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Managing modernization of nuclear power plant instrumentation and control systems

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FOREWORD

This report has been produced in response to the perceived need for collective consideration of the issues and approaches for the effective management of nuclear power plant instrumentation and control (I&C) modernization projects. Many nuclear power plants in the world are approaching 20 to 30 years of operation. With license renewal, even these plants still have at least 30 to 40 more years of useful operating life. The I&C systems in these plants, in general, consist of old technology and are demonstrating obsolescence, aging, and poor performance issues as well as increasing costs to maintain acceptable performance.

Therefore, I&C modernization programmes are becoming essential for many plants. These modernization programmes will require substantial capital investments. In order for them to be successful, both in terms of the modernization project and the long term performance of the modernized systems, proper management is necessary. This report is designed to provide guidance and good practices for upper management, project managers, and members of the project team of I&C modernization projects. This report is of interest to the utilities, suppliers/vendors, and consultants participating in I&C modernization projects.

The first IAEA Consultants Meeting on Effective Management of Nuclear Power Plant Instrumentation and Control (NPP I&C) Modernization Projects Including Development of a Database was held in Vienna from 9 to 12 April 2001 in order to exchange information on the national experience on management of I&C modernization activities and to prepare the first draft of the planned report. The second IAEA consultants meeting was held in Vienna from 11 to 15 February 2002. The final meeting related to this report was held from 31 March to 4 April 2003.

The scope of this report covers all of the management activities related to modernization of I&C systems in nuclear power plants. The scope includes the evaluation of all I&C systems to determine which can be successfully maintained and which need to be modernized. This evaluation needs to be made periodically so that the decisions are appropriate for the current status of the systems and the plant's goals, objectives, and commitments.

This report applies to the two commonly used approaches to I&C modernization. One is the approach of shutting the plant down for the required period to perform all of the I&C modernization activities. The second is the co-ordinated, incremental approach that does the I&C modernization activities over several refuelling outages with the objective of not increasing the length of any of the outages. The scope includes large, comprehensive modernization programmes that will modernize a large number of I&C systems, and small modernization programmes that will modernize a very few I&C systems, and all of the possibilities in between. The scope covers highly integrated systems and projects, as well as stand alone systems and projects.

Special thanks are due to J. Naser of EPRI, USA, who chaired the meetings, and to P. Salaun of the EDF — Research and Development center of France who along with him largely contributed to the report. The IAEA officer responsible for preparing this publication was K. Kang of the Division of Nuclear Power.

CONTENTS

SUMMARY 1

1. INTRODUCTION 3

1.1. Background 3
1.2. Overall objective 5
1.3. Scope 5
1.4. Relationship to other work 6
1.5. Readers and users of this publication 6
1.6. Summary/content of remaining chapters 6

2. MANAGEMENT LEADERSHIP AND SUPPORT 8

2.1. Manager responsibility 8
2.1.1. Management support 8
2.1.2. Strategic planning 8
2.1.3. Plant I&C endpoint vision planning 9
2.1.4. Design and implementation guidance 9
2.1.5. Monolithic versus incremental modernization strategy 10
2.1.6. Control room modernization planning 11
2.1.7. Strategic planning flexibility and expandability 11
2.1.8. Strategic alliances between the utility and the supplier 12
2.2. Corporate knowledge and staff resources 12
2.3. Management plan 13

3. PERCEPTION OF NEEDS FOR I&C MODERNIZATION 14

3.1. General goals, objectives, commitments of the plant 14
3.2. Development of plant specific strategic plans and guidelines 15
3.2.1. Management involvement 15
3.2.2. Infrastructure to support modernization 15
3.2.3. Plant specific strategic plans and implementation guidance 16
3.3. Identification of issues, needs and limits with current I&C systems 18
3.4. Forecasting problems and limits in the nearest future 19
3.5. Benefits of adopting new technology 20
3.6. Issues to consider in transfer from analog to digital technology 21
3.7. Decision to initiate I&C modernization activities 22
3.8. Advantages and disadvantages of incremental and monolithic approaches 22
3.9. Considerations of I&C modernization approaches 24
3.9.1. I&C modernization scope 24
3.9.2. I&C modernization functionality 25
3.9.3. I&C modernization operation methods 25

4. PROJECT PREPARATION AND FEASIBILITY STUDY 26

4.1. Organization of project preparation team/manager 26
4.2. Evaluation of existing systems 26
4.3. Prioritization of system implementations and schedule 28
4.4. Provision of resource requirements 28
4.5. The migration path 29
4.6. Justification to obtain resources 30

5. PROCESS TO DEVELOP PROJECT CONTRACT 31
5.1. Interaction with licensing authority 31
5.1.1. Determine necessity of licensing authority approvals 31
5.1.2. Initial interaction with licensing authority for agreement on applicable standards 31
5.1.3. Safety case development 32
5.2. Organization of project team 32
5.3. Basic design and engineering 33
5.3.1. Design criteria 33
5.3.2. Design and engineering 33
5.3.3. Interfaces to other systems 34
5.3.4. Functional and task analysis of human machine interface (HMI) 34
5.3.5. Requirements 34
5.4. Planning 34
5.4.1. Cost and schedule 34
5.4.2. Quality assurance 35
5.4.3. Configuration management plan 35
5.4.4. Verification and validation (V&V) plan 35
5.4.5. Human resources plans 35
5.5. Selection of supplier 35
5.5.1. Identification of potential suppliers and preparation of invitation to bid 35
5.5.2. Evaluation of bids 36
5.5.3. Detailed interaction with selected bidders 36
5.6. Contracts 36
5.6.1. Methodology of contract 37
5.6.2. Agreement on the final requirements 38
5.6.3. Documentation requirements 38
5.6.4. Cost and delivery schedule 38

