design and technical requirements. The phrases *Requirements Management* (RM) or *Requirements Management System* or *Requirements Management Programme* henceforth used in this publication are attributed to both design and other technical requirements including environmental, legal, financial and others.

1.4. STRUCTURE

This publication consists of five sections, with a brief explanation provided below regarding the content of each section.

Section 2 defines and discusses the eight principles for an effective programme to manage the requirements. It also discusses the scope of this management, its interaction with other facility management systems and the complexity of managing them. It also introduces a process to manage the requirements and discusses the benefits and the challenges of managing this process in an IT supported environment.

Section 3 identifies the governance arrangements that need to be in place for effective coordination among organizations involved in the management of requirements. The stakeholders involved and their roles and responsibilities in different life cycle phases are discussed.

Section 4 sets out the RM process in detail. It explains with a process diagram the various steps involved in requirements identification, commitment, and implementation (requirements realization) as a facility moves through various life cycle phases. It further explains why the management of requirements is an ongoing process with a continuous evolution of the requirements relevant to each life cycle phase as well as the importance of evaluating existing requirements as the facility evolves to the next life cycle phase.

Section 5 considers the following possible approaches to design requirements for different scenarios (or combinations thereof) that may exist in different Member States:

— New nuclear builds in countries that do not have any RM experience;
— New nuclear builds in countries that do have experience but on different technologies;
— Existing/old operating NPPs;
— NPPs undergoing decommissioning.

Three Annexes provide three case studies. Firstly, the experiences of the South Ukraine NPP in reconstituting design requirements information, where the original design information was not easily available, in combination with successive safety reviews leading to the necessary plant changes that enabled continued operation. Secondly, the approach Atomstroyexport has developed for its process to manage requirements to handle multiple nuclear projects in newcomer and established countries. Finally, the experiences of Tokyo Electric Power Company (TEPCO) in new and improved ways of managing requirements, following the Fukushima Daiichi accident.

2. TECHNICAL REQUIREMENTS FOR NUCLEAR FACILITIES

Nuclear industry organizations have typically been reliant on a high quantity of documented design and technical information available in various formats, from different departments or sometimes from different organizations. In order to validate and verify a design, design authorities, responsible designers, and regulators need to be able to trace the design and operational requirements and confirm their realization both in the detailed design and in the "as-built" condition of the facility. This can be very difficult in the absence of high quality technical and design requirement specifications and the ability to use them efficiently.

The correct interpretation of documents describing the technical design basis often depends on experienced personnel from different departments and sometimes from different organizations. The loss of key personnel and their knowledge (e.g. due to retirement, or large-scale staffing reductions) and in some cases the entire loss of key organizations holding technical design knowledge (e.g. due to the sale, merger or restructuring of organizations) can, if not recognized, pose a threat to the management and on-going availability of the specifics of the requirements and supporting documentation.

The process of identifying, documenting, verifying and maintaining the specification of the technical and design requirements is particularly challenging. For example, the successful implementation of design modifications can be highly dependent on the existence of and access to properly documented requirements. The development and updating of the design and technical requirements specifications is necessary to support activities such as design review, procurement, construction, commissioning, operation, facility modifications and maintenance.

The understanding and the management of technical design requirements for nuclear facilities is far from simple. There are often many governing regulations, reference standards and industry best practices or normative guidelines from which requirements are derived or interpreted. Design requirements or constraints may also be inherited from a reference design without a complete understanding of their rationale or correct specification. Requirements may sometimes be based on terms and definitions which are not consistent or conflicting.

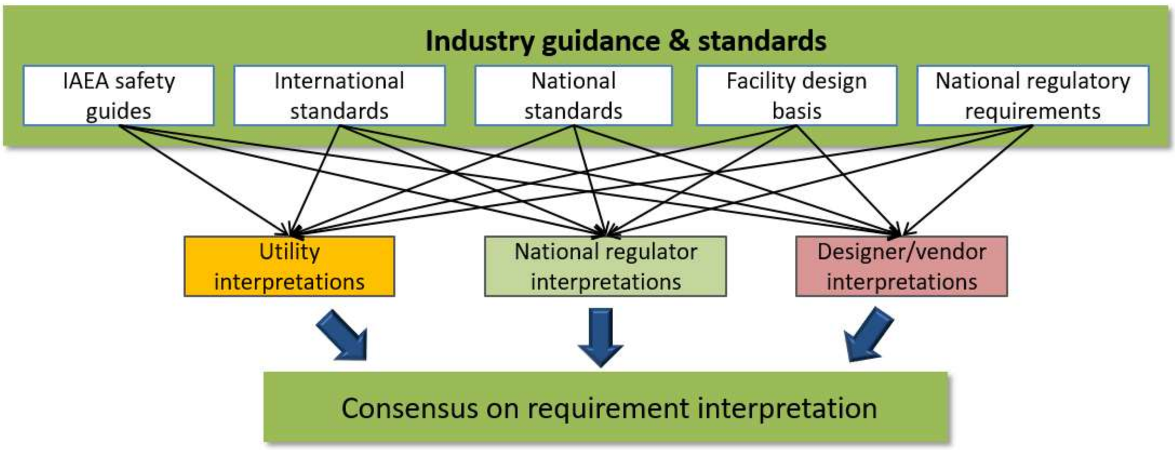

FIG. 1. Typical relationship between stakeholders needed to reach consensus on requirements interpretation.

It is important to reach consensus among all stakeholders involved regarding the interpretation of requirements as displayed in Figure 1.

2.1. THE SCOPE OF REQUIREMENTS MANAGEMENT

Requirements are typically allocated to SSC or to other configuration items. This allocation requires careful consideration of safety, reliability and economic aspects. The optimization and prioritization of requirements may be necessary considering the rationale behind their allocation and their importance to plant safety, reliability and economics.

There are many types of requirements and forms of specification. Requirements may relate to cost, performance, reliability, acceptable failure modes, design life, service conditions, duty cycle, maintainability, equipment qualification, environmental limits or conditions, temperature, material properties, fabrication, inspection, shipping, storage, records keeping, seismic, pressure, human factors, security of supply, redundancy, and design simplicity.

Requirements can also be expressed in the form of assumptions, limits or constraints, uncertainties, targets, accuracy, or tolerances. Requirements can be attributes of the design, the design process, the design documentation, or the design verification process. Finally, reviewability, traceability, and maintainability of requirements specifications across or through a set of design basis documents are important considerations and are typically relevant to a nuclear facility’s design.

Considering the complexity involved in arriving at the design and technical requirements for a nuclear facility, it is important to specify them accurately and clearly in plant design specifications and other documents. Other plant supporting documents such as safety analysis reports, technical specifications, plant operation and maintenance procedures, purchase specifications and quality assurance specifications need to take cognizance of the requirements carefully

Correct specifications of the requirements not only play an important role in supporting safe and reliable operation of a nuclear facility, they also support a wide range of functions including procurement, quality assurance, environmental monitoring and controls, radiation protection, emergency preparedness, chemistry control, fire protection, and training. Thus, almost all activities related to creating and managing a nuclear facility throughout its life cycle depend on adequate availability and maintenance of the specifications of the technical and design requirements. Therefore, it is essential to have an RM system which manages all the design and technical requirements in a manner that is easy to use and understand, and with an ability to trace back changes over time.

2.2. THE INTERACTION BETWEEN REQUIREMENTS MANAGEMENT AND OTHER PLANT MANAGEMENT SYSTEMS

Design and technical requirements are important elements of several management system processes that support key functions of nuclear facilities including configuration management, plant modification management, ageing management and work management.

RM is an inextricable part of the overall configuration management system and is crucial to ensure that plant configuration is maintained as per design intent throughout the facility life cycle [2], [3]. Figure 2 shows the relationship between design requirements and configuration management.

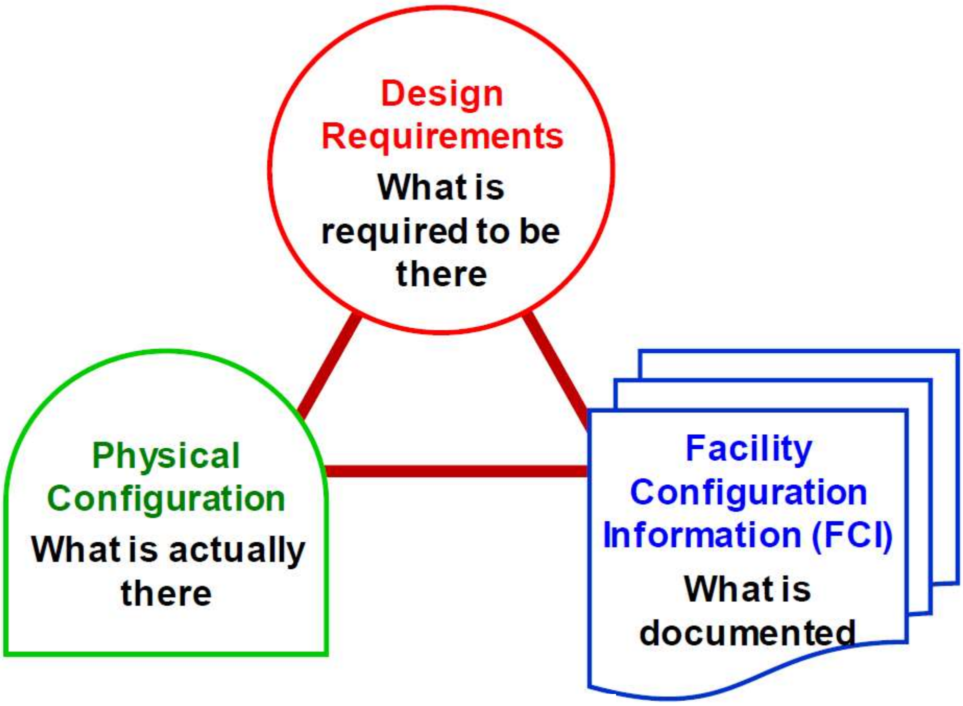

FIG. 2. Relationship between design requirements, documentation and physical configuration [2].

A nuclear facility usually undergoes modifications from its original design during construction, commissioning, and operational life cycle phases. Regardless of whether the need for modifications arises for economic, safety or performance improvement reasons, it is essential to make sure that the modifications are authorized and performed with full realization of design and technical requirements. Therefore, the system of modification control and management needs to interact with the design requirements. Likewise, the work control process which allows plant systems and components to be taken out of service in a nuclear facility needs to carefully consider design and technical requirements to make sure that design margins to safe operation are always understood and maintained.

2.3. COMPLEXITY OF MANAGING DESIGN REQUIREMENTS

Typically, nuclear facilities have hundreds of thousands of components. Each of these components interact with others through state-of-the-art process and instrumentation logics to support several plant functions. It is a highly complex task to describe design and technical requirements and their relationships in a document-centric management system.

Some of the components used in nuclear facilities perform the same type of functions but are designed to perform those functions at different performance levels. For example, one of them may be designed to have high reliability or to perform under harsh environmental conditions such as design basis accident conditions. Apparently looking at them may not reveal the subtle differences in many cases. Therefore, a system to identify such requirements and an understanding of the underlying reasons are important for effective and efficient management of nuclear facilities.

Figure 3 shows the complexity of the interactions of design requirements and the realization thereof within typical facility functions.

On the horizontal axis, various documents typically used in nuclear facilities are plotted. On the vertical axis, various SSCs (E11, B001, 20A-RRS-802-SS, etc.) reflecting the plant design configuration are represented in typical codes of standard. The lateral axis reflects various business functions involved in plant management across the life cycle of facilities. The balls represent the interconnection between the three axis entities; the size of the balls indicates the relative number of documents, drawings, etc.

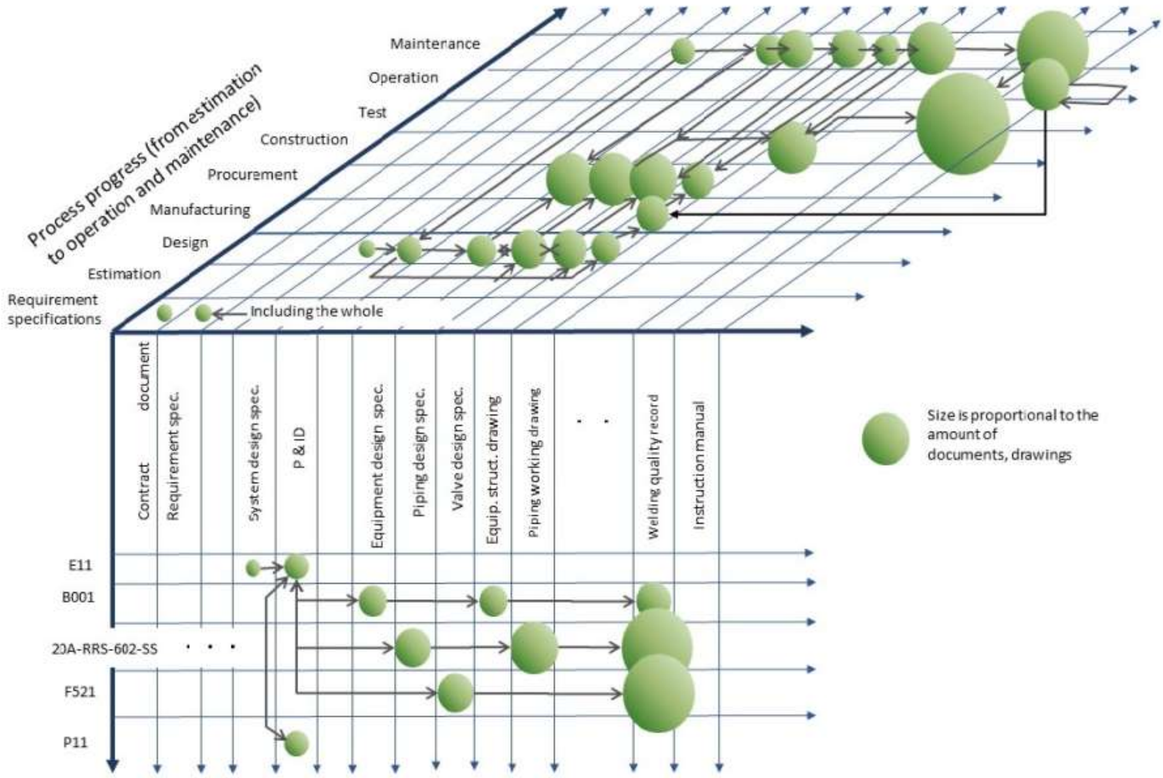

FIG. 3. The complex relationship between facility documentation and SSC across various functions through life cycle – reproduced courtesy of Hitachi-GE Nuclear Energy ©.

This complexity, reflected in Figure 3, highlights the challenges for a RM process, indicates that these challenges are continually evolving through the life cycle phases, and reflects the broad range of activities executed during each of these phases. Modern industry uses a computer-based system to manage the complex process of managing the requirements.

2.4. PRINCIPLES OF REQUIREMENT MANAGEMENT

As this publication aims to provide guidance for an efficient RM programme, it was deemed necessary to create a set of principles that describes the important considerations and attributes necessary for a high-quality RM. Personnel involved in developing a RM programme are expected to benefit by following the eight principles given below.

2.4.1. Competence to capture requirements

Principle 1: The capturing of requirements is a task that needs knowledge and experience in the technology, engineering, and scientific discipline being analysed and familiarity with the source documents being considered.

It may not be possible to capture the requirements by simply going through relevant documents as they may not be explicitly mentioned in them. Therefore, it is important that requirement information in a document is captured regardless of how the information is presented, noting that many documents do not present requirements in a structured way (text, diagrams, pictures, etc.).

The completeness of the set of captured requirements needs to be systematically reviewed to determine whether any have been missed (or orphaned).

2.4.2. Requirements as a living entity

Principle 2: The quantity and completeness of the specifications of the requirements increases and improves as a nuclear facility moves through different facility life cycle phases and as such it has to be maintained as a "living entity" throughout.

The process of specifying requirements for a nuclear facility starts from the moment the decision to establish the facility is taken. The high-level site requirements related to seismic, flooding and other natural and environmental issues are considered at the beginning to select the site. As the type, capacity, numbers and potential designs of the facility are selected, further high-level requirements for establishing such a nuclear facility are carefully determined.

Once the supplier and the design of a nuclear facility is determined, detailed design and technical requirements are established. At this stage, it is important to consider, national and international regulations, standards followed by the designer, and host country regulatory considerations in order to arrive at final design requirements for the facility. It is important to understand the rationale behind requirements dictated by national, international, regulatory and designer standards and regulations in order to arrive at a consensus that supports the safe, reliable and economical operation of a nuclear facility.

As the facility moves to the construction phase, requirements associated with project implementation, including procurement of equipment and components, need to be considered. The development of project instructions, construction work packages, equipment installation procedures, procurement specifications and quality assurance procedures need to carefully consider the specifications of the design and technical requirements and incorporate them in clear unambiguous terms.

During the construction phase, it may be necessary to implement engineering and lay out modifications and call for careful review with respect to design requirements. In some cases, it may be necessary to incorporate changes to design requirements. Similarly, when equipment and components are procured for facility construction, they may come with additional or modified requirements. It is important to capture these changes in a living RM process and in the supporting information management system.

As the facility moves to its commissioning phase, the development of equipment level, system level and integrated commissioning procedures needs to carefully incorporate design requirements. Also, most of the design requirements get validated during commissioning and they need careful assessment and adjustment. Again, these changes need to be captured in a living design RM process.

As a nuclear facility moves to its operational phase, the specifications of the design and technical requirements reach maturity in both quantity and completeness (see Fig. 4). The final safety analysis report, the technical specifications, plant operation and maintenance procedures, configuration control process, testing and maintenance schedules and plant modification process need to consider design and technical requirements in order to ensure safe and reliable operation of the facility. Operational handover of the facility to the operating organization is a critical point in the facility's life cycle where it needs to be confirmed that design and technical requirements identified, agreed on and documented were realized in line with the commitments made to all stakeholders involved.

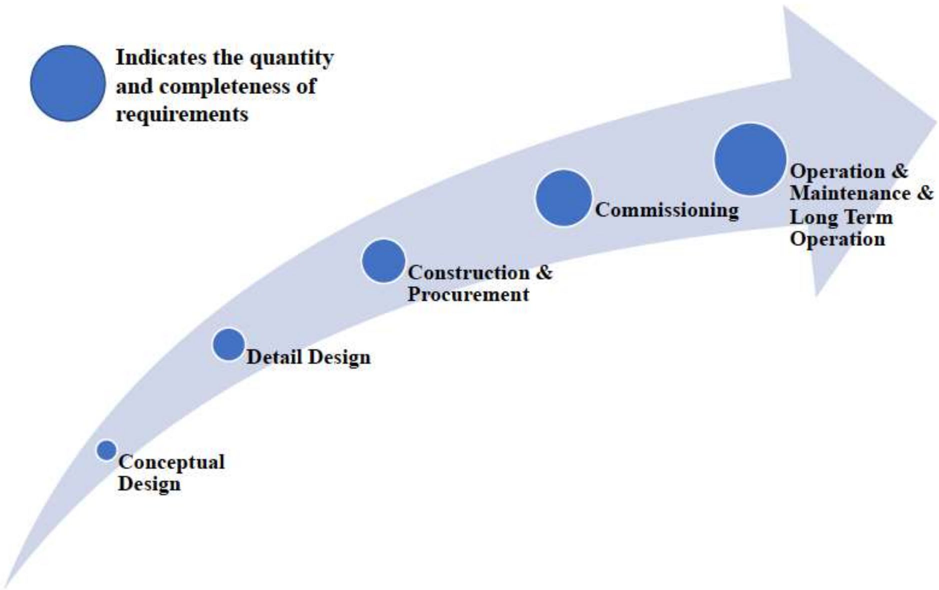

FIG. 4. RM as a living entity over a facility's life cycle.

The design RM process, therefore, needs to be a continuous and ongoing set of activities, executed in a standardized, repeatable and fully auditable manner as the facility moves through its life cycle phases.

Integrity of requirements is needed from design to decommissioning. Some rehabilitation requirements during plant decommissioning phase may need to be considered upfront in the design.

2.4.3. Ownership of requirements

Principle 3: Ownership of a requirement is clearly defined, assigned and managed for each facility life cycle phase and is transferrable between life cycle phases.

It is essential that the owner of a defined requirement be identified, and ownership assigned as soon as the requirement has been reviewed and approved as relevant and applicable to the facility. It is expected that the ownership of requirements will change with time, or as the facility moves through its life cycle. Transfer of requirement ownership, from one facility life cycle phase to the next, needs to be a documented, actively managed process and controlled with a full audit trail of continuous ownership. Otherwise requirements, and hence the knowledge of the facility, will be lost.

The conditions and the scope of RM related information to be transferred between parties (or from old to new owner), need to be formally documented and agreed on between organizations (e.g. in the contract between the vendor and the owner- operator (O/O)).

2.4.4. Unique identification of requirements and configuration items

Principle 4: Requirements are decomposed to the lowest possible level to ensure that only one requirement is covered per unique identification (UID) created.

The industry typically uses a plant breakdown structure (PBS) to uniquely identify units, buildings, systems, components and other configuration items (e.g. welds). Utilities can apply such a structure either across their fleet, or to a particular NPP. The chosen PBS approach needs to be able to accommodate multiple units and shared buildings and systems. There are many different approaches to this unique identification, e.g. Kraftwerk-Kennzeichensystem (KKS) [4]. It is vitally important that every configuration item is uniquely identified to enable an effective RM process (Fig. 5).

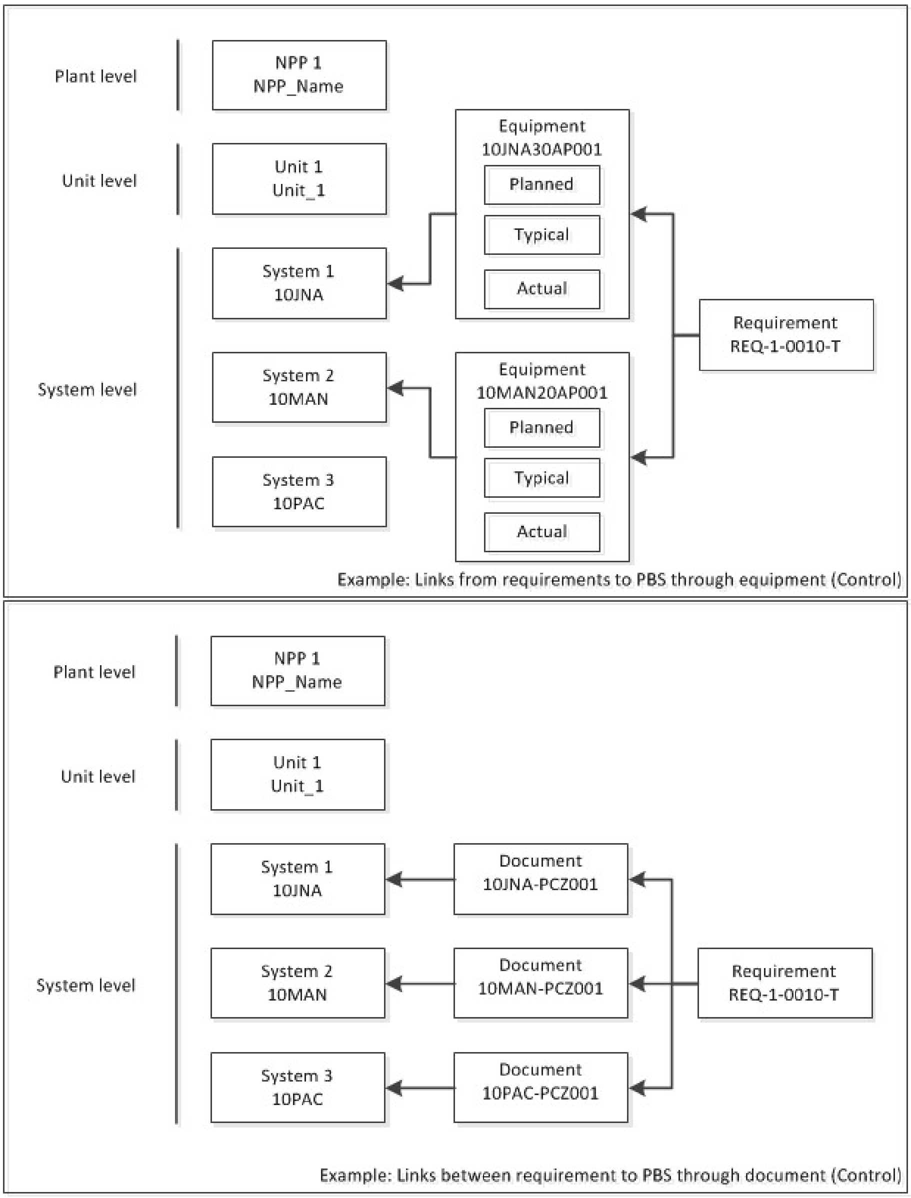

FIG. 5. Example flow diagrams showing requirements linked to PBS for SSC.

The PBS provides a framework through which uniquely identified requirements can be allocated to the SSC or other configuration items affected by the requirement. When an electronic approach is used, it allows direct linkages to be formed from the requirement to the SSC to improve the RM process. The allocation of requirements to SSC need to be performed in a systematic way so that the linkages and relationships are made clear.

Requirements are typically allocated to SSCs. The process of allocation needs careful consideration of many factors including importance to safety, reliability, performance, and the rationale for allocation.

Requirements established during the requirements identification stage of the RM process need to be uniquely identified. A requirement needs to be refined to meet the requirement criteria (see Fig. 11), and it needs to be decomposed (simplified) until it defines a single requirement. It is at this point that the requirement unique identifier is applied.

The allocation of requirements using the framework of the PBS allows a transparent way to monitor the fulfilment of requirements by significantly reducing the number of direct links between the design basis and artefacts. The hierarchical nature of PBS coding systems also facilitates allocation of the requirement to the correct level, e.g. some requirements may cover the entire plant, while others may be very specific to an individual, uniquely SSC coded equipment or component.

A design basis requirement is allocated to the lowest level in the PBS in which its implementation is planned. Bearing in mind that, if a requirement is related to a specific plant component, it needs to be associated with the PBS object to which the component will be linked.

Sometimes it may not be possible to link a requirements item to a component of the PBS, in which case the SSC hierarchical approach needs to be supplemented by a nodal approach, e.g. by linking requirements to a safety analysis report, or by having a document structure in place where non-plant requirements can be managed and controlled (e.g. fire zone controls).

Software-based RM systems are capable of handling large quantities of information. These systems furthermore allow the development of descriptive data about the requirements (as requirements meta-data), the linking of related datasets and facilitate dynamic updates of requirements.

Due to the vast volumes of design basis artefacts and requirements that need to be managed, an object-based approach has been found to offer advantages such as:

— Allowing relationships to be created and automatically managed between objects;
— Providing “at a glance” access to information;
— Providing fast “configuration accounting” capability for requirements, (e.g. there are 24 drawings associated with the Plant PBS/SSC item in addition to 1 safety case, 1 site safety report, 8 requirement management commitments, 2 occurrences, and 3 modifications).

2.4.5. Revision and version control of requirements

Principle 5: Once a requirement is established, it undergoes revision control over the entire life cycle to ensure traceability.

Changes in regulatory requirements can have an impact on previously identified requirements; the revision control mechanism facilitates to determine the point of change.

Any change in project requirements needs to be documented using specialized project management systems.

The introduction of changes to requirements needs to be justified and agreed upon by all the stakeholders.

Any change in a requirement needs to be made within the scope of change management processes. It is necessary to evaluate each change by its own merits, but also by considering its impact on the project as a whole.

2.4.6. Management of stakeholder interfaces

Principle 6: The owner of the requirement needs to manage the interfaces necessary to ensure that stakeholder perspectives are addressed to ensure the correct development, commitment and implementation of the requirement.

Part of the requirements definition process is the identification and management of the interfaces between the various stakeholders involved when it comes to requirements identification, statement of commitments/design intent and implementing the design basis (see Section. 4.1.5).

It is important that those defining design requirements communicate with other stakeholders to ensure that they understand what is needed from them in order to meet the intent of the design and technical requirements.

2.4.7. Interaction of requirements management with other management processes

Principle 7: The RM process needs to be a part of the integrated management system of the O/O and are appropriately interfaced with other management processes (e.g. configuration management, modification process, etc).

Integrated interactions between RM and other engineering management processes, such as configuration management and change/modification processes, are needed to ensure that these plant functions use the current/updated requirements applicable for the facility.

2.4.8. Requirements properties for control

Principle 8: In setting up the RM programme, the properties required for control and management need to be defined and their usage explained.

The use of a standard, defined set of requirement properties is an essential aspect of establishing and managing the RM programme.

A detailed description of and the reasons for requiring the properties needs to be captured. The purpose for which the property is required (or will be used for), needs to be clearly explained and understood by all responsible parties. This is vital for properties that are deemed mandatory.

Pre-defined “picklists” are usually used for property fields. This ensures consistency in the capturing of properties and reduces the risk of using varying terminology that is not understood by all stakeholders.

These properties are implemented as meta-data for software-based RM systems. The benefits of using a software-based meta-data approach are improved:

— Security;
— Information integration;
— Search and find capabilities;
— Reporting;
— Status management;
— Consistency in deliverables.

An example set of requirement properties is provided in Appendix I.

2.5. REQUIREMENTS MANAGEMENT

2.5.1. Relationship between requirements and design basis

The design basis of a SSC is the set of information that identifies conditions, needs and requirements necessary for the design, including the:

— Functions to be performed by a SSC of a facility;
— Conditions generated by operational states and accident conditions that a SSC has to withstand;
— Conditions generated by internal and external hazards that a SSC has to withstand;
— Acceptance criteria for the necessary capability, reliability, availability and functionality;
— Specific assumptions and design rules.

The design basis of an SSC is completed and supplemented by specification sheets and by detailed design calculations [5].

Considering the above, decisions will need to be made about the inclusion of such information in the RM process. The information may result in the creation of a requirement that is then linked to SSC, or to more than one SSC. Reliability requirements may, for example, be expressed as a system requirement, or may be allotted to components in a system.

Incomplete definition, or inadequate consideration of such factors, may significantly affect the identification of requirements and their subsequent management in downstream activities such as maintenance, operations and safety analysis.

2.5.2. The requirements management process

Due to the large extent of potential sources that can trigger a requirement for a nuclear facility, it is essential to implement a process to identify requirements from the various sources, defining the commitments required to approve these requirements from various stakeholders and realization of the approved requirements in all activities of a facility life cycle. A simplified process can be defined as three distinct activities which are briefly discussed in Figure 6.

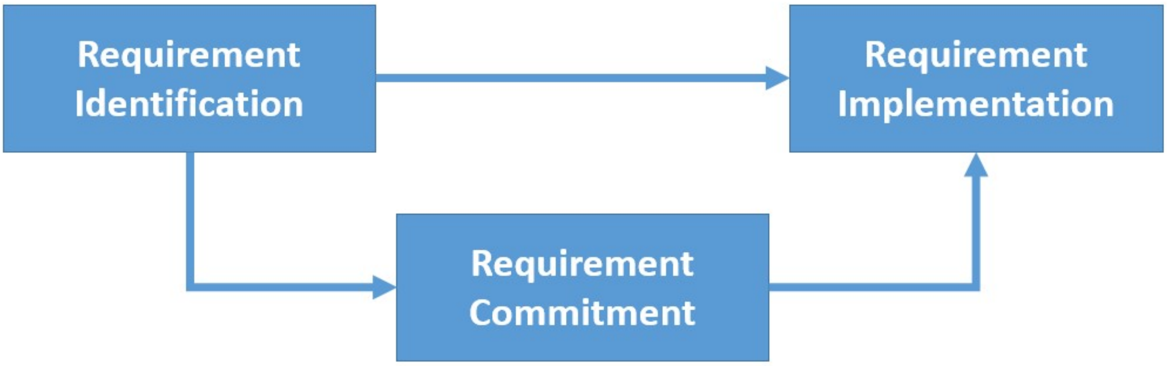

FIG. 6. A simplified view of the requirements management process.

2.5.2.1. Requirement identification

In the requirements identification stage, steps are taken to identify requirements from various sources. The requirements are decomposed, classified, grouped, ranked and prioritized during this stage. It is important that stakeholders ensure the requirements are correctly defined, captured and interpreted.

This activity is concluded with the agreement and approval of all stakeholders that a valid and applicable requirement has been identified.

2.5.2.2. Requirement commitment

The commitments needed to meet requirements are identified, documented and approved by stakeholders. Note that some requirements result directly in implementation, e.g. codes and standards.

2.5.2.3. Requirement implementation

These activities are focused on implementing requirements and associated commitment(s).

The RM process is discussed in detail in Section 4.

2.5.3. Requirements change management

Within a facility life cycle, as work progresses, there will be a need to include new or modified requirements. For this purpose, a formal requirement change management process needs to be put in place.

Also, as a facility moves through life cycle phases, new requirements may be identified, and existing requirements may acquire different significance. All such new or modified requirements will need careful review. Sometimes new or additional requirements have an impact on existing requirements, safety cases and compliance commitments; in which case such existing requirements need to be evaluated (impact assessment) and updated to meet the potential new requirement (depending on the impact). Therefore, in order to effectively review and monitor the whole process of RM, suitable control mechanisms are essential. The control mechanism needs to have suitable revision control mechanisms in order to help track the revisions/changes.

The requirement change management process is explained in detail with a reference flow diagram (see Fig. 10) in Section 4.

2.6. BENEFITS OF EFEECTIVE REQUIREMENTS MANAGEMENT

The two main areas benefitting from effective RM are:

- **Safety**: RM establishes clarity about how safety requirements are considered and incorporated in the design of safety related SSC and how the safety requirements of the SSC are maintained over time and properly considered when changes need to be made. The use of an IT system (object oriented, database) offers benefits over a traditional document-based approach as the RM data associated with the safety requirements can be more readily available for the safety demonstration (safety report) where safety claims, safety arguments and associated evidence need to show how the safety requirements have been implemented;
- **Project Management**: By dealing with requirements early on in a project, the scope can be fixed and managed reducing project risks. This leads to:
  - Economic Benefits: Fixed scope and a de-risked project avoids cost escalation that can be caused when requirements have not been identified or planned for, in the later stages of the asset life cycle;
  - Reduction in project execution time: By documenting and then addressing requirements, a reduction in the time, and hence cost, it takes to get approvals can be achieved as compliance can be more readily demonstrated;
  - Better quality: Requirements are dealt with more efficiently and design basis integrity can be assured by evaluating all identified requirements to ensure compliance, avoiding concessions, re-work or unplanned design changes.

Balanced total cost management can be achieved as displayed in Figure 7.

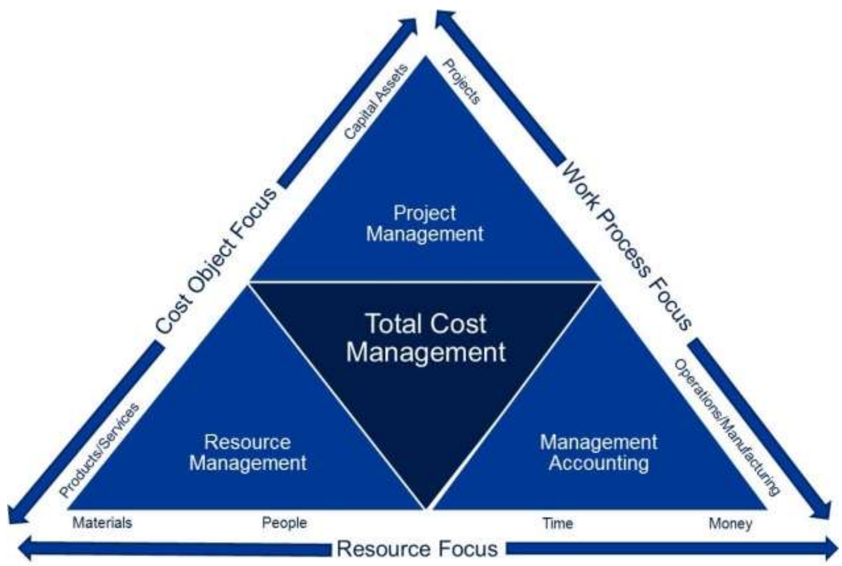

FIG. 7. Good RM supports achievement of balanced total cost management.

2.7. CHALLENGES OF REQUIREMENTS MANAGEMENT

The identification, decomposition, optimization and the prioritization of requirements is very challenging, as it involves a comprehensive understanding and review of the plant design basis, which cuts across multiple engineering and science disciplines and addresses several governing regulations, reference standards, industry best practices and normative guidelines. RM demands the expertise of experienced professionals for both its initial development and subsequent implementation throughout the facility life cycle.

Typically, the lifetime of a nuclear facility spans a time period of close to 100 years from the point of its conception, through its design, construction, commissioning and operations up to the point of decommissioning and site rehabilitation. Given the long duration of the facility life cycle there will be a need to be able to accommodate changes that arise, for example:

- Advances in computer technology make it inevitable that there will be at least two, if not more occasions in the facility's lifetime where there will be a need to replace the computer technology, due to the obsolescence of the originally installed equipment [6];
- The systems and equipment in nuclear facilities often undergoes changes due to ageing, wear-out, maintenance, replacement, upgrades, availability or improvements [7];
- In some cases, design changes and improvements are made based on research and development, or from lessons learned from industry operating experience;
- Nuclear facility designers, manufacturers, owner's groups, international nuclear organizations, and national regulators identify recommendations for change, e.g. to meet improved industry standards, or to learn from nuclear incidents that require nuclear facilities to take remedial actions;
- Member States have requirements to periodically review the safety of their NPPs, e.g. to address changes to international and national safety requirements [8], [9].

This calls for changes to existing requirements, or the introduction of new ones. Managing such changes in a complex environment with several thousands of requirements acting on plant SSCs through plant work processes, plant documentation and management systems is not only a huge task, but a very complex and resource intensive one. Industry experience [10] shows that a conventional document-centric approach to establishing and controlling RM process is not easy. A computer-based system approach is not only useful but essential for an efficient RM process to support the facility.

The following are some potential difficulties if the requirements for a nuclear facility are not identified and managed efficiently:

- Different parties need different design requirements in different forms at different phases of the life cycle (this is generally known ahead of time, but not always);
- Uncertainty about who is responsible to create, modify, or maintain technical or design basis requirements, or who can/should validate or approve them;
- In some countries operating organizations may no longer have a right of access to the original sources of information for significant parts of their NPPs design basis. Reconstitution of the design basis by the operating organization is a very difficult and expensive effort, that may be needed in order to demonstrate continued safe operation, request license extensions, and plan for decommissioning;
- Due to changes in the world political and or economic landscape, the original direct connections between stakeholders can be difficult to maintain (especially between design organizations and operators);
- Newcomer countries embarking on a nuclear energy programme may not have all the necessary educational and nuclear engineering skills and experience to readily establish an effective DA, capable of managing the design base handover from the vendor to the operator at the plant commissioning phase;

— A significant challenge is to keep design integrity intact during a facility's life cycle ensuring that technical requirements are maintained in compliance with the approved legislative basis, regulatory and industrial norms, and operating experience;
— Capturing all the requirements needed to accurately characterize the way in which complex systems operate can be difficult, i.e. systems which include interactions between individuals, technical systems and organizations and their management systems;
— In a new NPP project the level of detail of the design often stops at a functional level and does not identify actual equipment or system suppliers. Supplier selection itself may be subject to national requirement to localize equipment, goods and services. Thus, the requirement links to some equipment may not be identified until the procurement stage of the project.

There are a number of challenges that need to be considered which affect the management of requirements and the permissible distribution of and access to information. There is a need in any NPP project for information to be communicated openly between the organizations involved, but at the same time the flow of information must be controlled to protect the information for security, commercial and intellectual property (IP) reasons.

Nuclear facility lifetimes of the order of 100 years, result in information management challenges such as:

— The proper handling and information backup of design data for long archive periods;
— Ensuring the full compatibility of "Big Data" information data sets considering the continuous evolution of IT platforms and their changing data management requirements;
— Ensuring reliable knowledge transfer from the conceptual design phase to the decommissioning phase, among all stakeholders (considering risks like the collapse of national and international commercial organizations and the possibility of relationship breakdown between vendor and operator, especially for export projects);
— Ensuring appropriate security of information to protect nuclear security, and commercial and IP rights.

2.7.1. Management of classified (secret/confidential/security) information

For nuclear facilities, information needs to be controlled or suitably protected for a variety of reasons, including nuclear (or national) security, proprietary or IP rights. Due consideration needs to be given to the relevant country's legal view/requirements regarding the handling of such information.

During the development of a facility design, as design details are developed and decisions are made by the designers regarding aspects such as the location of equipment to meet the requirements for system reliability and resilience against internal and external events, sufficient information may be aggregated in design documents and artefacts where the information is controlled for their storage and distribution.

Many modern systems used for RM offer multi-level user access controls. These controls need to be defined and implemented in the software system configuration. There are also system configuration options available where only meta-data is visible on certain data sets and access to actual documents/records is separately controlled. Depending on information security issues and requirements, these capabilities need to be enabled to implement a solution that meets regulatory requirements.

It is essential that the security classification of information is respected, and the information managed accordingly. The RM system has to address the needs of security classification of information through use of access controls available in software system configuration. This may, however, present practical problems where the information requires a high security classification. Organizations involved will need to ensure that they have the necessary approved protocols in place to allow use of items such as databases to be transferred or shared between them, e.g. controlled transfer of ownership between two organizations/stakeholders.

2.7.2. Confidential commercial information

Some requirements contain sensitive or confidential commercial information, which needs to be subjected to access control. As such, the required non-disclosure agreement mechanisms need to be put in place to ensure that these requirements are suitably managed.

During the design of systems, designers may decide (for valid commercial reasons) to establish only functional design solutions to meet requirements such as diversity options (e.g. steam driven compared to electrically driven pumps). Management of these aspects at the detailed design level (i.e. technology choice) may become complicated as there may be a need in the detailed design level to identify potential technology solutions without implying a particular selection (a challenge to the designer not to foreclose options, or unduly limit sources of supply) to ensure that a sound commercial position is maintained during the procurement process.

2.7.3. Intellectual property

Certain requirements will be realized with plant, equipment or system designs that are considered to be the IP of the vendor and in some cases the operating organization's DA. Where this applies, the RM system needs to be capable of identifying IP implicitly to prevent unintentional release of IP that could result in legal action. From a regulatory perspective there is an expectation that the O/O becomes knowledgeable about its chosen technology so that it can be operated safely.

The extent to which knowledge/IP will be transferred or made accessible by the vendor to the O/O is subject to the relationship and organizational arrangement between the vendor and the O/O. To maintain regulatory confidence a close, long-term, open relationship with full disclosure or full access to information is viewed as being beneficial for all parties involved.

Where such a relationship is not (or cannot be) established, the O/O needs to pay attention to the rights it has to establish in order to access information about the facility design to ensure safe operations and modifications/upgrades towards performance improvement in the future can be done safely and within the parameters of the design basis. The regulator will also need to monitor such situations to retain confidence that the O/O is able to access and understand the information it needs in this regard.

2.7.4. Digital documentation & digital signatures

Many countries still expect that approval processes are based on transactions where an inked signature is made on a physical document. This expectation is generally tied to the established legal requirements regarding the documentation. Considerable benefits, from an information flow perspective, can be realized if the dependence on physical signatures can be minimized. Some countries have established electronic signature mechanisms that can offer an equivalent level of assurance as using paper documents.

This is a challenge that needs to be considered and resolved and may require application to the regulator for approval.

2.7.5. Trans-national impact (vendor-designer to licensee/regulator)

When a vendor seeks to build a nuclear facility in a country other than the country of origin of the technology, there will be considerable differences in approaches in licensing and design and technical requirements that will need to be identified and addressed. In this regard, some Member States, such as the members of the European Union and Switzerland (through the European Utilities Requirements and Western European Nuclear Regulators Association's reference levels) have taken steps to identify and minimize differences in these approaches.

Globally, the vendors of NPPs located in the USA, Canada, France, Russian Federation, People's Republic of China, Republic of Korea and Japan have designs that are either under consideration to be built or are being built in countries other than their origin. In each of these circumstances the vendor is faced with a process of establishing and documenting the utility and regulatory specific requirements of the recipient countries.

It is also not uncommon for the vendor to be faced with managing a situation where the utility and regulatory requirements will vary from country to country, such that the fleet of a particular design will have a number of variants drawn from an original reference design.

A further complication may arise if the vendor is successful in getting the design accepted for more than one location in a country where there may be differences in local site requirements (e.g. coastal vs. estuary cooling). An example of such variations is provided in Table 1.

Whatever the circumstances, it is essential that the vendor has a robust RM system to ensure that variations from the reference design are clear and that the rationale for the difference is maintained for each design variant.

When design changes occur in one variant of the design (e.g. home market) it will be necessary for the vendor to determine if appropriate changes can/should be made in other variants (e.g. overseas market), considering the localized variations on a case by case basis.

TABLE 1. POSSIBLE VARIATIONS FROM A NATIONAL REFERENCE PLANT DESIGN TO ACCOMMODATE REQUIREMENTS IN OTHER COUNTRIES, LEADING TO MULTIPLE VARIANTS NEEDING REQUIREMENT MANAGEMENT

Reference Design	**Home Market**	**Overseas 1**	**Overseas 2**
NPP Version 1.0, reference plant, e.g. cooling water only by cooling towers	NPP Version 1.1, cooling water by small river with cooling towers	NPP Version 1.2, reference design plus modification 'A' to meet country requirements for a coastal site	NPP Version 1.4, reference design plus modification 'A' (coastal site) + modification 'C' to meet local requirements for diverse instrumentation and control systems
		NPP Version 1.3, reference design plus modification 'B' to meet country requirements for an estuary site	

2.7.6. Case law impact - national legal systems

In Member States, in addition to the establishment of the main nuclear regulatory requirements through statute (laws and regulations), the regulatory framework also evolves over time as a result of a number of factors, e.g. new knowledge, new safety standards, regulatory decisions and through the results of cases brought to court for judgement (case law).

It is essential in all Member States to establish a formal process that reviews changes in legal requirements, and that these changes are addressed as applicable in the technical and design RM system. One such process that is established in Member States is the periodic safety review (based on the IAEA Safety Requirement and Safety Guide) [8]. A key factor in the review is to consider changes to the legal framework. The O/O, as part of its formal requirement management review process, will need to consider the findings from such a periodic safety review and make updates as necessary.

2.7.7. Learning from major events

Besides periodic safety reviews, the major recent example that has affected all nuclear operating countries has been the need to address the lessons learned from the accident at Fukushima. All Member States and the IAEA established mechanisms to review the lessons [11], evaluated the implications through a series of 'stress tests' on their designs and established safety upgrades or retrofit programmes to make design changes. All these changes, from a national requirements level, down to individual plant modifications on the NPP, were implemented in a relatively short time scale due to the urgency to address the concerns over safety.

2.7.8. Complexity in engineering systems

Many nuclear facilities, particularly NPPs, have complex engineering systems. Prominent examples are instrumentation and control systems and technologies used to monitor and control the reactor and its associated systems. Establishing the appropriate operator interactions with the plant under normal, abnormal and accident conditions and the definition of the requirements in this area are subject to considerable analysis. Review of these interactions is a critical aspect of the design review of the instrumentation and control systems. Instructions to the operator to ensure the correct design interface are considered part of the design.

Capturing all the requirements depends on having a complete understanding of the system and achieving such an understanding is made difficult by the complexity of the interactions between individuals, technical systems and organizations in the totality of the entire system. Therefore, the way the systems works in practice may not be fully predictable. To guard against this problem, design requirements that limit the complexity in safety systems are identified to ensure the protection of the reactor under fault conditions [12]. This is an area where ongoing research contributes to a better definition of requirements through structured or formalized methods to better express an understanding of the complex system and, thus, fulfill the necessary requirements.

3. GOVERNANCE ARRANGEMENTS FOR ORGANIZATIONS INVOLVED IN REQUIREMENTS MANAGEMENT

Nuclear facilities operate in a highly governed and regulated environment. As such they need to ensure that governance is implemented within their organization to control the management of requirements. This section details the recommended governance framework elements to be in place to manage requirements.

The typical stakeholders involved in the facility life cycle phases need to know and act as per the requirements applicable at that stage. The RM process and implementation need to take cognizance of this.

The RM process needs to be supported by policies, procedures, standards, guidelines and infrastructure that facilitate a consistent, repeatable and auditable execution of the process across the entire facility life cycle.

It is important that the integrity of the design requirements is maintained throughout the facility life cycle, and to do this the ownership of the process needs to be clearly defined as the facility moves through its life cycle. This is particularly important in cases where a handover of ownership between stakeholders from one life cycle stage to another takes place.

The O/O of a facility plays the key role in this process. Although in the initial stages of design and construction of the facility, requirements are controlled by the DA and/or an engineering procurement and construction (EPC) organization, it is important for the O/O to have an early understanding of the requirements and how they are incorporated in plant design and construction. The O/O also needs to learn how the requirements are inherited in the plant governing documents such as technical specifications, safety analysis reports, and plant operation and maintenance procedures.

3.1. STAKEHOLDERS INVOLVEMENT IN THE REQUIREMENTS MANAGEMENT PROCESS

The stakeholders of a nuclear facility such as the regulatory body, designers, vendors, suppliers, O/O, technical support organizations (TSO), and research and development (R&D) organizations play different roles and functions for each facility life cycle phase. Table 2 indicates the typical role(s) played by the various stakeholders in the RM process.

TABLE 2. STAKEHOLDER INVOLVEMENT REGARDING REQUIREMENTS MANAGEMENT FOR FACILITY LIFE CYCLE PHASES

Type of Organization/ Stakeholder	Life Cycle Phase Requirements Management					
	Conceptual Design	Detail Design	Construction and Manufacturing	Commissioning	Operation, Maintenance and Long-Term Operation	Decommissioning
Regulatory Bodies	CR; D; I; R	CR; D; I; R	CR; D; I; R	CR; D; I; R	CR; D; I; R	CR; D; I; R
Vendors	RC; RR; R; I	RC; RR; R; I	RC; RR; R; I	RC; RR; R; I	RC; RR; R; I	RC; RR; R; I
O/O	CR; RC; U; O; R; I	CR; RC; U; O; R; I	CR; RC; U; O; R; I	CR; RC; U; O; R; I	CR; RC; U; O; R; I	CR; RC; U; O; R; I
Designer	RR; R; I	RR; R; I	R; I	R; I	R; I	R; I
Suppliers	R; I	R; I	R; I	R; I	R; I	R; I
TSO	R; I	R; I	R; I	R; I	R; I	R; I
R&D	R; I	R; I	R; I	R; I	R; I	R; I

Legend:
CR - Create requirement
RC - Make requirement commitment

RR - Realize (implement) requirement
O - Owns requirement
R - Requires visibility to requirements
U - Update/maintain requirements
D - Delete/Cancel/revoke requirements
I - Informed of requirements and changes thereto

3.2. LEVEL OF EFFORT FROM STAKEHOLDERS ACROSS THE DIFFERENT PHASES

The responsibilities of RM stakeholders, as well as the resources needed, change over the facility's life cycle. Table 3 provides generic/average typical percentages of level of effort from stakeholders during the various facility life cycle phases. The distribution percentages may differ depending on a Member State's nuclear programme and regulatory and O/O maturity. The changing level of support is visually depicted in Figure 8.

TABLE 3. RELATIVE EXTENT OF STAKEHOLDER INVOLVEMENT DURING NPP LIFE CYCLE PHASES

Type of Organization/ Stakeholder	Stakeholder Involvement - Life Cycle Phase Requirements Management					
	Conceptual design	Detail Design	Construction & Manufacturing	Commissioning	Operation, Maintenance and Long-Term Operation (LTO)	Decommissioning*
Regulatory Bodies	15	30	10	20	10	-*
Vendor/Designer/EPC	80	50	45	20	5	-*
O/O	5	20	45	60	85	-*

*Decommissioning contains a set of life cycle phases in its own right for which stakeholder influence and roles vary significantly from phase to phase. The influence of the key stakeholders during decommissioning is indicated in Table. 4.

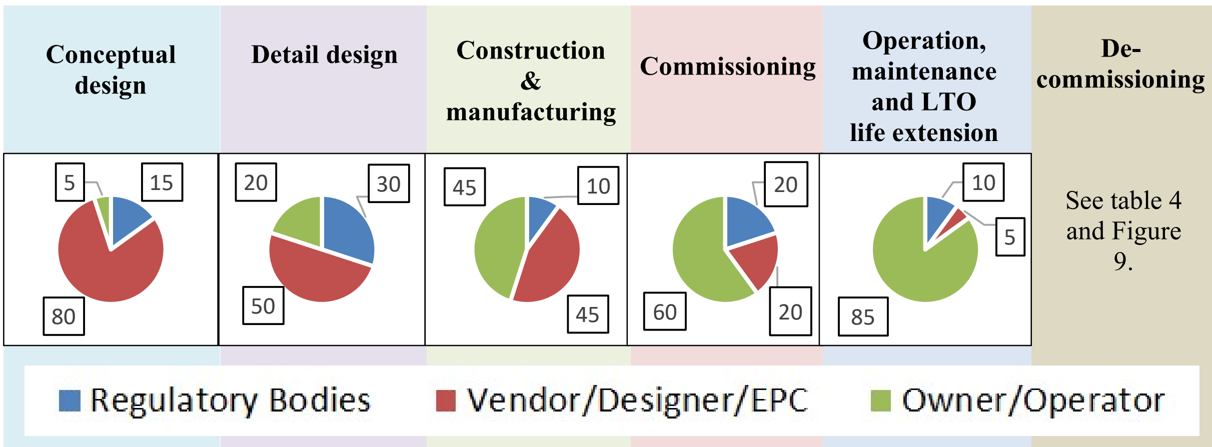

FIG. 8. Influence of stakeholders across NPP asset life cycle phases.

When it comes to decommissioning, there are very specific requirements governing the sub-elements of the decommissioning phase of the plant [19].

More details regarding the specific roles of the various stakeholders are provided in Sections 4.2.1 to 4.2.3.

TABLE.4. EXTENT OF STAKEHOLDER INVOLVEMENT DURING NPP DECOMMISSIONING LIFE CYCLE PHASE

Type of Organization/ Stakeholder	Stakeholder Involvement - Decommissioning Phases					
	Post Operation Cleanout	Decommissioning Project Design Phase	Decommissioning/ Deconstruction Phase	Site Rehabilitation	Storage	Disposal
Regulatory Bodies	30	25	20	15	10	5
Vendor/Designer/EPC	0	60	70	75	0	0
O/O	70	15	10	10	90	95

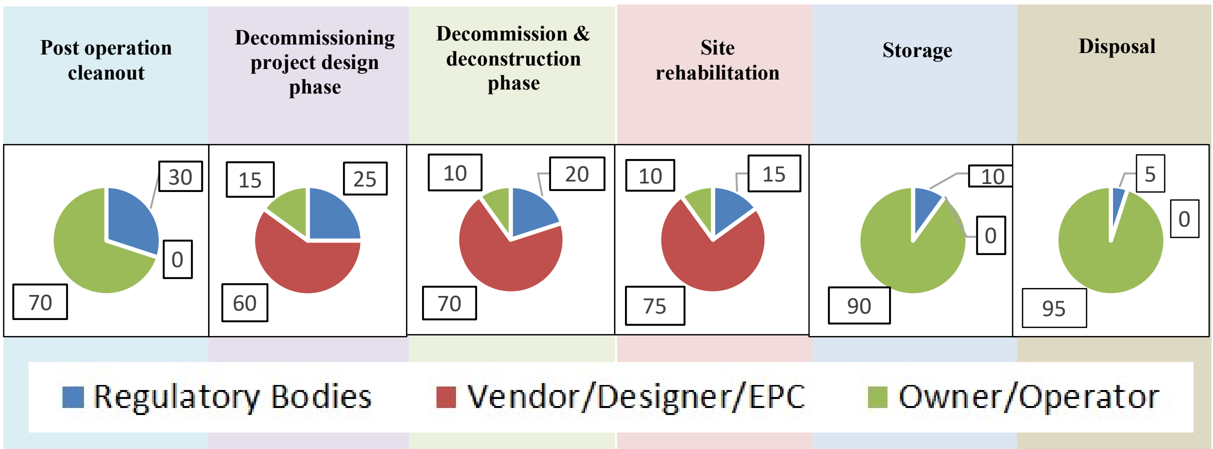

FIG. 9. Influence of stakeholders across NPP asset life cycle decommissioning phases.

3.2.1. Designers, vendors, and engineering, procurement and construction organizations

Designers, vendors and EPC organizations play a key role in establishing the initial RM process for a nuclear facility. There are several strategic models of how these stakeholder entities are constituted in different countries. Depending upon the model being followed in a country, sometimes all of these entities reside under one organization while in others, they function as totally separate organizations. In some cases, TSOs support the design organization or the vendor organization. Nevertheless, for the intent of this discussion, they are grouped under one organization to address their functions and responsibilities for the management of requirements.

As mentioned, vendor, designer and EPC organizations have a significant role to play in the development of requirements specifications. The O/O and the regulator influence the decisions or recommendations of a vendor, designer and EPC organizations by bringing their expertise and uniquely defined requirements into the process of establishing the requirements relevant for the proposed nuclear facility. The regulator and the O/O need significant experience and resources to perform this function.

In the case of a newcomer country, the regulatory and the O/O organizations need to find ways to acquire the services of experienced nuclear professionals who can help in this endeavor. The designer, vendor, and EPC organizations need to have a good understanding and consideration of O/O needs of design and other technical information for a safe, reliable and efficient operation of the facility during the operation phase including requirements to support operation, maintenance, engineering, training, equipment reliability, procurement and long-term operation (LTO).

During the facility design, manufacturing, and construction, the vendor, design and EPC organizations have the lead role in the identification, interpretation and implementation of requirements through well planned quality control/assurance plans. Developing the specifications of the requirements for sourcing materials, equipment, and components, and for manufacturing and construction methods are key responsibilities of these organizations. It plays a vital role in long-term plant safety and reliability.

During the facility commissioning phase, tests are conducted to verify and approve the performance requirements of individual equipment and components, and integrated plant sub- and main process controls and functions [13]. The vendor, designer and EPC organizations play an important role in establishing or helping to establish plans and procedures for these commissioning tests to assure that the requirements envisaged in the facility design are verified and approved.

To facilitate safe and reliable operations, the O/O needs to have comprehensive operating procedures for all modes of plant operation including the procedures to manage abnormal operations and accident conditions. The O/O also needs to take ownership of equipment surveillance procedures, maintenance policies and procedures, training programmes and facilities, procurement specifications, and support documents such as safety analysis reports, technical specifications and configuration control, and work management processes. The vendor, designer and EPC organizations need to play an active role in establishing or helping to establish the requirements for these functions as they possess the information and knowledge to support these functions.

Generally, the O/O takes over the RM process before the facility transitions to the operation phase. Depending on the contract model and conditions, clear policies and procedures need to be established to ensure a smooth transfer of responsibilities. The necessary training, guidance and support for the RM process need to be discussed and agreed by all stakeholders involved.

The designer and vendor organizations need to continuously improve the performance of their plant SSC based on R&D and other industry requirements. This may call for additional requirements to be introduced to the facility's RM programme or for changes to be made to existing requirements. The RM process needs to include provisions to incorporate such changes.

3.2.2. Owner/Operator

When an O/O accepts turnover of the facility from the supplier, it assumes full responsibility for all aspects of the safety of the nuclear installation for all subsequent stages of its life cycle. This responsibility includes, among other things, maintaining the integrity of the NPP design and keeping it in compliance with legislation, rules and regulations.

Practically, this activity is performed by the DA. The DA could be a specialized department or be part of another engineering department with the specifically assigned functions of a DA [14] [15].

The main task of the DA is maintaining the design basis and approved design of NPP in compliance with applicable laws, regulations and rules. In addition, changes in NPP design (e.g. modifications of procedures, equipment, systems and plant components) may be caused not only by changes in the normative basis, but also by equipment wear-out, operating experience, and activities for enhancement of safety, efficiency and reliability of the facility. In such cases, but specifically for safety related SSCs, analysis of the impact of the change on the design basis needs to be performed before changes are implemented.

The typical responsibilities and tasks to be performed by the O/O to establish a RM programme are summarized in Table 5.

TABLE.5. STEPS INVOLVED IN ESTABLISHING A REQUIREMENTS MANAGEMENT SYSTEM IN THE O/O ORGANIZATION

Task	Description	Life Cycle Phase
1	Establish DA	Design
1.1	Recruit and qualify adequate number of personnel	
1.2	Ensure adequate resources	
2	Implement a RM programme	Design
2.1	Implement the required documents and records management system where requirements and commitments can be captured and managed	
2.2	Implement the required formal change management processes to manage the requirements as well as design basis for the NPP	
2.3	Define, document and formally communicate the responsibilities of the various stakeholders involved	
3	Manage design requirements	
3.1	Ensure that design requirements that covers all facility life cycle phases are included in the handover package for new builds	Commissioning
3.2	Identify requirements from the various stakeholders during the operation phase	Operation
3.3	Interpret and clarify requirements, and define requirements commitments	Operation
3.4	Resolve any conflicting requirements with stakeholders involved	Operation
3.5	Perform the risk and safety assessments required to substantiate the commitments made and demonstrate successful requirements implementation	Operation
3.6	Participate in development of corrective/compensatory measures	Operation
3.7	Evaluate completeness of implementation measures	Operation

3.2.3. Regulatory body

For the regulator it is important that the O/O demonstrates that it is in control of the facility technical and design requirements programme. It is important that the regulator has confidence in the capability of the O/O to manage the information from the vendor, that the O/O understands the hazards of the nuclear installation and that, during the operations phase, sufficient safety provisions to control the risks of harm to the public and the environment at acceptable levels are in place.

A key attribute the regulators look for is the visibility of the safety requirements and that suitable SSCs are identified and implemented. Generally, this is demonstrated to the regulator through the vast array of safety documentation developed by the vendor and the O/O (sometimes referred to as a "safety case"), which has to be prepared and submitted to the regulator when modifications or changes to the design basis are proposed. The regulator confirms that such proposed changes are acceptable through its inspections of design records and other supporting documents, and the associated processes the O/O and vendor have, along with assessing the competence of the staff involved.

In the early conceptual stage of a design, a regulator may have an involvement through R&D programmes, particularly if there are test rigs or research reactors involved. In some countries, once a vendor's reference design is established, the regulator may be asked to conduct a "license-ability" review of the design to establish whether the key features of the reference design sufficiently meets regulatory requirements. This may be a significant task for the regulator in the vendor's home country.

During the basic design phase, the regulator usually has an increased level of interest. Where a design is new to a country, the regulator may subject the design to an intense review over several years, to confirm that its safety requirements are met. As a result of this review the regulator may require design changes, and hence new requirements may be introduced.

While the regulator still maintains a high level of activity in reviewing the design, the regulator's activities will extend its focus to consider site specific aspects and the capability of the O/O's organization as well. During the detailed design phase there will be a significant increase in the involvement of the O/O as it prepares to take on responsibility for the design and take lead in the management of requirements, considering the responsibilities and commitments (e.g. procurement, installation and maintenance of actual SSCs) that come in the later life cycle phases, particularly the operational phase.

Prior to construction the regulator seeks confidence that the O/O is ready to assume responsibility for the NPP and has in place all the mechanisms it needs to achieve this goal. Once permission or approval has been given, the regulator will shift its attention to see how the commitment and implementation phases of the RM are being delivered.

Similarly, during commissioning the regulator focuses on gaining confidence that the implemented requirements meet their performance specifications and that it is safe to proceed to the next stage.

Prior to operation, the regulator seeks confidence in the O/O's readiness to safely operate the facility for a defined period, that it has sufficient operating and emergency procedures in place and that it has established the necessary limits and conditions for a safe operation. The regulator needs to be confident that the O/O has a suitable management system in place to manage the facility through its design life, that the organization is capable and that a culture of safety is established. The regulator will typically achieve this through its inspections of records, documents, and the associated processes the O/O has in place, in addition to assessing the competence of the staff involved.

During the operations phase, the regulator focuses on sustained safe operations with the right learning processes in place (e.g. operating experience, safety reviews, corrective action programmes, configuration and modification management, and staff competence). The O/O is expected to manage all these requirements in a coordinated and joined-up manner [16].

3.3. DOCUMENTS

Design and technical requirements play a key role in almost all business processes followed in a nuclear facility like NPPs. Therefore, the requirements are essential part of almost all documents and activities followed in different facility life cycles. At the same time, new requirements come into action and old requirements change/modify as the facility moves through life cycles. While RM process ensures the additions and changes are captured and maintained through a living process, it is important to have policies, procedures and programmes to ensure the requirements applicable at any point of the life cycle phases are implemented efficiently in facility activities and business processes.

3.3.1. Policies

A RM policy has to be put in place, documenting:

— Applicable legal and regulatory requirements;
— Scope of the RM programme;
— Applicable codes and standards;

3.3.2. Programmes

A formal requirement management programme needs to be put in place at the NPP facility. This will allow auditing and traceability of the requirements identified by the NPP.

3.3.3. Standardization

A standard approach to the management of requirements is strongly recommended. This ensures consistency in the identification and capturing of requirements, commitments made to meet the requirements, and the management of commitment realization in the form of the NPP design basis and other related artefacts.

3.3.4. Procedures

Approved procedures and standard operating practices (SoPs) need to be established to ensure a standardized and optimized RM process execution. A life cycle information handover specification is a significant document that describes the document types and formats. It identifies the typical requirements implementation documents that need to be produced and managed across the different facility life cycle phases. This specification needs to be available to all stakeholders involved in the RM management process and its implementation.

The relevant organizational methods of managing requirements need to be put in place. The use of standard templates to ensure consistent capturing and management of requirements is highly recommended.

4. THE REQUIREMENTS MANAGEMENT PROCESS

This section elaborates the RM process described in Section 2. In this publication, to facilitate consistent use of terminologies for facility life cycles, conceptual design, detail design, construction and manufacturing, commissioning, operation and maintenance, long-term operation (LTO), and decommissioning are considered as various life cycle phases.

A comprehensive RM system, which can foresee and address the necessities of downstream functions of the various facility life cycle phases such as procurement, operation and maintenance functions until decommissioning, needs to be developed and implemented early in the facility life cycle. The RM system may be supporting other facility functions and management systems. It is important to consider these aspects early and make provision for them in the RM programme content development.

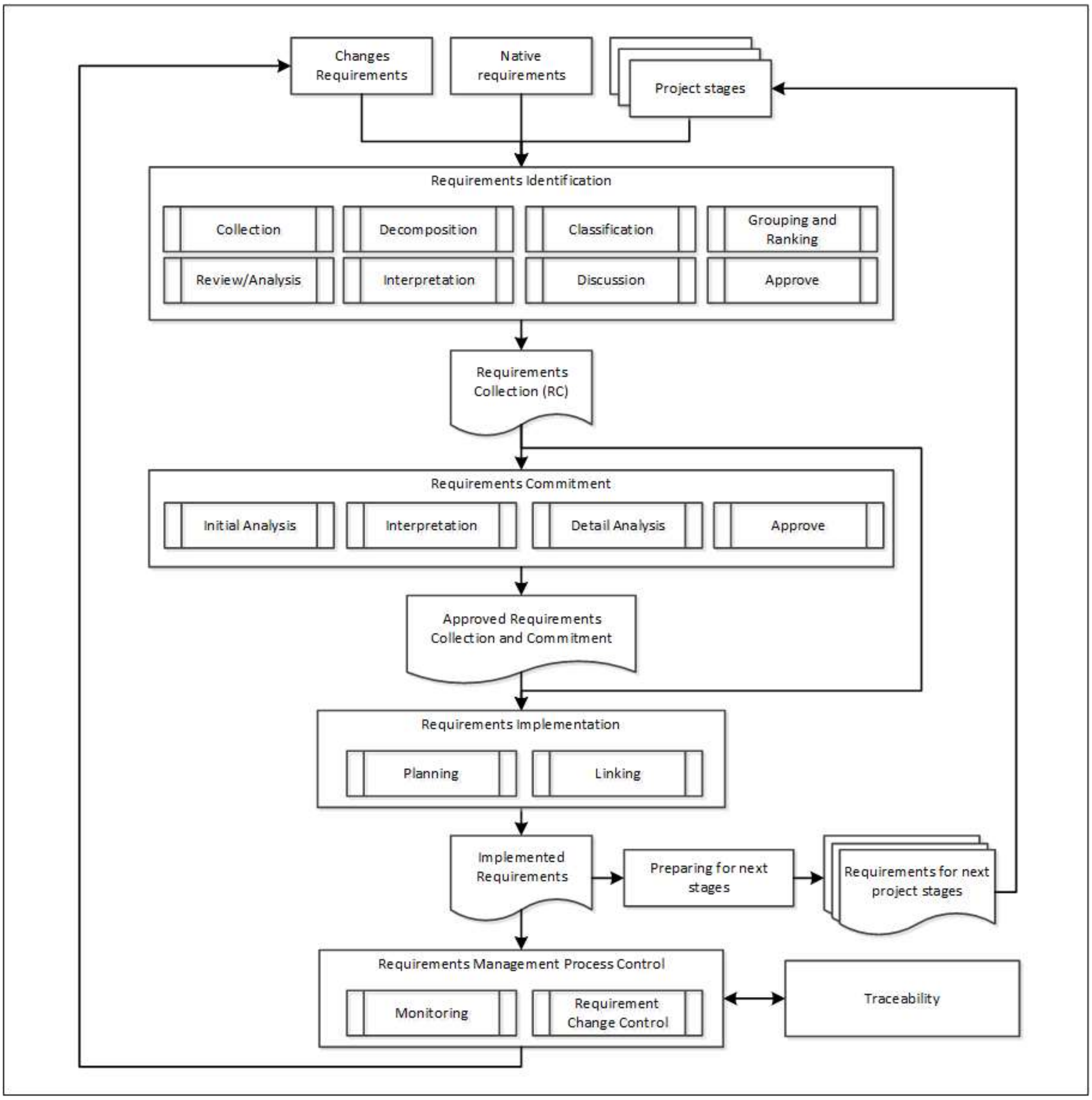

FIG. 10. RM process flow diagram (design stage).

Figure10 provides a typical RM process diagram for the design phase and it indicates the high-level steps involved in a typical RM process. The process of identification, commitment (approval) and implementation (realization) of requirements are sequentially arranged for a particular facility *life cycle* stage (project stage) and can thus be a repetitive process across the life of the nuclear facility. This is in line with the fundamental principle that requirements need to be managed as "living entities".

For each facility life cycle stage, the identification of requirements is a combination of identifying new requirements and re-using requirements generated from the proceeding stage after evaluating and incorporating necessary changes to them by considering their applicability to the present life cycle phase. As such, some requirements will move across the entire facility life cycle and may require review at the start of each phase to ensure continued applicability and compliance.

While formulating the requirement specifications, their compliance with the below key attributes needs to be assured.

In addition, ISO IEC 29148 p.5.2.5 [17] identifies some characteristics of individual requirements (see Fig. 11).

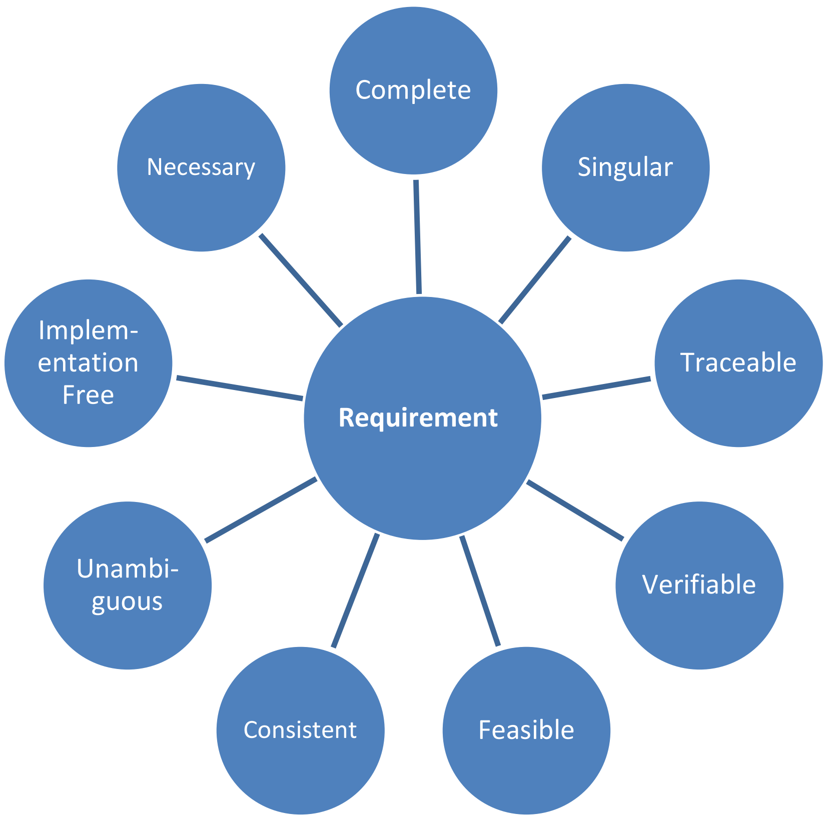

FIG. 11. Characteristics for good quality requirements.

The process involved in identification, commitment (approval) and implementation is explained in the following paragraphs.

4.1. REQUIREMENTS IDENTIFICATION

Identification of requirements needs to consider the activities and functions performed in a specific life cycle phase in order to select appropriate requirements for that phase. The main objectives of the requirements identification process are:

- Bringing all requirements to a consistent format in the project;
- Unambiguous interpretation of all requirements by each stakeholder;
- Demonstrate fulfilment of all requirements;
- Provide early opportunities to assess the risks of implementing the requirements (before the signing of the contract for the construction of NPPs);
- Facilitate automating RM processes for all life cycle phases.

Personnel involved in the identification of requirements need to have a good understanding and knowledge of activities and functions performed during that phase. The most common option is identifying lead experts in each area (specialization) from the number of potential project participants.

It is important that requirement information is captured regardless of how it is presented in a document, noting that many documents may not present them in a way that is necessary for a requirement statement.

The identification of requirements needs to be performed by those with suitable knowledge related to relevant scientific and engineering technology disciplines and with familiarity of source documents. The completeness of the set of captured requirements needs to be systematically reviewed to determine whether any have been missed (orphaned).

Requirements Identification is a 4-step process as explained below.

4.1.1. Collection

It is necessary to collect requirements for each stage of the life cycle. Source data for requirements that are relevant can be requirements from any other stages (predecessor as well as successor life cycle phases) as well as requirements specific to the life cycle phase.

The requirements are typically sourced from one or more standards and design documents, or site-specific conditions. It is important to pay careful attention to all applicable documents and site conditions that play a role in designing constructing and operating the facility. Examples of such documents include:

- Regulatory standards;
- National standards;
- International standards;
- Contractual agreements;
- Reference design;
- Site specific conditions.

At the beginning of this step, it is recommended to identify and prioritize the list of sources that will be further explored and decomposed. Sources not included in this list generally form a separate list of requirements that is considered and accounted for as a single requirement.

Requirements may typically be related to safety, cost, performance, or reliability. It is important to identify all of them in a careful and systematic manner. Sometimes requirements may also be expressed as:

- Assumptions;
- Limits or constraints;
- Uncertainties;
- Targets;
- Accuracy or tolerances;
- Multiple documents capturing decisions regarding inclusion into or exclusions from the set of requirements.

4.1.2. Decomposition (requirements taxonomy and ontology)

After collection of the requirements from different sources (documents, standards, etc.), they are carefully analyzed and decomposed (simplified) to the lowest possible level. The typical process of decomposition of a source document is shown in Figure 12.

FIG. 12. Process of decomposition.

The source information is analyzed and decomposed into a set of searchable properties such as:

- Title - the selected text reflects the title of the source document (e.g. the name of the standard, regulation, decree, or appendix of contract);
- Heading - the heading of the relevant document section;
- Description (not the requirement) - while the selected text is not a requirement in the current source document it can help understanding the next, or previous requirement in the text;
- Requirement - the selected text has the characteristics of quality requirements (see Fig. 11), otherwise the requirements need to be corrected at the commitment stage (see Section 4.2).

Consideration of the entire content in a source document is important to ensure the effective decomposition process. Some document content may not lead to a requirement at this stage. It is important that the end point of the decomposition step is defined in the RM process.

For example, if a requirement for emergency core cooling system reliability is 10^{-4}, then it is decomposed and allotted to reliability requirements of its components such as pumps, heat exchangers etc., in the system as envisaged in the proposed design. In this manner, the requirements are decomposed and given an initial UID number.

4.1.3. Classification

A careful thought process is necessary to arrive at the most appropriate set of classifications needed in the requirements database for deriving meaningful information from them for downstream functions and activities.

Classifying requirements into various categories helps to retrieve useful information about them that aids in sorting, exercising security controls, reporting and using information efficiently and effectively. Software enabled applications with linked data capabilities (maintaining relationships between system objects) offer advantages to manage the tens of thousands of requirements for a nuclear facility. Appendix I.1 provides a typical list of requirement classifications.

4.1.4. Grouping and ranking

One NPP unit typically accounts for more than 10,000 contract requirements. When all requirement types are considered together, their number can increase to tens of thousands. The grouping of requirements according to certain criteria, therefore, allows focusing on a limited number of requirements and aids in managing them. The typical properties table (Appendix I.1) shows, for example, grouping of requirements based on stakeholders involved, facility life cycle, security classification, and type of requirement (e.g. technical, legal).

The ranking or prioritization process is intended to identify the most essential and critical requirements in terms of their significance and helps to identify and confirm that appropriate commitment actions have been identified for implementation and subsequent monitoring methods to track requirements implementation.

Grouping and ranking are thus aimed at simplification of the RM process and increasing the speed of analysis, interpretation, control, and approval of requirements.

4.1.5. Review/analysis

The review/analysis process involves the collaborative review and analysis of identified requirements by all stakeholders. Through participation in this process, stakeholders develop a common, explicit and uniform understanding of each requirement and their established connection with SSC through the PBS.

The review/analysis process is crucial because the key risk within the RM programme are differing expectations from stakeholders regarding the implementation of requirements.

Due to the complex supply chain relationships that can exist in the life cycle of nuclear facilities as well as trans-national regulatory requirements, there may be conflicting requirements. In such cases, a formal conflict resolution procedure needs to be implemented as part of the overall requirements programme to ensure that conflicting requirements are properly identified, and a resolution is found.

The outcome of conflict resolution cases and subsequent decisions needs to be formally documented and controlled in the RM programme for auditing and future reference.

Therefore, the key objective of the review/analysis process is to develop a common understanding of each requirement by all stakeholders and a clear identification of those responsible for each requirement.

4.1.6. Interpretation

Interpretation is the elaboration of the requirements and analyzing proposals for requirement implementation by all stakeholders, based on a common understanding of the requirements identified through the review/analysis process. The different ways of implementation of the objective of requirements need to be evaluated. The consideration of the facility's design basis is very important in this process.

4.1.7. Discussion

The collaborative discussion process involves all relevant stakeholders and aims to identify the process for requirements implementation. This includes the agreement on approaches that will be followed regarding the implementation of the various identified requirements. The main objective of this process is to develop a uniform understanding for implementation of identified requirements through communications and discussions.

At the end of the discussions, either a uniform approach to implementation of relevant requirements is identified, or necessary modification to relevant requirements need to be defined. The rationale behind such changes and/or decisions made is to be formally captured in the RM system for future review, understanding and use.

The discussion process can be organized in the RM system of the project, but all sub processes need to be described in appropriate requirement management procedures to prevent an uncontrolled flow of suggestions and remarks in "chat" format between involved stakeholders.

4.1.8. Approve

Requirements need to be approved for implementation after undergoing review/analysis, interpretation, and discussion to arrive at consensus and common understanding. The approval process needs to capture the discussions, interpretations and analysis information to ensure common agreement between all stakeholders regarding requirements implementation, and also to be available in for use in subsequent facility phases if/when the rationale for requirements is needed.

4.2. REQUIREMENT COMMITMENT

This is the point at which stakeholders review requirements critically to ensure that the commitments made will meet the design intent for the facility. The steps involved in requirements commitment and approval are explained below.

4.2.1. Initial analysis

The key objective of this step is to analyze requirements with a view to develop potential commitment scenarios in order to meet the requirements in lieu of implementation or where direct implementation is not practical. For example, new or improved safety systems are incorporated in facilities based on feedback from industry experience or new innovations. Although the SSCs associated with new or changed design are carefully evaluated through engineering calculations and/or simulated tests at manufacturing/test facilities, it may sometimes be necessary to evaluate their actual performance when the plant is commissioned. In such situations, the commitment scenarios for meeting the requirements at different life cycle phases need to be identified and understood.

4.2.2. Interpretation

The interpretation process involves elaboration of the requirement scenarios and analyzing a number of proposals for each requirement implementation by all stakeholders, based on common understanding of the requirement arrived within the initial analysis step. The different ways of implementation of the objective of requirements need to be evaluated with due consideration to the design basis of the facility.

This step involves a collaborative discussion on the potential commitment scenarios for requirements implementation. The main objective of this process is to develop a common understanding of identified requirements implementation through communications and discussions. Detailed analysis needs to carefully consider the risks associated with the safety, economic and long-term reliable performance of the facility with due diligence.

Detailed analysis end in selecting the preferred commitment scenario. The rationale behind the commitment scenario is to be formally captured in the RM system for future understanding and audit.

4.2.3. Approve

Commitments are approved for implementation once an agreement among stakeholders has been reached.

4.3. REQUIREMENTS IMPLEMENTATION

The steps involved in implementation of requirements are explained below.

4.3.1. Planning

A formal plan for implementing the requirements in tasks and functions performed in that life cycle phase is drawn up considering all approved requirements/commitments identified in the previous stage.

Examples of typical implementation approaches in such plans include:

- Introduction of a check point in the procedure of assembly of a component;
- Development of a comprehensive functional test procedure to validate the performance of equipment as per requirement;
- Introducing a limiting condition of operation in the facility’s technical specification document.

4.3.2. Linking

Linking connects the requirements/commitments and their implementation in the RM process to the engineering processes, i.e. the SSCs and other configuration items. The engineering process encompasses all activities/functions, which have an impact on requirements (e.g. quality assurance programmes, surveillance test programmes, and development of procurement specifications).

4.4. REQUIREMENTS MANAGEMENT PROCESS CONTROLS

As requirements of a facility keep increasing and changing as it moves through different life cycle phases, it is essential to have suitable mechanisms and controls in place to manage the requirements as a living entity in order to ensure that the facility’s activities and functions are performed safely and reliably.

4.4.1. Monitoring

Establishing a system of periodical review, continuous monitoring and final verification to compliance (as per the requirements specified in the implementation plan) is crucial to ensure appropriate implementation of requirements in facility activities and functions for each life cycle phase.

Through appropriate monitoring, stakeholders are able to demonstrate that all the requirements and commitments have been met.

4.4.2. Requirement change control

The identification, commitment, approval and implementation of requirements is a continuous process. The number of requirements identified may grow to tens of thousands in numbers over a facility's lifetime.

In addition, there may be changes to plant SSC, procedures and other processes as part of the continuous improvement and they, by their very nature, necessitate changes to requirement specifications. It is, therefore, essential to have suitable control mechanisms to assess, change and approve requirements.

4.5. TRACEABILITY

Traceability of requirements implementation is important as verification and understanding the requirements implementation process may become very relevant later in a facility's lifetime. Traceability is also needed for the causal analysis and in support of impact assessment through the change management process.

Provision needs to be made to have the ability to trace the requirement/commitment to SSC or other configuration items and also have the ability to trace from the SSC or the other configurations items to a requirement(s)/commitment(s) throughout a facility's lifetime.

4.6. REQUIREMENTS MANAGEMENT DURING FACILITY LIFE CYCLE PHASE CHANGES

A nuclear facility's life begins with its conceptual design and passes through different life cycle phases for a time period of nearly 100 years before ending with a decommissioning and site rehabilitation phase.

RM, as explained in Sections 4.1 through 4.3, starts early in the design stage and moves through the various life cycle phases over time. The transition from one life cycle phase to the next needs to be thoroughly planned and executed with consideration of requirements for the subsequent phase.

This process involves the analysis and elaboration of both existing as well as new requirements relevant to the next stages of the NPP life cycle. While many new requirements come into place for the next facility life cycle phase, parts of requirements used in previous life cycle phases may be transferred to the next stage without any changes. By establishing a single RM system from early design phase to decommissioning phase with links and communication between the phases, it is possible to trace the requirements identification, commitment and realization in all proceeding phases. The tracing of nuclear facility requirements throughout all life cycle stages allows identification of the links and relationships between objects and requirements and ensures the safe and effective operation of the facility.

Another important consideration, as the RM process moves through different facility life cycle phases, is the ownership of identified requirements. Clear ownership needs to be established in each phase and the transfer of ownership of the requirements between stakeholders from one phase to another needs to be driven by a clearly established and well-documented procedure.

5. REQUIREMENTS MANAGEMENT - DESIGN REQUIREMENT MANAGEMENT SCENARIOS

RM helps both designer/vendor and O/O to ensure the maximum feasible compliance of the current or proposed plant design with both national regulatory basis and common industrial standards. In some cases, designer/vendor standards and regulations can be fully or partially accepted (or adapted) by the regulatory body and O/O, in which case a concession or waiver can be applied. This is not the case when designer/vendor and O/O are located within the context of the unique environment where the facility operates in the same country. The process of acquiring and managing design requirements is driven by the available experience, existing processes and plant maturity.

Design requirements from the vendor are likely to be readily available on new build projects and these vendors usually have adaptable processes in place to meet the design RM needs of the O/O. Additional efforts may, however, be needed from the O/O to establish an appropriate and adequate DA capable of managing the design requirements during the facility's operational phase.

Existing (old) plants looking towards life extension may be less likely to have full access to all design requirements, being potentially constrained by existing processes and available information, which is mostly document-based. The reconstruction of the design basis of an existing plant is governed by the availability of documented requirements, design basis and design realization artefacts.

Plants that are approaching their end of service life and are planning for decommissioning have to pay particular attention to the changing requirements for decommissioning and site rehabilitation based on local (country/state specific) criteria.

Processes and procedures for new build projects are likely to already reflect the addition of new information management system technology and the ability to deal with both current (paper format) and electronic media available and used to prove design requirements implementation. The requirements and subsequent design basis are likely to be agreed and approved prior to extensive design implementation activities. In many cases this process is complicated due to differences in designer's and O/O's national regulations.

An experienced nuclear plant O/O (customer) is likely to be more capable of transferring existing and proven processes and data/information into newer information management system technologies that are used for RM.

A newcomer O/O may most likely be challenged by the lack of RM experience with nuclear technology and processes and may need to either consider introducing (importing) a generic RM processes or investing in the development of RM processes to reflect the current project/plant operations and requirements.

The processes and strategies that govern this activity (and which the relevant nuclear facility will decide on) will most likely reflect the scenarios described further below (or even combinations thereof in the case of a fleet of nuclear power station units).

5.1. APPROACH FOR EXPERIENCED CUSTOMERS (NEW BUILD)

For the instances where an experienced O/O is considering a new build project, it is likely that the O/O will have long standing working relationships with vendors in its own country. The O/O will also have had access to its reactor technology owner's group and be familiar with the range of technical and design requirements through its existing facilities.

The O/O will have established practices for the review of NPP safety and will most likely also have access to the required in-house and external support organization's knowledge to review a new facility design. For an O/O, its focus will be on its fleet performance and ensuring sufficient resources to adequately support the operating plant.

For O/Os in this position there may be a strong economic driver to stick to tried and tested processes to manage the technical and design requirements, as any new systems that are introduced carry the risk of adversely affecting existing operational RM process stability. This might result in a conservative or incremental system implementation strategy that results in a decision to use a partial electronic and partial paper-based system. Should there be problems with introducing a new system the O/O would look to have a route to a secure known "fallback" position, to ensure business recover and continuity. This position may mean that the benefits from a fully electronic system may be harder to establish, especially if the technology adoption risks are perceived as too high.

Regulators may in these circumstances evaluate whether appropriate learning has been applied by the O/O from past experience, and that this learning is applied for current projects. The regulator may also evaluate whether current practices represent good, if not best practices. The regulator's inclination may be to seek evidence of improvement in the way the O/O manages its activities, especially whether there is an increase in the visibility of how safety is being managed and maintained at required levels.

It is possible that for a new build project the O/O may select a vendor with advanced practices in design RM. In such a case, the O/O has to review its established practices so that it can interface with the vendor in an effective way.

As an example, this may mean that within the O/O organization there may be different practices between new build and operating NPPs, or the O/O may mandate a single approach; with the implication that it has to implement a consistent, fully electronic system that meets the requirements of all involved parties.

Issues may arise as a result of having varying systems between facilities, or by having the same system between varying facilities. The implications of both scenarios have to be evaluated on a case-by-case basis and the O/O needs to select the scenario that poses the least risk to safe operations and business activities. See Annex II with regard to the experience of Atomstroyexport.

5.2. APPROACH FOR EXISTING (OLD) OPERATING NPPS

Reconstitution of the design basis is a challenge for many NPPs built 30 years ago or before. For many years, the management of design requirements were not a nuclear facility operator's function. Thus, the initial project documentation package handed over to the station by the vendor after commissioning of the station, in many cases either did not contain design requirements, or this information was incomplete.

Despite the challenges, these shortcomings need to be resolved if the station intends to continue operation beyond its originally designed service lifetime. The main problems faced by the old stations in the reconstitution of the design basis, and in particular the design requirements, are listed below:

— There is no (or incomplete) documentation describing the design requirements at the station;
— The design organization or equipment supplier no longer exists;
— The existing documentation provided as paper-copies, is partially unreadable or cannot be recovered;
— The facility requirements are outdated and do not correspond to current legislative, regulatory and/or technical basis;
— Changes made were not documented consistently to the extent needed for acceptable design RM;
— There are insufficient facility personnel who can effectively perform the reconstitution of design requirements or they do not possess the required nuclear plant design skills and competencies.

Due to the variety of problems encountered by the operators of old stations when restoring a design basis, it is impossible to give unified recommendations for the optimal solution of this task. Based on the existing practice of IAEA Member States, the following approaches are provided for consideration:

— Obtain all necessary documents from the supplier (designer);
— Try to obtain missing documents from twin stations (the same design type);
— Restore necessary information from various documents available and formalize it in a new document;
— Re-develop the full set of design requirements, considering the current legal and regulatory framework;
— Retrieve information from former NPP/designer/vendor staff through structured discussions and build the knowledge base about the plant design

The approaches listed above can be implemented separately or in combination. The decision on the most appropriate approach needs to be made considering the requirements of the regulatory body, timing of the implementation, and the availability of the required human and financial resources to undertake what will likely be a significant design base reconstitution effort.

A vital element in a successful design basis reconstitution project will be the establishment (or use) of a DA made up of appropriately qualified staff within the O/O organization. See Annex I regarding the experience of the South Ukraine NPP in reconstituting its design basis.

5.3. APPROACH FOR NEWCOMERS (NEW BUILD)

Countries new to the world of nuclear energy, for obvious reasons, do not have much experience in managing design requirements for NPPs.

In practice, the process of RM is not unique to the nuclear energy industry as similar processes are well developed in IT, pharmaceutical and aerospace industries. However, expert-level knowledge and experience in the field of NPP technology, safety assessment methodology, design principles, and legal and regulatory frameworks are needed to analyze the content of the requirements, to identify conflicts with other requirements, and to evaluate the relevance of requirements.

In this context, it is important for newcomers, who are just starting with their first NPP project, to create their own engineering support for the O/O and the regulator as early as possible. As part of this system, it is recommended that an engineering unit be created within the O/O organization that will deal with design issues, including design RM.

Newcomers do have the advantage that the NPP supplier usually has extensive experience and highly qualified personnel available for the design, construction and commissioning of a nuclear facility. For the O/O, a well-defined RM programme implemented from day one will allow them to leverage the knowledge and experience of such suppliers to build their knowledge base. This is a crucial undertaking because, after the facility is put into operation, the entire responsibility for the safety and reliability of the NPP is borne by the O/O. In IAEA Member States, there are different approaches to address this lack of qualified personnel. Below are some of them:

— Advance development of a national network of scientific and technical support for nuclear energy;
— Gradual transfer of experience from the supplier(s) to the customer during design, construction, commissioning and the first years of operation of nuclear facilities;
— Contracting external experts to solve complex engineering problems either on a permanent basis or in the form of short-term contracts/specific projects;
— Conclusion of contracts for NPP construction on terms where the supplier(s) remain fully responsible for the safety and reliability of NPPs at all life cycle stages (in the form of ‘Engineer, Procure, Construct, Manage’ (EPCM) contracts).

The decision to apply one of these approaches (or a combination thereof) needs to be made considering many factors including, but not limited to:

— Level of development of higher technical education;
— Availability of highly qualified engineers and other specialists;
— Deadlines for the implementation of NPP construction projects;
— Availability of financial resources for contracting external experts on a long-term basis;
— Long-term energy strategy of the country.

Recognition of the importance on this matter early on in the nuclear energy development programme [18] and the creation of a RM structure within the nuclear energy programme implementing organization (NEPIO) or O/O as early as possible is a crucial task in developing and establishing RM ownership by the nuclear facility operating organization. As such, the O/O is one of the stakeholders working with the facility design requirements at all stages of the life cycle. See Annex II regarding the experience of Atomstroyexport.

5.4. RECOMMENDED APPROACH FOR DECOMMISSIONING

Decommissioning is the final phase in the life cycle of nuclear facilities (in some cases, site remediation is considered as a final phase). However, this activity is a practically isolated project and has few connections with the NPP design requirements but deals with current design of a plant (as is). It is vital, however, to consider material selection and design features earlier in the NPP's life cycle as these may have a significant effect on decommissioning (e.g. avoiding easily activated materials like cobalt).

Decommissioning consists of several stages, including:

— Unloading of fuel from the reactor;
— Removal of spent fuel from the spent fuel pools;
— Disassembly of structures;
— Processing and long-term storage of liquid and solid radioactive waste generated in operation;
— Dismantling of radioactive equipment and structures;
— Conservation or dismantling of non-radioactive civil structures.

The tasks associated with the above activities have a connection to requirements in the initial plant design.

Obtaining a large amount of data from the initial NPP design as well as operational data is vital for the decommissioning project. For newer plants, this can be facilitated through the use of a Plant Information Model (PIM) and IT technologies. For older facilities this task is not as easy but can be resolved via reconstitution of the design basis.

Given the complexities that can arise during nuclear plant decommissioning and site rehabilitation, it is valuable to define a comprehensive set of design requirements for decommissioning at the NPP initial design stage. This can result in considerable decommissioning cost reduction.

Provided below are examples of requirements developed during the design phase for decommissioning:

— The NPP design should foresee further site exploitation after reaching the brownfield state of decommissioning;
— The recycling of non-radioactive wastes resulting from dismantling of the plant structures should be foreseen;
— The site infrastructure needs should be foreseen for the periods of plant decommissioning;
— The application of materials that are not activated by exposure to ionizing radiation should be foreseen to the extent possible.

Sufficient workspace (access to structures and components) required for dismantling, workers and tools should be foreseen. For radioactive equipment this requirement should also consider the usage of radiation shields and other protective measures during the design phase.

At present, there is no unified decommissioning strategy for nuclear facilities. The development of unified strategies and methodologies may not be feasible due to:

— The large variety of NPP designs;
— Differences in legal and technical normative basis;
— Availability of modern dismantling tools at each Member State;

Thus, the availability of comprehensive design requirements related to decommissioning activities in the initial NPP design is a key element for safe and cost-effective decommissioning [19]. Requirements related to the decommissioning phase need to be periodically reviewed and re-confirmed during all phases of the facility life cycle. The review will become more extensive as the NPP facility enters life extension or the end-of-operating life stage at which point decommissioning requirements including funding need to become part of short to medium term planning.

6. CONCLUSIONS

This publication demonstrates the importance of design and technical RM and identifies RM approaches used in the nuclear industry over the life cycle of nuclear facilities. This publication also provides examples from Member States regarding their practices to manage requirements for nuclear facilities.

This publication can help Member States understand and implement improved ways of facility RM. This publication can also help Member States embarking on new nuclear programmes to understand the importance of this topic and the methods and systems of RM currently applied in the nuclear sector.

This publication identifies eight core requirement management principles which are considered essential for a RM programme. These are:

- The capturing of requirements is a task that needs knowledge and experience in the technology, engineering, and scientific discipline being analysed and familiarity with the source documents being considered;
- The quantity and completeness of the specifications of the requirements increases and improves as a nuclear facility moves through different facility life cycle phases and as such it has to be maintained as a “living entity” throughout”;
- Ownership of a requirement is clearly defined, assigned and managed for each facility life cycle phase and is transferrable between life cycle phases;
- Requirements are decomposed to the lowest possible level to ensure that only one requirement is covered per unique identification (UID) created;
- Once a requirement is established, it undergoes revision control over the entire life cycle to ensure traceability;
- The owner of the requirement needs to manage the interfaces necessary to ensure that stakeholder perspectives are addressed to ensure the correct development, commitment and implementation of the requirement.
- The RM process needs to be a part of the integrated management system of the O/O and are appropriately interfaced with other management processes (e.g. configuration management, modification process, etc);
- In setting up the RM programme, the properties required for control and management need to be defined and their usage explained.

APPENDIX

Table A.I provides a typical set of properties, their purpose and the data associated with the property either as possible content or as a selectable item from a drop-down picklist in a database. While organizations developing an RM database need to consider properties and classifications suitable for them, the ideas provided in this table serve as a general guidance.

TABLE A.I PROPERTIES FOR REQUIREMENTS MANAGEMENT

Property	Purpose of Property	Example Content or Pick List
UID for Requirement	A unique system generated number allocated by the system to each identified requirement.	Software system generated, or in accordance with the adopted coding system on the project.
Requirement Title (Short Description)	Description of the requirement.	Memo field completed by requirements owner.
Detailed Description	Where there is significant detail to a requirement, a more detailed description can be provided for clarity.	Memo field completed by requirements owner.
Requirement Status	Indicate the status of the identified requirement. This can change over time and depends on business processes and the facility life cycle phases.	Including but not limited to: — Generated; — Being harmonized; — Agreed; — Approved; — Submitted for execution; — Executed; — Rejected.
Reference/Source	The source or reference document in which the requirement was identified as being relevant to the facility.	Memo field completed by requirements owner, but should ideally contain source description, source document number, revision of the reference/source and date of receipt or capture as a requirement. In a software system this can be a pick list that auto-generates as more reference documents and/or sources are added.
Responsible Department/Specialist	Assignment of requirement to a department or specialist that will own the requirement and its implementation. This may change throughout the facility life cycle.	Can be a multi-selectable pick list that would generally be based on the project and O/O organizational structure.
Reference Requirements	If the requirement has impact on other requirements this will be documented property. The same applies if this requirement was generated by another requirement. In software systems, this relationship can be automated by means of “drag & drop” relationship creation between objects in the software system.	Can be a memo field completed with required details or can be a system-generated pick lists of available other requirements for the facility.

TABLE A.I PROPERTIES FOR REQUIREMENTS MANAGEMENT cont.

Property	Purpose of Property	Example Content or Pick List
Reference PIM-elements	If the requirement has impact on the PIM aspects, it will be documented with this property. The affected PIM elements will be listed with this property. In software systems this relationship can be automated by means of "drag & drop" relationship creation between PIM objects in the software system.	
Type of Requirement	Classification of requirements into a high-level hierarchy.	Including but not limited to: — T-Technical requirement; — I-Information requirement; — L-Legal requirement; — H-Header/sub header of requirements.
Requirement Classification	To create a sorting capability based on the type of requirement identified. In software system this can be a multi-selectable pick list to cater for requirements that span different types of requirements (e.g. an environmental requirement can also involve design basis requirements).	Including but not limited to: — Statutory; — Regulatory; — Environmental impact assessment; — Licensing; — Safety; — Construction; — Commissioning; — Handover; — Operating; — Maintenance; — Life extension; — Decommissioning; — Site rehabilitation.

TABLE A.I PROPERTIES FOR REQUIREMENTS MANAGEMENT cont.

Property	Purpose of Property	Example Content or Pick List
Requirements Category		Including but not limited to: — Project management; — Documentation management; — Configuration management; — Quality management; — Site layout; — Construction and installation work; — Commissioning; — Project schedules; — Maintenance schedules; — Tests and inspections; — Training; — Operator qualification; — Licenses; — Process; — Turbine; — Nuclear island; — Fuel supply and management; — Design, safety analyses; — Architectural; — Station-wide facilities; — Maintenance philosophy; — Maintenance strategy; — Operating philosophy; — Operating strategy; — Safety case; — Maintenance activity basis; — Operating baseline; — Spares management strategy; — Plant monitoring strategy; — Risk management; — Technology adoption; — Training; — Testing; — Inspection; — Health & safety; — Certification; — Security; — Fail-safety; — Capability/functional correctness; — Reliability; — Availability; — Response time; — Operability; — Maintainability; — Responsiveness; — Process flexibility; — Site space management; — Operational disruptions; — Life extension; — Nuclear incident remedial action; — Nuclear incident preventive measure.

TABLE A.I PROPERTIES FOR REQUIREMENTS MANAGEMENT cont.

Property	Purpose of Property	Example Content or Pick List
Stakeholders Involved	Identification of the stakeholders that are involved and/or affected by the requirement and have to be kept up to date with its management throughout the facility life cycle. Multiple selection of stakeholders is possible in the case of software system meta-data field.	Including but not limited to: — Nuclear regulator; — Energy regulator; — Environmental agency; — DWAF (Departments of Water Affairs & Forestry); — National government; — Regional government; — Local government; — Owner; — O/O; — EPC contractor; — Suppliers/vendors; — DA; — Implementation partner.
Facility Life Cycle Phase Involved	The facility life cycle phase(s) on which the requirement will have relevance (single or multiple phases).	Including but not limited to: — NPP construction plan; — Siting of NPP; — Concept design; — Basic design; — Detailed design; — Construction; — Commissioning; — Handover; — Operate & maintain; — Life-extension; — Decommissioning; — Rehabilitation.
Information Security Classification	The classification of the requirement in terms of information security requirements. To control access to information in line with legislation.	Including but not limited to: — Top secret; — Secret; — Confidential; — Business unit only; — Controlled disclosure; — Public domain; — Unclassified.
Intellectual Property	Indicate if IP aspects are involved that will result in restricted access to the information and its distribution to stakeholders in the facility.	— Yes; — No.
Requirement Impact	Multi-selectable option to indicate the impact the requirement will have on the facility and its construction. An additional memo option is usually implemented to provide a short narrative of the rationale for assigning the various impact levels chosen.	Including but not limited to: — Safety; — Licensing; — Cost; — Project schedule.

TABLE A.I PROPERTIES FOR REQUIREMENTS MANAGEMENT cont.

Property	Purpose of Property	Example Content or Pick List
Safety Impact	Indication that the requirement relates to safety and nuclear facilities in general (or any of its systems).	— Yes; — No.
Cost Impact	Expert assessment of the impact of the requirement on the cost of the facility construction project is set by the project participants at the pre-contract stage.	Including but not limited to: — "0" - the fulfilment of the requirement completely fits into the expected cost of the project; — "1" - the fulfilment of the requirement may lead to an excess of the expected cost of the project; — "2" - the fulfilment of the requirement is impossible within the expected cost of the project.
Project Schedule Impact	Expert assessment of the impact on the implementation time of the facility construction project established by project participants at the pre-contract stage.	Including but not limited to: — "0" - the fulfilment of the requirement fully complies with the expected terms of the project expected for inclusion in the facility construction contract; — "1" - the fulfilment of the requirement may result in the failure of the anticipated deadlines for the project to be included in the facility construction contract; — "2" - the fulfilment of the requirement is impossible within the expected terms of the project, expected for inclusion in the facility construction contract.
Requirement Records of Decisions	Typically, a memo field that can be used to capture discussions held on requirements and the outcome of decisions. This is specifically relevant in cases where agreement has to be obtained between all stakeholders as to validity of the requirement and how it will be implemented.	Memo field completed by requirements owner.
Requirement Revision	Date of issue of the document - the source of the text fragment in the format.	Date or Number
Requirement Version	Date of actual change of the text fragment in the format.	Date or Number

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ABBREVIATIONS

ASE	Atomstroyexport
DA	design authority
DCD	design criteria documents
EPC	engineering, procurement and construction
GBS	global breakdown system
HVAC	heating, ventilation, air conditioning
I&C	instrumentation and control
IEC	international electrotechnical commission
IEEE	institute of electrical and electronics engineers
IP	intellectual property
ISO	International Standard Organization
IT	information technology
KKS	Kraftwerk-Kennzeichensystem
LOCA	loss of coolant accident
LTO	long-term operation
NPP	nuclear power plant
O/O	owner/operator
PIM	plant information model
PBS	plant breakdown structure
P&ID	piping and instrumentation diagram
R&D	research and development
RM	requirements management
SOP	standard operating practice
SSC	system structure and components
TEPCO	Tokyo Electric Power Company
TSO	technical support organization
UID	unique identification

ANNEX I. EXPERIENCE OF MAINTAINING THE DESIGN BASIS OF THE SOUTH UKRAINE NPP (SUNPP) POWER UNIT 1, UKRAINE

I-1. INTRODUCTION

Unit No. 1 of the South Ukraine NPP (SUNPP) was designed in the 1970s (see Figure I-1). Construction of the power unit began in 1975, and it was connected to the national grid in December 1982 and put into commercial operation in December 1983.

FIG. I-1. South-Ukrainian NPP. Unit №1 (on the left side of the photograph).

VVER-1000 reactors operate on a two-circuit scheme: the primary circuit is a high-pressure water circuit that directly takes heat from the reactor, the secondary circuit (non-radioactive) is a steam circuit that receives heat from the primary circuit and uses it in a saturated steam turbine.

The VVER-1000 reactor has a thermal power of 3000 MW. The operation of the reactor is based on the controlled chain reaction of fission of ^{235}U. Borated water is used as the moderator for neutrons and coolant at a pressure of 160 bar. The reactor operates as a part of a reactor installation, which has 4 loops of the main circulation circuit. Each loop includes a steam generator with a capacity of 1470 t/hr of saturated steam with a pressure of 64 bar, a main circulation pump with a capacity of 20000 ÷ 27000 m^3/h, two main gate valves and pipelines with an inner diameter of 850mm.

Circulating water in the primary circuit passes through the active zone of the reactor with a total flow through the reactor of 89000 m3/hour, water temperature at the entrance to the reactor is 286 ºC and at the output 316 ºC. The water of the primary circuit gives off heat in the steam generators to the water of the second circuit and evaporates it at a pressure of 64 bar. A turbine generator consisting of a steam turbine K-1000-60/1500 with a power of 1030 MW and a rotor speed of 1500 rpm (live steam inlet of 60 bar, at a temperature of 274 °C) and a TVV-1000-4-UZ electrical generator.

The electrical power output is provided to the switchyard at 24 kV stepped-up by a transformer to 330 kV. Cooling of the condensers of the turbine is done by circulating water supplied by pumps installed on a block pump station connected through a supply channel with a cooling pond. Electricity from the power unit enters the united electrical grid of Southern Ukraine and can also be transferred to the countries of near and far abroad. Electricity is supplied from open distribution devices (ORU) at 750, 330 and 150 kV. The Vinnitsa, Dnipro, Isakcha, Ukrainka, Quartzite and Trikhaty high-voltage power transmission lines are connected with the industrial regions of Ukraine.

I-2. DESIGN BASIS

The codes and standards applicable during the initial design of the NPP, were those of the former Soviet Union and are now outdated and superseded. The main ones were:

- OPB-82 “General Provisions for the Safety of NPPs in the Design, Construction and Operation”;
- PBY-04-74 “Nuclear safety rules for NPPs”;
- NRB-76 “Radiation safety standard”;
- SP-AES-79 №615/9-79 “Sanitary rules for design and operations NPPs”;
- OSP-72/80 “Main sanitary rules for handling radioactive materials”;
- Codes and standards for calculating the strength of elements of reactors, steam generators, vessels and pipelines of NPPs, experimental and research nuclear reactors and installations, 1973. Codes for calculation for seismic impact. Temporary methodology for calculating brittle strength;
- RTM 108.020.01-75 “Calculation of pipelines of NPPs for strength.”;
- Standards for of civil construction design of NPPs with reactors of various types;
- P&N AE-5.6 Rules and regulations.”

The design of the unit was originally carried out in accordance with the OPB-82 "General Provisions for the Safety of NPPs in the Design, Construction and Operation" [I-1], and currently meets the requirements of NP 306.2.141-2008 "General Safety Provisions for NPPs" [I-2].

I-3. MODIFICATION OF THE NPP DESIGN

Throughout the life of the project, Unit 1 underwent several modifications. The main reasons for the modifications of the power unit project were to address:

- Imperfections of the initial design;
- Operational experience;
- Changes in the national nuclear energy regulatory framework;
- Consideration of international requirements and recommendations for safety of NPPs.

Small design changes are carried out in accordance with nuclear industry procedures. Significant design modifications included industry-scale safety and reliability upgrade programmes. Modifications affecting safety at all stages of implementation are controlled by the Regulatory Authority for Nuclear and Radiation Safety. Design modifications that do not affect safety are monitored by the technical supervision inspection at the site of the NPP.

I-4. SAFETY UPGRADE PROJECTS

Due to the fact that large-scale modifications of the NPP project require significant capital investments and, often, R&D, implementation of such safety upgrade measures are carried out according to special industrial-scale programmes. Figure I-2. shows the main programmes to improve safety in connection with events in the nuclear power industry.

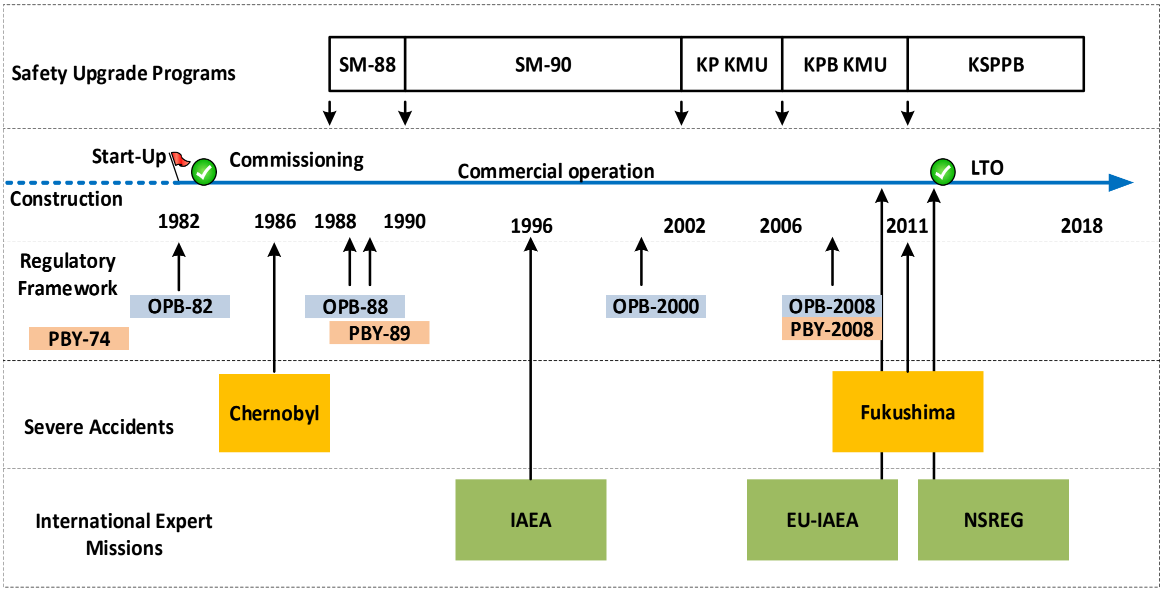

FIG.I-2. Significant events resulting in design modifications

I-4.1. Design gaps of the SUNPP-1 arising from the requirements of national standards and regulations in nuclear energy

For the period of operation of the SUNPP Unit 1 from 1982 to the present, the regulatory and technical basis on which the power unit project was developed was changed several times. Maintaining the power unit's design in line with the current national regulations and rules is an ongoing process that is controlled by the regulatory body and is a condition for an operating license unit. Analysis of the gaps of the current design compared to the requirements of the current regulations is provided in the Final Safety Analysis Report (FSAR) of the power unit and is updated annually. The consolidated list of project deviations from current regulations includes an assessment of the impact of a gap and identifies measures to eliminate or compensate for the non-compliance. Based on the results of the analysis, schedules for the implementation of improvement measures have been developed and agreed with the regulatory body.

When life extension of Unit 1 was agreed to at the end of 2012, there were 38 gaps in the list, of which only 8 were associated with the power unit design. As of 31 December 2017, the 14 remaining gaps were determined not to have a practical effect on safety.

I-4.2. Recommendations of international expert missions to improve the safety of the power units

Between 8 and 19 July 1996 an IAEA mission to the SUNPP was conducted to identify the fundamental deficiencies in operational safety and design decisions of VVER-1000/302 and VVER-1000/338 and provide advice on the completeness and adequacy of safety enhancement activities. Based on the results of the mission, the IAEA-EBP-WWER-14 report "Safety Issues and Their Ranking for “Small Series” WWER-1000 NPPs" [I-3] was developed. This report was a publication of the Extrabudgetary Programme on the Safety of WWER and RBMKNPPs; also known as the “IAEA Green Book”. The purpose of the report was to present a consolidated list of safety issues categorized in accordance with their significance for the safety of the station as a whole.

The IAEA experts identified the following main issues which needed to be addressed to improve safety:

— Physical separation and functional isolation between backup systems which is important for safety has not been performed;
— There is no redundancy of the reactor protection system;
— Scenarios of damage to the collector of the steam generator are not considered in the analysis of design basis accidents;
— There is a probability of failure of the insertion of control rods into the core;
— Potential problem, in terms of maintaining and monitoring the integrity of the pressure boundary of the primary circuit, in the reactor vessel;
— There are no improved systems of operational control and diagnostics;
— Qualification of safety and safety related equipment is necessary;
— Improvement of fire protection and fire-fighting capabilities is necessary;
— A comprehensive safety analysis of each power unit is required, namely, to develop a full report on the safety analysis of the power unit;
— The importance of human factors in the operation of VVER-1000 is not fully considered.

All the safety issues identified by the IAEA mission were divided into four categories:

— Category I: issues that reflect a departure from recognized international practices;
— Category II: issues that are of safety concern. Defence in depth is degraded. Action is required for resolving the issue;
— Category III: issues which are of high safety concern. Defence in depth is insufficient. Immediate corrective action is necessary. Interim measures might also be necessary;
— Category IV: issues of the highest safety concern. Defence in depth is unacceptable. Immediate action is required to overcome the issue. Compensatory measures have to be established until the safety problems are resolved.

In total, 74 safety issues were noted (in some safety issues there were from 1 to 4 questions). To eliminate the safety issues identified during the mission, the operating organization had developed measures, which were all included in the safety enhancement programme. At the time of life extension of the power unit's operation, most of the safety issues had been resolved, and the remaining 5 safety issues were in the process of being resolved (see Fig. I-3). Of these, 1 is classified as Category III, the rest as Category II.

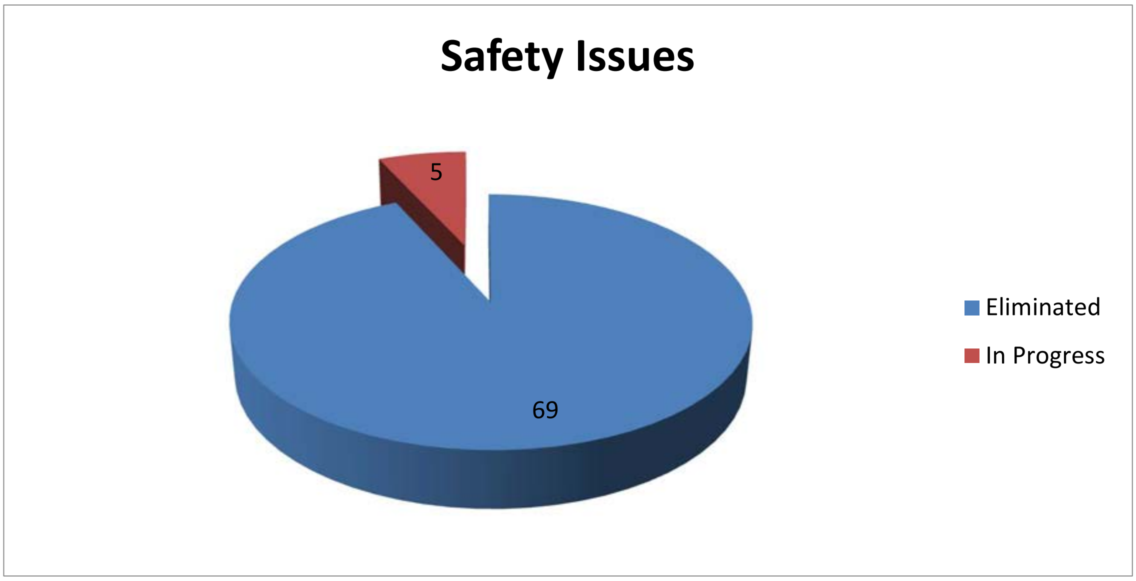

FIG. I-3. Status of the SUNPP-1 safety problems (IAEA-EBP-WWER-14 "Safety problems and their categorization for NPPs with VVER-1000", "small series") as of 31 December 2012

As of 31 December 2017, all the safety issues identified in the IAEA Extrabudgetary Programme on the Safety of WWER and RBMK NPPs, at the SUNPP-1 power unit have been resolved.

I-4.3. The EU-IAEA mission for assessing the design safety of SUNPP-1

Within the framework of the European Commission, IAEA and Ukraine’s joint project on the “Safety Evaluation of Ukrainian NPPs”, an EU-IAEA mission to SUNPP Unit 1 was conducted between 2 and 11 February 2009 to assess the NPP’s design safety.

The IAEA/EC/UA-T.1-MR03 "Report on the results of the mission for assessing design safety. Task 1. Evaluation of design safety. South-Ukrainian NPP. Power Unit No.1" [I-4], recorded the following with regard to compliance with IAEA Safety Requirements NS-R-1 Safety of NPPs: Design [I.5]: (see also Fig. I-4).

— Full compliance confirmed for 165 items;
— Partial compliance was identified for 26 items;
— No non-compliance has been identified for any of the requirements of the IAEA standard.

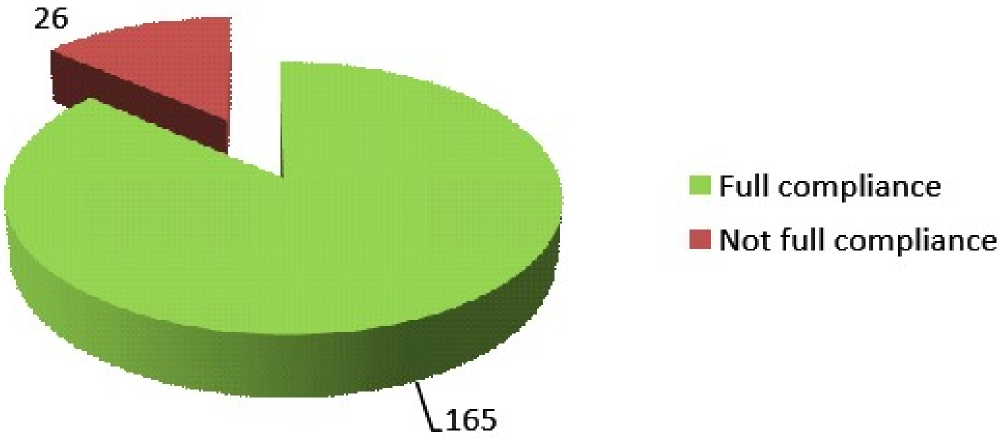

FIG. I-4. EC-IAEA assessment of SUNPP-1 with respect to compliance with the requirements of Safety Standards Series NS-R-1 Safety of NPPs: Design

The experts of the EU and IAEA concluded that:

"... the SUNPP-1 design fully corresponds to the overwhelming majority of the NPP design requirements set out in the IAEA Safety Guide NS-R-1 Safety of NPPs: Design requirements for which no full compliance has been revealed relate to:

- *Attestation of equipment;*
- *Accounting for severe accidents;*
- *Ensuring an appropriate margin of seismic resistance in the design;*
- *Protection against internal events and common cause failures;*
- *Probabilistic safety assessment.*

In all cases, the station has already realized the need for additional measures to correct the situation, as a result of which the IAEA experts came to the indicated conclusions. In most cases, active work is being done to implement measures aimed at eliminating these discrepancies. Significant progress has been achieved in achieving compliance with the design requirement of the IAEA."

As of 31 December 2017, all the requirements for the NPP design specified in the IAEA NS-R-1 Safety Standard have been fully met at the SUNPP-1 power unit.

I-4.4. Stress test and national action programme

The accident at the Fukushima Daiichi Nuclear Power Station in Japan on 11 March 2011 triggered the need for a coordinated action at EU level to identify potential further improvements of NPPs' safety. On 25 March 2011, the European Council concluded that the safety of all EU nuclear plants should be reviewed on the basis of the comprehensive and transparent risk and safety assessments - the stress tests. The stress tests consist of three main steps: a self-assessment by licensees followed by an independent review by the national regulatory bodies, and by a third phase of international peer reviews. The international peer review phase consists of 3 steps: an initial desktop review, three topical reviews in parallel (covering external initiating events, loss of electrical supply and loss of ultimate heat sink, and accident management), and seventeen individual country peer reviews.

Ukraine, while not a member of the EU, decided to voluntarily join the EU programme of stress tests. The main activities, the need for which was established as a result of an extraordinary safety assessment of Ukrainian NPPs (stress tests), were included in the existing safety enhancement programme (CCSUP). This programme received the status of a "national level programme", and its scope and funding were agreed by the Ukrainian government on 7 December 2011.

According to the Regulatory Decision No. 13 of 25 January 2011, in order to extend the operation of Ukrainian NPPs beyond the 30-year period, the operator should fully perform the following:

- Ensure the stability of equipment, pipelines, buildings and structures required to perform basic safety functions for seismic actions (0.12 g for the South Ukrainian NPP);
- Ensure the operation of basic safety functions of NPP equipment in "harsh" environmental conditions;
- Introduce emergency ventilation systems for civil defence at power units with WWER-1000 reactors;
- Implement measures to ensure the replenishment (cooldown) of the SG and the spent fuel pool in the event of a prolonged full blackout of the station and/or loss of the final heat sink;
- Implement Severe Accident Management Guidelines (SAMG) related to both the reactor and the spent fuel pools, as well as symptom-oriented instructions for eliminating accidents for NPP units in a shutdown state.

With the exception of the introduction of an accident ventilation system for containment, the above measures were already at different stages of development, or implementation before the accident at Fukushima.

To implement the requirements of the Ukrainian severe accident management guidelines (regulator) and the recommendations of the European Nuclear Safety Regulators Group (ENSREG) partner review, the regulatory body and the operating organization developed a National Action Plan to improve the safety of the Ukrainian NPPs. The plan included a number of activities related to the power unit project (see Table I-1.)

As of December 31, 2017, all measures (except emergency ventilation of the containment) were implemented at SUNPP-1. The remaining measure is under implementation. The installation of the system was planned for Outage-2018.

TABLE I-1. NATIONAL ACTION PLAN SAFETY IMPROVEMENT ACTIVITIES TO BE IMPLEMENTED AT SUNPP-1

Measure	Status of implementation at SUNPP-1
Account for the full range of initial accident events for all operational conditions of the reactor facility and the spent fuel pool	Done
Complete an analysis of the possibility of failure of the containment after the melted corium went out of the concrete reactor cavity. Calculation justification of measures to retain the corium within the containment	Done
Improve the reliability of the emergency power supply	Done
Install a means of controlling the concentration of hydrogen in accidents	Done
Develop and implement measures to remove hydrogen from the containment for beyond design basis accidents	Done
Implement a post-accident monitoring system (PAMS)	Done
Implement a system for preserving information for design and beyond design basis accidents ("black box")	Done
Introduce a system of "industrial" television to monitor for dangerous situations (fire/explosive) and unattended premises	Done
Complete an analysis of severe accidents. Develop severe accident management guidelines (SAMG)	Done
Complete an analysis of the survivability and habitation of the internal and external crisis centers during the conditions of severe accidents	Done
Introduce a system to enable the discharge of a vapor/gas from containment	In progress
Introduce mobile diesel pumps to provide emergency heat removal from the secondary circuit	Done
Provide heat removal from the spent-fuel pool (SFP) during long-term blackout conditions at the site of the NPP	Done
Introduce an isotopic composition monitoring system in the containment during severe accidents	Done

I-5. LONGTERM OPERATION AND RECONSTITUTION OF THE DESIGN BASIS

One of the tasks to prepare for the long-term operation (LTO) of SUNPP-1 was an analysis of the completeness and the adequacy of the design basis and the reconstitution of missing documents as necessary.

The basic design of the SUNPP-1 was provided by the Moscow “Atomenergoproject” Institute. The site-specific design was provided by Kharkov “Atomenergoproject” with scientific support provided by the “Kurchatov Institute”, and the TSO in Moscow was VNIIAES (All-Russian Scientific Research Institute for Operation of NPPs). Due to the highly centralized structure of the nuclear power industry in the USSR there weren’t any members of SUNPP staff at the power plant assigned direct responsibilities for design integrity.

After the collapse of the USSR, a significant number of the original design basis documents remained at the Moscow based design institutes. The Ukraine had to establish its own national regulatory system and technical standards to reconstitute the design basis for the NPPs. This activity has taken more than 15 years. The results of the design analysis are provided in the Periodic Safety Review (PSR) Safety Factor 1 - Design, which summarizes SUNPP efforts to reconstitute the SUNPP-1 design basis before extension of the NPP unit's lifetime.

The design basis of SUNPP-1 is distributed among different documents:

- "TOB AES" - safety analysis report for the SUNPP;
- "TOB RU" - safety analysis report for VVER-1000/302 reactor installation;
- "DMAB"- additional materials for safety analysis;
- Drawings;
- P&IDs;
- Algorithms;
- Calculations;
- Design technical notes.

The design documents at the plant site are located in different places:

- Constructors archives;
- "Atomenergoproject" on-site design bureau;
- NPP archives;
    - Technical library;
    - PTO (production department) technical archive;
    - Workshops archives;
    - Engineering departments archives;
    - NPP computer network;
    - Central archive of microfilms (Kharkov).

The design documents are available in design institutes (Kharkov "Atomenergoproject", Kiev "Atomenergoproject"). Some design documents are available in TSOs.

During the Periodic Safety Review for SUNPP-1 all sources listed above were revised (it was noted that none of the above listed sources had a complete set of SUNPP-1 initial design documents) and some missing documents were completed at SUNPP. However, complete reconstitution of the SUNPP-1 design basis was not achieved. Some of the problems that were revealed included:

- Some documents with design basis information have been lost;
- There were lot of duplicates of design documents in different plant archives, many of them were not updated since the 1980s. At the same time operational documentation had been maintained in perfect condition;
- Some documents with design basis information were never provided by the general designer (e.g. set of design requirements, justification of radiation safety zone, justification of control algorithms and setpoints, etc.);
- Some documents were outdated (mainly OKB "Gidropress" documents);
- A lot of documents were unreadable (old blueprints);
- Some documents were incomplete (mainly stress calculations);

— Revision of old paper archives was not efficient and requires a lot of manpower;
— Microfilming of paper archives was not completed, this activity is postponed as the archive is located far from SUNPP and remote access is not possible;
— Obtaining design documents from abroad (Russian Federation) is complicated due to “commercialization” of relationship between design organizations;
— All initial stress calculations were no longer valid since the relevant regulations and methodology have totally changed.

The measures implemented to eliminate/mitigate problems included:

— Missing and obsolete calculations have been re-done from the scratch, using state-of-the-art methodologies and computer codes;
— The FSAR (“TOB AES”) has been completely re-done, with all available safety related design information either included or referenced;
— Paper documents had been scanned and put into an electronic database;
— Design institutes (Kharkov “Atomenergoproject” and Kiev “Atomenergoproject”) have been contracted to re-develop some important missing documents;
— Design documents related to maintenance are being developed jointly by all Ukrainian NPPs.

I-6. CONCLUSION

During the period of operation of the SUNPP-1, the regulatory and technical basis on which the power unit design was developed had been changed several times. While the original design standards are now out of date SUNPP-1’s design has, on more than one occasion, been reviewed against current safety standards and safety improvements as necessary have been implemented to keep the design up-to date. Maintaining the power unit's design in line with the current national regulations and rules is an ongoing process that is controlled by the regulatory body and is a condition for a license for the operation of the power unit. Currently there are no important safety issues, from national regulations or standards with regard to the design of SUNPP-1.

The Ukraine is open for international cooperation, in particular in the field of nuclear energy. Therefore, the recommendations of IAEA experts on the improvement of the power unit project are implemented in priority order.

During the nearly 35-year operation period of Unit 1 of SUNPP, several hundred measures related to the power unit design were implemented resulting in an internationally acknowledged level of safety of SUNPP-1. At the same time, additional efforts are needed to complete and systemize the pool of design requirements and other documents, since this activity practically started only in 2008, when the power unit was being prepared for LTO. Currently, while the DA functions are clearly defined, their distribution among several divisions and not concentrated in a specialized subdivision of the NPP, is considered to make the management of the design basis less effective.

REFERENCES TO ANNEX I

[I-1] OPB-82 "General Provisions for the Safety of NPPs in the Design, Construction and Operation".

[I-2] NP 306.2.141-2008 "General Safety Provisions for NPPs".

[I-3] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA-EBP-WWER-14 "Safety Issues and Their Ranking for “Small Series” WWER-1000 NPPs" [I-3], 1996, Vienna.

[I-4] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA/EC/UA-T.1-MR03 "Report on the Results of the Mission for Assessing Design Safety. Task 1. Evaluation of Design Safety. South-Ukrainian NPP. Power Unit No.1", Vienna.

[I-5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Standards Series, Safety Requirements NS-R-1 Safety of NPPs: Design, 2000, Vienna.

ANNEX II. REQUIREMENT MANAGEMENT PRACTICES OF ATOMSTROYEXPORT (ASE), RUSSIAN FEDERATION DURING THE DESIGN STAGE

II-1. INTRODUCTION

Atomstroyexport (ASE), as part of the ROSATOM Nuclear Power State Corporation, is the Russian Federation's nuclear power equipment and service exporter.

ROSATOM Nuclear Power State Corporation is divided into 4 divisions:

— Nuclear Power Complex;
— Applied and Basic Science;
— Nuclear and Radiation Safety;
— Nuclear Icebreakers.

The group of companies ASE forms part of the Nuclear Power Complex as NPP Design, Engineering and Construction Company. At the moment, ASE is involved in the simultaneous design and construction of more than 30 NPP units. In scope, it makes up about 30% of nuclear projects worldwide with a company presence in 18 countries.

The process of requirement management in ASE, for the design and construction of a new NPP project, starts before signing of the contract takes place.

II-2. DOCUMENTS

The high-level procedures of requirement management are developed before starting any work with requirements during the design stage. At this early stage, the requirement management procedure needs to be aligned with the procedures for configuration and change management used in the Project.

Through the requirement management procedure, the rules for working with requirements, identifying and fixing sources, volume and decomposition level of the requirements will be determined. At the same time this procedure will define the methods of interaction between all participating stakeholders (interested parties) in the requirement management process, will set targets and describe the tasks for the development of databases and the customization of software for requirement management. It will also define the required control mechanisms for requirements implementation on all stages of the contract.

The focus in the requirement management procedure will then shift towards developing a set for each life cycle stage of the project. The main aim of this activity is to ensure that the responsibility for requirement implementation assigned to participants and their sub-contractors, as well as the software and related information systems that will be used for managing the requirement management process are described and documented in detail.

II-3. SOFTWARE

An investigation into the user experience and an analysis of the functionality available in the various commercially available RM software in the market had indicated that there was no single solution that would enable ASE to perform all of the functions required by any organization involved with the requirement management process.

To fulfill all the functions ASE needed for its RM system process ASE decided to develop an integrated RM information system.

In defining the information system, ASE (EC) adopted the concept of the Integrated Information Management System requirements. The integrated system makes use of complex and advanced software technologies, each of which is designed to perform specific functions within the RM process.

The ASE RM system provides the following capabilities:

- Accounting and planning of the fulfilment of all requirements for the NPP and its construction project;
- Maintaining the project requirements database;
- Establishing links for the project documents and the requirements that are listed in the document;
- Access to requirements and their attributes for all project participants at the same time;
- Differentiation of the participant access rights to requirements and contents within the RM system;
- The ability to determine the authors who made changes to the wording and attributes of the requirements (including a date and time stamp of when such changes were made);
- Link between the requirements and the project documentation;
- Examination of the links between the requirements and the project documentation;
- Exchange information with the customer's RM system if necessary;
- The ability to group requirements by specialty (engineering and design disciplines);
- Version control of requirements based on configuration baselines;
- Managing the complex interaction between the RM system software platforms in use.

The approach of using a combination of advanced software systems provides the user with the ability to leverage and maximize the strong capabilities within each of the information systems, while eliminating their shortcomings.

II-4. REQUIREMENT IDENTIFICATION

Requirement Identification is the most important stage in the requirement management process. Without this key aspect, the implementation of the RM process stands a very low chance of being successful.

II-4.1. Collection

Depending on the type of contract (e.g. EPC) or Engineering, Procure, Construct and Manage (EPCM) a list of project technical requirements may also be added to the list of requirements defined by the owner as full scope. These additional requirements are transferred to all potential participants in the tender process either for review or inclusion and form part of discussions with the contractor(s) during the procurement process.

Based on an owner company's experience in dealing with technical requirements, the information regarding requirements can be received by the contractor in several ways.

Experienced owner company

In an experienced owner company, this will be achieved by exporting fully identified requirements (with unique identification, types of requirements, classification, etc. as properties inside) in an open data format for exchange (e.g. XML or another available format for data processing). This manner of data provision by the owner company is deemed to be the most efficient way because there are no additional actions required for manipulating/converting this information before uploading it into the requirement management system. An example of content from such an XML file is presented in Figure II-1.

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<root xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <Row>
        <UID>000001X-1</UID>
        <ObjectIdentifier>REQ-2.1-0010-R</ObjectIdentifier>
        <ObjectText>Example of good requirement text</ObjectText>
        <TypeOfText>Reqirement</TypeOfText>
        <ObjectVersion>2018-01-01</ObjectVersion>
        <SafetyImpact>1</SafetyImpact>
    </Row>
</root>
```

FIG. II-1. Example of XML file for data exchange.

Inexperienced owner company

With less or in-experienced owner companies, technical requirements will most likely be provided in editable mode file (*.doc, *.docx, *.rtf, *.txt, etc.) accompanied by partially identified requirements. Generally, the boundaries of requirement would be clearly indicated in the document and their unique identification may be reflected in the text. This method is the most common scenario in owner company practice and, therefore, needs additional data manipulation/conversion to enable automatic selection of the unique identifier from the text to upload it to the RM system. An example of what this scenario looks like within a document is presented in Figure II-2.

Title of document

1 Heading of chapter

1.1 Sub-Heading of chapter

1.1-0010-R

Example of good requirement text

1.1-0020-N

Example of description text

FIG. II-2. Example of file with partially identified requirements.

Owner company provides requirements as editable data

In another scenario the owner company provides requirements in editable mode file (*.doc, *.docx, *.rtf, *.txt etc.) as technical requirements, but without any specific identification of requirements. This method requires experts of the owner company to perform the full process of requirements identification. An example of a document where no requirements are implicitly indicated is presented in Figure II-3.

Technical Assignment for NPP development

1. **Heading of chapter 1**

This document developed for… and… and here a good requirement text

Example of description text

Example of good requirement text

2. **Heading of chapter 2**

…

FIG. II-3. Example of file without any identification of requirements.

Owner company provides requirements as non-editable data

In the last scenario the owner company does not provide the requirements in any editable mode file format (*.pdf, *.jpeg, *.tiff, *.bmp etc.). This method is the least common in company practice. Presenting technical requirements in this way usually happens when the owner company wants to define the initial technical requirements based on a previously built NPP project. These contracts usually consist of RM activities such as identification and linking requirements to already developed project documentation during all life cycle stages of the NPP.

As a rule, together with the technical requirements, the contract specifies a list of codes and standards that are to be met in the process of developing technical solutions for the project.

Obligatory sources of requirements are the requirements related to the legislation of the country of construction of the NPP and those used in conjunction with the requirements set by the regulator on the basis of which licenses will be obtained for the design, construction and commissioning of the NPP.

In addition, the owner company may also, as a source of requirements, specify codes and standards and other applicable regulatory documents from the reference NPP that will form part of the requirements basis and need to be considered.

II-4.2. Decomposition

II-4.2.1. Scenario 1 - Requirements without a unique identification

For the case where technical requirements are received from the owner company without any unique identification, a formal identification process is initiated.

To support this methodology as a baseline step of requirement identification process ROSATOM developed a specialized standard [II-1]. Representatives from most of the enterprises within ROSATOM participated in the development of this standard in the ROSATOM engineering and construction division. This standard is mandatory for use in ASE.

For the requirement qualities' estimation, the criteria are based on the international standard ISO/IEC/IEEE 29148 [II-2]. The following *quality criteria* for requirements (and requirements contained in the documentation that covers project requirements) were developed and formulated in the ROSATOM standard as displayed in Figure II-4.

— **Uniqueness** - each requirement should be formulated as a requirement of the project only once and should not be repeated in any other project requirement;
— **Necessity** - each requirement should document characteristics or limitations of a product or a process necessary for realization of the set task execution;
— **Abstract** - the content of the requirement should point at what is necessary to realize the requirement and should not point at the way how it will be realized or contain completed project solutions;
— **Single value** - the formulation of the requirement should be clear and exclude the possibility of being interpreted in more than one way;
— **Consistency** - there should not be any inconsistency in the requirement;
— **Accuracy** - each requirement's formulation should explain a complete idea or statement and should not need additional conditions;
— **Brevity** - each requirement should be concise and contain only relevant expressions;
— **Traceability** - each requirement should lead to the compliance with the proposed project solution and should be clearly traced to its implementation;
— **Measurability** - the formulation of the requirement should contain a set of points or measurable parameters with clear boundaries;
— **Indivisibility** - each statement listed should be unique and should contain only one requirement.

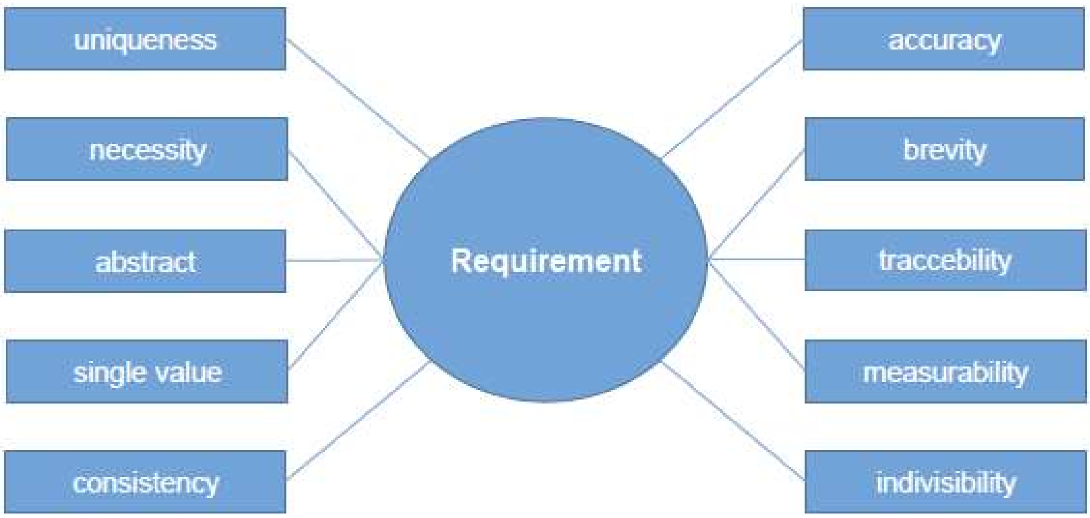

FIG.II-4. Quality criteria for requirements from the ROSATOM standard

Together with the definition of the *quality criteria* for requirements, the following requirements for documentation were also formulated:

- Each document in the project should have a unique document code;
- Every partition (section) in the document of the project should be enumerated;
- Each paragraph of text should contain only one requirement and describe its realization/ implementation;
- A link can only be made to a full requirement (linking to a part of a requirement is not permitted because of the quality criterion that the requirement should be indivisible);
- The number (quantity) of pictures should be minimal.

Expert groups are defined in line with their engineering specialization (e.g. architectural, instrumentation and control, quality management, mechanical, etc.) and each group is used to assist in the requirement identification process.

In the pre-contract stage, all expert groups participate in negotiations with the customer in the formulation of requirements. The result of this cooperation and negotiation is the inclusion of a fixed list of technical requirements in the contract, and the uploading of all technical requirements to the requirement management system for the next analysis phase that is described in II-4.2.2 and II-4.2.3.

II-4.2.2. Scenario 2 - Partially identified requirements

For the case where requirements are received from the owner in the form of partially identified requirements, the expert group(s) analyzes the received requirements using, but not limited to, the following criteria:

- Possibility of applying reference solutions;
- Compliance with the characteristics of what is deemed good quality requirements;
- Identification of poorly defined requirements that need to be discussed and clarified with the owner;
- Analysis of requirements to identify repetition of previously implemented requirements at other projects;
- Identification of typical solutions in AES's database.

II-4.2.3. Scenario 3 - Requirements in the form of editable data

In cases where requests from the owner are received in an editable format without fixed boundaries of requirements, the expert group(s) additionally split the text into fragments using a specialized template. The laying out of the text using the template later helps to automate the loading of the data into the RM system. In this automated loading process, each object (text fragment) is assigned attributes from the list of pre-defined characteristics suitable for subsequent work with requirements such as:

- UID;
- Object identifier;
- Type of text;
- Object text;
- Object version;
- Safety impact.

Depending on the requirements of the project in the process of decomposition of requirements with using a specialized template, additional attributes can be added such as:

— Responsible organization;
— Requirement criteria;
— Implementation stage;
— Documentation type;
— Classification;
— Object level;
— Cost impact.

After the decomposition of the requirements using this specialized template, all technical requirements are uploaded into the requirement management system to perform the next tasks.

II-4.2.4. Scenario 4 - Requirements in the form of non-editable data

The least common case for the provision of requirements is where the format of the technical assignment for the design is delivered in non-editable data. This situation can arise when the owner wants to restore historical data for an existing NPP to implement a project, e.g. modernization of the NPP. Due to the numerous changes that may have occurred during the operation of the NPP, it is possible that a significant number of documents, and the configuration of the equipment being used, may have been lost or changed resulting in a challenge to prove that the plant configuration is in compliance.

To identify requirements using these types of sources, preliminary recognition (scanning) of the submitted materials from a non-editable to an editable format is carried out by means of software conversion. After the text containing the technical requirements has been converted to an editable format, the expert group(s) begin the process of decomposing the requirements in the same way as described in item II.4.2.3 and subsequently analyze them in accordance with the scenario described in II.4.2.2.

II-4.3. Classification, Grouping and Ranking

Upon completion of the requirements decomposition, the expert group(s) conducts the process of classification, grouping and ranking.

The list of additional classifications is formed based on the project requirements and is expanded in accordance with the internal needs of the ASE. After that, the list of classifications provided to the customer will be fixed on the basis of these requirements on the list of additional classifications for the ASE's internal needs.

The most frequent option for grouping requirements is grouping based on their specialization (engineering/design discipline). This makes it possible to significantly reduce the labor costs of specialists at the planning stage of project requirements implementation.

II-5. REQUIREMENT IMPLEMENTATION

II-5.1. Planning

Fulfilling the requirements during the planning stage is mandatory before the design commences. When planning the distribution of requirements for their subsequent implementation, the approach is based on the structure of decomposition of the NPP as a product (Product or Plant Breakdown Structure, i.e. the PBS).

The application is based on the use of a PBS structure, which is designed to organize all types of project activities of the NPP construction project in the context of a finite number of NPP systems allowing the development, verification and validation of product requirements at the system design level. The use of a PBS ensures that the process of drawing up documentation and information on NPPs is based on system requirements. In the PBS, buildings/structures are considered as a system (making up a clearly delineated list of NPP elements designed to perform certain functions).

For ASE projects, the PBS is based on the KKS codes for power stations [II.3], which contains a clearly defined list of systems for each NPP unit. All technical documentation for the project is necessarily associated with certain elements of the PBS. At further stages of the project implementation, the PBS is detailed by specific equipment or elements of the NPP in terms of buildings/structures. The structure of the volumetric (location) decomposition of NPPs is done using the global breakdown system (GBS) to uniquely identify the exact location of specific premises.

Applying requirements planning based on a PBS has the following advantages:

- Availability of a detailed plan when approving the PBS and its invariance when changing the number of project documentation;
- Possibility of reference application of the plan with the invariance of design decisions;
- Possibility of step-by-step refinement of the plan as the project and details of technical solutions are developed.

To organize the planning of the fulfillment of requirements related to the management of quality requirements for individual processes, document-based planning is applied. In this case, the fulfillment of requirements is confirmed by a specific project document.

The result of planning activities is the development of specialized design specification documents for each PBS project with the following mandatory sections:

- Common Technical Requirements - A list of common requirements that, based on the results of requirements identification, apply to the entire design object as a whole, without the possibility of binding it to a specific document or PBS;
- Technical Requirements - A set of requirements that, at the identification stage, was associated with the specialty (engineering discipline) and, as a result of the analysis of the expert groups, is attributed to this PBS;
- Codes and Standards - A list of standards, laws and regulatory documents that are mandatory for accounting in the development of the project but are considered as one requirement in the RM system. Subsequently, in the project documentation they are reflected as reference documents;

- Functional Requirements from PBS - Based on the work of the expert groups, a list of additional requirements from the PBS system under consideration is formed, which should be addressed when developing other PBS systems;
- Functional Requirements to PBS – A list of functional requirements for the PBS system under consideration for other PBS systems.

Upon completion of the planning phase, all design specifications should be coordinated with the project owner. A prerequisite for the implementation of the planning phase is 100% accounting for all technical requirements of the project for the current stage of the project's life cycle.

Approved design specifications serve as the boundary conditions and input data for the designer in the development of the project documentation. For each PBS, the specialty and the corresponding group of specialists or a project unit are fixed.

For the owner, the design specification is one of the tools used for monitoring the fulfillment of project requirements during the acceptance phase of the current stage of the project's life cycle.

II-5.2. Linking

In accordance with the distribution of PBS in engineering specialties, responsible specialists need to develop the project documentation.

Depending on the requirements of the project and its technical preparation, there are two ways to perform the linking of the technical project requirements with the project documentation:

- Automatic;
- Manual.

In most projects that are in the process of issuing project documentation, an automatic method of linking requirements to project documentation is applied. The following advantages of this method can be singled out:

- The built-in mechanism to verify the correctness of the requirements specification reduces the influence of human factors, when specifying a unique requirement code;
- Significant reduction in labour costs compared to the manual linking approach;
- Significant reduction of information necessary to search in the text of the project document to find the place in which the implementation of the technical requirement is described;
- Reduction in the scope of development of project documentation due to the automated generation of registered requirements lists related to codes and standards based on established links.

A manual linkage method is used for projects where the stage of the project documentation release is completed, and its re-release is done only to indicate the place of requirements implementation in the body of the document.

II-5.3. Automatic linking method

To perform automatic linking of the project requirements to the project documentation, a specialized automatic reference checking solution has been developed. It is accompanied by a set of regulatory instructions for involved designers.

The main activity of the designer in the development of project documentation with subsequent automatic linking to the requirements of the project is to indicate the UID number of the requirement in the text of the document (in the established format). An example of such linked requirement UIDs within the document is shown in Figure II-5.

> **1. Heading of chapter 1**
>
> In the text of this paragraph, the designer provides a technical solution for the implementation of one project requirement. {REQ 1.1-0010-R}
>
> **2. Heading of chapter 2**
>
> In the text of this paragraph, the designer provides a technical solution to meet another project requirement. {REQ 1.1-0030-R}

FIG. II-5. Example of requirement indication in project documentation for automatic linking process.

This type of requirements indication within the document makes it possible to check the presence of the identified requirements (by a unique identifier) in the database and, if available, form an appropriate relationship in the system between the requirements objects and the project documentation. In addition to the formation of relationship links, this activity also fixes a unique requirement UID for each requirement into the correct position in the document body.

When this unique UID number of requirements in the database of the RM system is missing, the automatic reference checking mechanism will provide an indication of the errors both in the body of the document and in the form of an automatic linkage report. An example of this shown in Figure II-6, where the requirement in green was confirmed by the automatic reference checking mechanism to be a valid UID correctly linked in the system, while the requirement in red was either an invalid requirement UID or was incorrectly linked and associated.

> **1. Heading of chapter 1**
>
> In the text of this paragraph, the designer provides a technical solution for the implementation of one project requirement. {REQ 1.1-0010-R}
>
> **2. Heading of chapter 2**
>
> In the text of this paragraph, the designer provides a technical solution to meet another project requirement. {REQ 1.1-0030-R}

FIG. II-6. Example of requirement status indication in project documentation after automatic linking process and specialized reference check confirmation.

II-5.4. Manual linking method

This way of linking the project requirements with the project documentation is more labor-intensive but nevertheless still effective.

The binding (relationship creation) process consists of three key actions:

— Search for requirements in the RM system;
— Search for project documentation in the engineering data management system;
— Linking these objects by means of a "drag & drop" method, which will establish a relationship link between the requirement and the project documentation.

The result obtained is similar to that obtained for automatic linking (binding) except that the indication of the place of fulfillment of the requirement and the page or section number in the body of the document will not be indicated as in Figure II-6.

II-5.5. Linking requirements of codes and standards

The requirements of most codes and standards do not go through the stage of decomposition of requirements. This is due to several factors, notably:

— Decomposition of all codes and standards (for each project there are more than 3000) is too time-consuming and not convenient;
— ASE is not a developer of codes and standards and, therefore, their decomposition in the absence of agreements with the vendor will not be considered legitimate;
— There are no specific requirements from the owner for the implementation of certain sections from the composition of codes and standards. The designer is expected to follow these codes and standards;
— Not all requirements in a single document of codes and standards may apply to the project (e.g. the standard for bends or pipes for which only one position may be relevant to the project).

Considering this, the documents relating to codes and standards are counted as single requirements for which the unique requirements identifier is the document code.

Linking codes and standards with the project documentation is done in a separate interface of the engineering data management system. The interface allows to repeatedly search for codes and standards in the database and form relationships between these objects and project documentation as required.

II-5.6. Results of linking stage

At the end of the linking stage, the requirements as well as the codes and standards reporting lists are automatically generated in the document content section. An example of these types of reports are shown in Figure II-7.

List of Requirements

Requirement Identification	Document Code	Note (page)
REQ 1.1-0010-R	NPP-Project_Doc_Code_001	1
REQ 1.1-0013-R	NPP-Project_Doc_Code_002	3

List of Codes and Standards

Code of Codes and Standards	Name of Codes and Standards	Document code	Note
ISO 29148	Systems and software engineering — Life cycle processes — Requirements engineering	NPP-Project_Doc_Code_001	

FIG. II-7. Example of automatically generated technical requirements and the codes and standards reporting lists.

II-5.7. Monitoring and control of implementation

To implement the required monitoring processes and control the implementation of requirements, a group of specialized reports has been developed. Their use depends on the purpose of their application. Below is an example of some of the available reports:

— Dashboard indicating the statuses of the requirements for the customer (loaded, linked, implemented, approved, etc.);
— Control of linking requirements (used by project managers);
— The status of meeting the requirements of design specification(s);
— Status of classification requirements;
— Status of distribution of requirements by specialization;
— Status of changes in requirements.

Reports can be generated in various modules of the company's RM system and be static (at the time of generating the report) and dynamic (reflecting the actual state at the time of viewing the report).

REFERENCES TO ANNEX II

[II.1] ROSATOM, Unified Guidelines for the Formulation, Identification, Processing and Assessment of Quality Requirements in NPP Construction Projects.

[II.2] ISO/IEC/IEEE 29148, Systems and Software Engineering Life Cycle Processes — Requirements Engineering.

[II.3] KRAFTWERK-KENNZEICHEN SYSTEM (KKS) Identification System for Power Stations (KKS), Guideline 7th Edition, ISBN 978-3-86875-329-5, VGB Power Tech Services GmbH, Essen.

ANNEX III. APPROACHES TO DEFINE AND MANAGE DESIGN REQUIREMENTS AND DESIGN BASIS BY TOKYO ELECTRIC POWER COMPANY, JAPAN AFTER THE FUKUSHIMA ACCIDENT

III-1. INTRODUCTION

After the accident of the Fukushima Daiichi Nuclear Power Station, it became very important for the Tokyo Electric Power Company (TEPCO) to manage design requirements and their basis for SSCs important to safety and TEPCO initiated discussions about the methods to manage these requirements and basis. While various approaches can be conceived, TEPCO decided to pursue the simplest way to establish a document in which design requirements and basis are described.

The contents of the document, linking methods between the document and reference information, and the concept of support IT system are described in this Annex.

III-2. DOCUMENTATION OF DESIGN REQUIREMENTS AND THEIR BASIS

III-2.1. Design Criteria Document

Important design requirements and design basis to be understood and controlled by plant utility members should be compiled in a series of documents as it is necessary to properly maintain and manage them through all phases of a plant's lifetime. At TEPCO, these documents are called design criteria documents (DCDs). DCDs include not only regulatory requirements but also voluntary requirements and should be revised regularly so as to maintain their consistency with the latest regulatory requirement knowledge and findings.

A DCD is defined as a design requirement, which is one of three components in a configuration management equilibrium model [III-1].

Difference between DCD and System Design Specification

The DCD summarizes the design requirements and their basis that should be understood by plant utility members, but it is not a deliverable of the design process. The system design specification summarizes the specific performance (value) necessary for the function of the system and is one of the design output documents. Since both documents are closely related, they should be managed by associating each other using a traceability tool or document management system described in the following section.

III-2.2. Types of Design Criteria Document

DCDs are categorized into the following three types according to their contents. The contents described in each are defined as follows:

— **Topical DCD** - A Topical DCD describes the design requirements and their basis for common design programmes against external events, internal events, severe accident events, etc.;
— **System DCD** - A System DCD describes the design requirements and their basis on each system;
— **Structure DCD** – A Structure DCD describes the design requirements and their basis on specific structures, specific buildings, and interaction and response of specific structures and buildings.

Since the scope of the DCDs is very broad, it is quite difficult to prepare all DCDs in a short period of time. Therefore, prioritization is imperative. Currently, TEPCO put higher priorities on DCDs for systems to cope with a Loss of Coolant Accident (LOCA) and newly installed filtered containment ventilation, see Table III-1.

TABLE III-1. SCOPE AND PRIORITY FOR EACH DCD

Type of DCDs	Scope and Priority
Topical DCD	Common design disciplines: • Seismic design; • Design for other external events (Tsunami, Tornado, etc.); • Fire protection, internal flooding; • Separation of electrical equipment.
System DCD	Safety Related Systems 1st Priority: • RHR System; • Filtered venting system (FCVS). 2nd Priority: • HPAC system, etc.; • Emergency diesel generator; • Boron injection system, etc.
Structure DCD	Safety Related Structures: • Tidal embankment; • Primary containment vessel; • Reactor building.

III-2.3. Standard Contents of System DCD

It is recommended that the requirements are managed at the system level so that a DCD is prepared for each system with a standard table of contents for the System DCD (see Table III-2). However, it is also important to describe design requirements and their basis for component/equipment, which has a significant influence on the required functions of the system.

It is also a very important for utilities to manage the system margins, i.e. design margin and operation margin. Therefore, the basis to set each margin should be described in a DCD.

TABLE III-2. STANDARD TABLE OF CONTENTS OF A SYSTEM DESIGN DCD

Introduction	— Objective; — Scope; — Definitions and acronyms; — Related DCDs.
Related regulatory requirements, codes and standards	
System requirements	— Functional requirements; — Performance requirements for each operational mode; — Design requirements for component arrangement, power supply, instrument & control, Heating, ventilation, and air conditioning (HVAC), shielding, etc.; — Design requirements to protect the system from internal/external event.
Design requirements for major components within the system	— Mechanical components (pumps, heat exchangers, valves, etc.); — Electric components; — Instrumentation and control equipment.
Interface requirements	
Design requirements for testing and maintenance	
Margins	
Quality assurance Requirements	
Reference	
Appendix (if needed)	

III-2.4. Various information sources for a DCD

Information sources for a DCD are shown in Figure III-1. The shaded (yellow) area shows the documents or information that a Japanese utility does not receive from the original plant manufacturers, because they are regarded as the proprietary information of the manufacturers.

While it is difficult for a Japanese plant utility to acquire this information, the utility has to prepare a method to access this information. Although it isn't mandatory to acquire and own this information, the utility should be able to ensure accessibility to the information by clarifying who has access and the method to access the information.

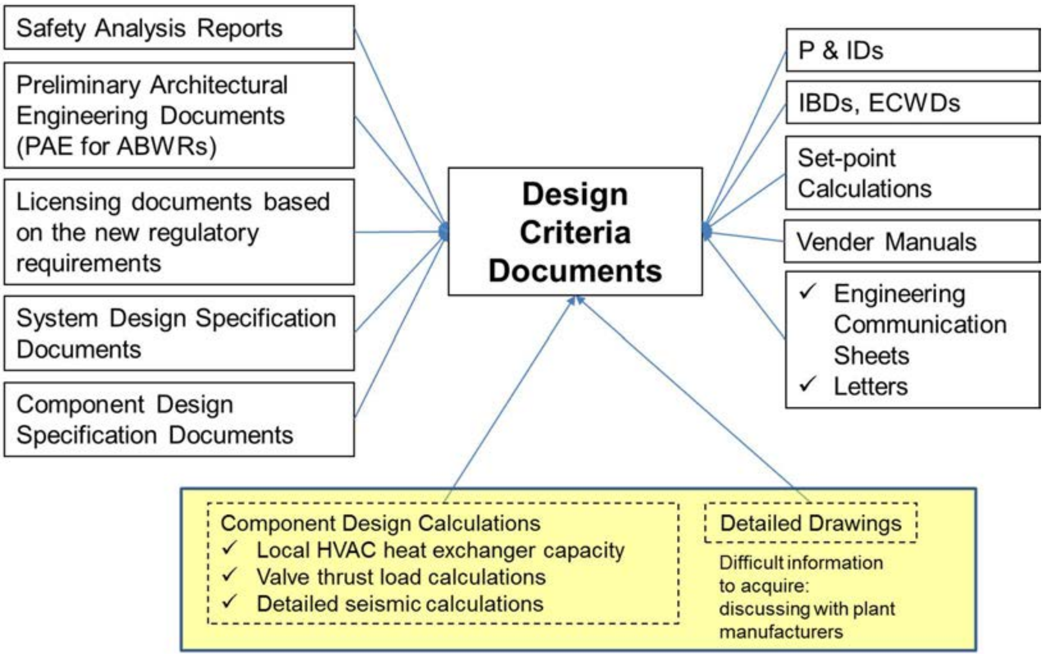

FIG. III-1. Source documents for system DCDs.

III-3. SUPPORT SYSTEM FOR DESIGN REQUIREMENT MANAGEMENT

III-3.1. Making links between a DCD and related documents (TEPCO)

The DCD refers to various documents and information as mentioned above. When it becomes necessary to revise one DCD, referenced documents should also be reviewed and revised if needed. In order to assure that the documents affected by the revision of the DCD are identified accurately, links between the DCD (Fig. III-2) and the referred documents should be provided and managed by a support system. Such a system can analyze the links and suggest which documents should be reviewed, when a design change is implemented.

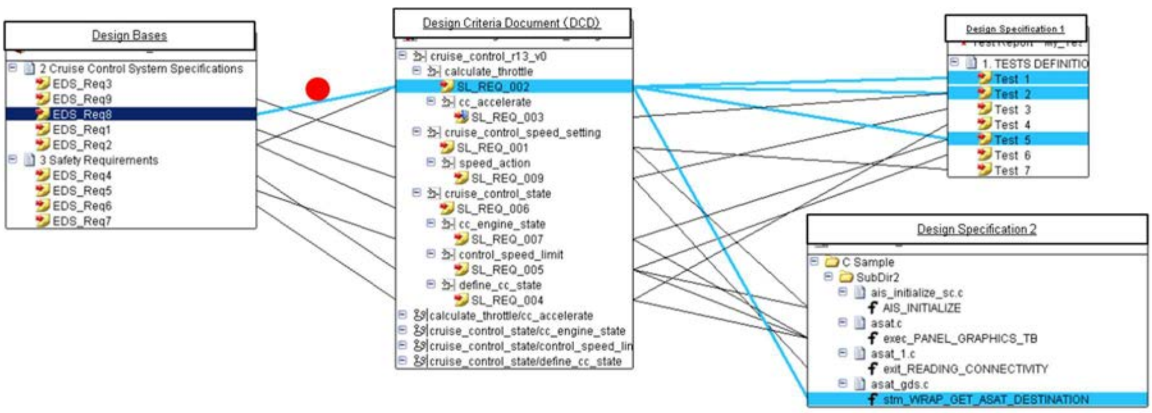

FIG. III-2. Support system for design requirement control.

III-3.2. Making links between the DCD and the P&ID (Hitachi-GE)

Another example is to manage the documents on the basis of the piping and instrumentation diagram (P&IDs) by connecting the P&IDs and the document management database (see Fig. III-3). Specifically, when the piping or equipment is chosen on a P&ID drawing, the P&ID and document management database are connected as a "key" in the facilities ID and the documents related to facilities are displayed. The development of a system, such as the above, is considered for P&ID embodied system design and is suitable for understanding the relations between the facilities and the DCD of the system unit. In addition, the management of the documents related to the facilities is enabled comprehensively by managing it in the P&ID in this way.

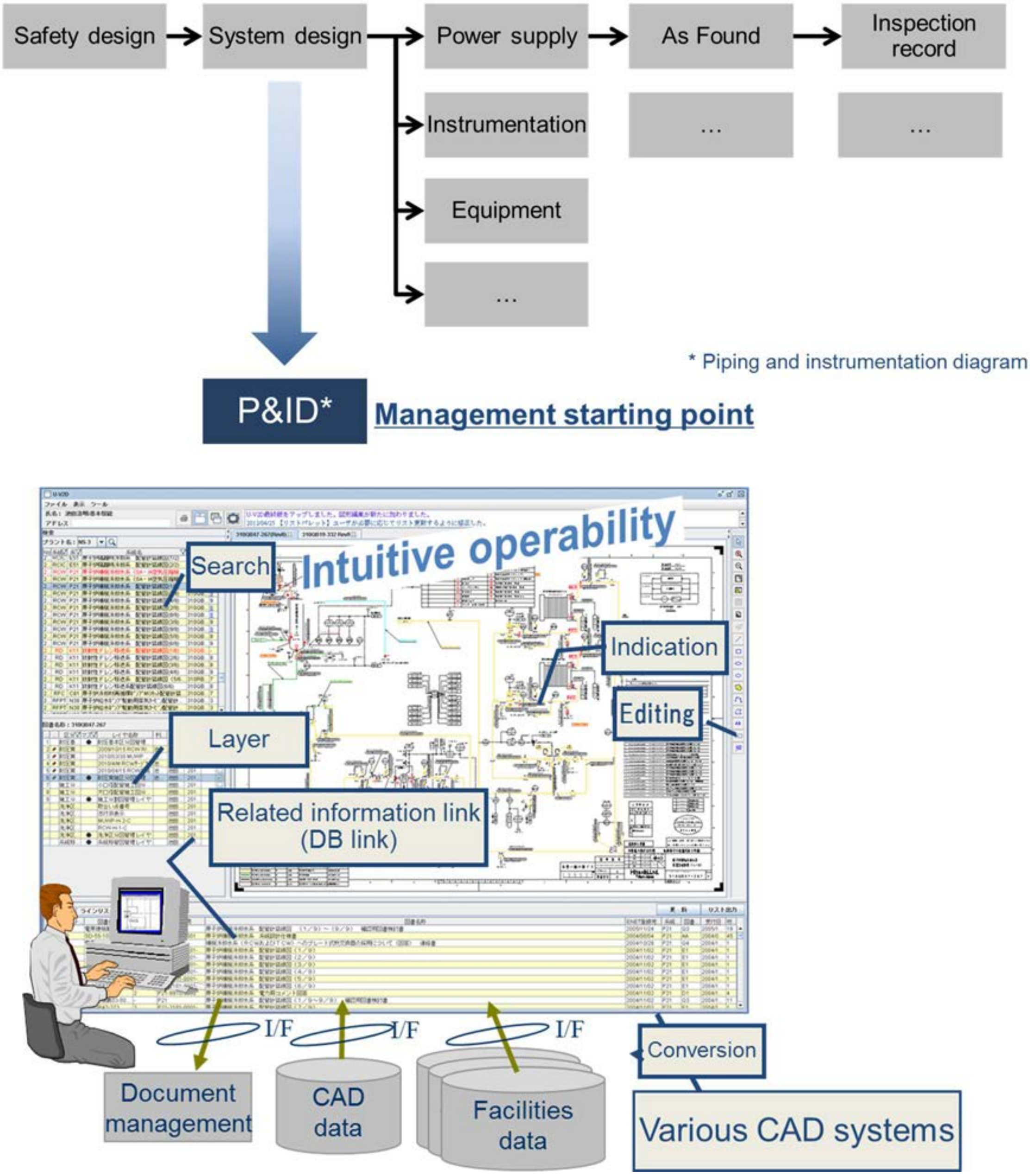

FIG. III-3. Images of making relationships between DCD and P&ID.

III-3.3. Approach to design requirements reconstitution

In the case that a nuclear plant utility does not have, or cannot access, the information essential to maintain plant safety and stable plant operation, it is necessary for the utility to reconstitute design requirements and their basis urgently.

In promoting reconstitution work, the following three items are defined as the basic idea, and the document category (see Table III-3) should be applied:

— Reconstitution of design requirements and basis does not mean to correct the complete document package, but it is important that some documents, which are needed to support plant operation, should be prepared;
— According to the standards which are established by nuclear industries, all documents categorized as group 1 should be accurate and the documents which are categorized grade 1 but not available should be reconstructed;
— Documents which are categorized as grade 2, 3, 4, and 5 should be reconstructed, unless it is possible to prove that the system, structure, and component can demonstrate the required safety function by some other information and test data.

TABLE III-3. DEFINITION OF DOCUMENT CATEGORY

Grade	Definition of document category
1	Design documents, which define the safety limits of technical specifications, operation limit, set point limit of safety function, and surveillance requirements. These documents indicate that the systems, structures, and components which are written in technical specifications can demonstrate required safety function (e.g. set-point list, valve list, instrument equipment list, fuse list, breaker list, Q list, sequence of diesel generator, etc.).
2	Design documents which define control parameters of SSCs that support SSCs written in technical specifications or design documents that demonstrate their dynamic functionality.
3	Design documents which define the control parameters of safety-related structures, lines and equipment that do not belong to grade1 and 2, or design documents that demonstrate their dynamic functionality.
4	Design documents which define the control parameters of safety-related structures, lines and equipment, or the functionality related to those passive considerations (e.g. seismic resistance considerations, etc.).
5	Design documents which show design of non-safety type structures, lines and equipment, and whose failure/damage can inhibit the functions of safety-related structures, lines and equipment.

REFERENCE TO ANNEX III

[III.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Configuration Management in Nuclear Power Plants, IAEA-TECDOC-1335, 2003, Vienna.

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