6. PROJECT IMPLEMENTATION 38
6.1. Introduction 38
6.2. Specific topics about this phase 39
6.2.1. Human resources 39
6.2.2. Schedule and work plan 39
6.2.3. Interaction with stakeholders 40
6.3. Design phase 41
6.4. Testing and acceptance 43
6.4.1. Acceptance criteria and test procedure for factory acceptance test 43
6.4.2. Acceptance criteria and test procedure for site acceptance test 44
6.4.3. Test procedure for commissioning 45
6.4.4. Plant simulator for system testing 45
6.4.5. Usage of full scope simulator for V&V 45
6.5. Training 45
6.5.1. Training identification 45
6.5.2. Training plan 46
6.5.3. Simulator upgrade 46
6.6. System installation 47
6.6.1. Installation strategies 47
6.6.2. Installation planning 47

6.6.3. Installation execution 48
6.7. System documentation 48
6.7.1. Configuration management plan 49
6.7.2. Final, as built documentation 49
6.8. Operating experience and error reports 49
6.9. Maintenance management 50
6.9.1. Elements to be considered by the manager 50
6.9.2. Maintenance management plan 50

7. LESSONS LEARNED AND EXPERIENCE GAINED 51
7.1. Project planning 51
7.2. Project organization 52
7.3. Project execution 52
7.4. Human machine interface design 53
7.5. Staff training 53

8. CONCLUSIONS AND RECOMMENDATIONS 54
8.1. Conclusions 54
8.2. Recommendations 55
8.2.1. I&C system modernization management 55
8.2.2. Needs, requirements and preparation of specifications 55
8.2.3. I&C modernization project preparation 55
8.2.4. I&C modernization project implementation 56
8.2.5. Tools, methods, procedures and documentation 56
8.2.6. Licensing 56

APPENDIX A: QUESTIONNAIRE FOR I&C MODERNIZATION PROJECTS IN THE NUCLEAR POWER GENERATION SECTOR 57
APPENDIX B: APPROACHES TO DATABASE DEVELOPMENT 85
APPENDIX C: EXPERIENCE IN REFITTING IN THE FIELD OF SAFETY INSTRUMENTATION AND CONTROL 91
APPENDIX D: EXPERIENCE FROM SUCCESSIVE MODERNIZATION OF INSTRUMENTATION AND CONTROL SYSTEMS OF FORSMARK 1&2 95
APPENDIX E: MODERNIZATION OF THE COMPUTERIZED INFORMATION SYSTEMS (CISS) AT THE TIHANGE NUCLEAR SITE 105

REFERENCES 111

TERMINOLOGY 115

CONTRIBUTORS TO DRAFTING AND REVIEW 117

SUMMARY

There are many reasons why I&C systems need to be modernized in nuclear power plants, including obsolescence, results of aging technology, failure rates, and the need for additional functionality and improved performance. For many plants, I&C modernization will be one of the largest and most important activities over the next decade or longer. Modernization of I&C systems will represent a major capital investment for the plants in the future. Therefore, good and informed management to determine what needs to be modernized, how it should be modernized, and then to do the actual modernization is essential in order to minimize the costs and maximize the benefits. While many reports have discussed I&C modernization topics, one topic that needs more work is how to management I&C modernization projects efficiently.

In order to have an efficient modernization project, it is essential that the plant does strategic planning to determine what needs to be done with I&C systems in the context of the overall plant goals, objectives, and commitments. This includes determining what features the the overall I&C, and control room, of the plant should look like at the end of the time period considered by the strategic planning effort, what systems need to be modernized, what systems can be maintained, the priority order of the systems to be modernized, how the systems should be modernized, and so on. To ensure that the individual I&C and control room modernization projects are done consistently with the strategic plan and the overall plant goals, objectives, and commitments, it is important that management establishes a set of plant specific guidelines and generic requirements and processes that the project will need to follow and that can be used as part of the requirements specifications for the new systems.

High level management leadership and support is needed for I&C modernization in order to maintain the high level, plant-wide perspective needed to initiate and foster the development of these strategic plans, plant specific guidelines and generic requirements and processes, and to ensure that individual I&C modernization projects conform to them. High level management is also essential for providing adequate resources for successful projects in terms of both people and finances. High level management attention is also necessary to define and assure proper interactions between the plant and regulators and suppliers. This attention is also essential to make sure that all stakeholders for a given project have input into the project.

A valuable input to I&C modernization project is information on I&C modernization activities in other plants around the world. This report is one example of information available that has been collected through a network of I&C specialists connected to IAEA. There are several benefits of using this kind of information to support new I&C modernization projects. This information may for instance help in anticipating future problems, check approaches and solutions that other plants have used, to identify reasons for successes and failures in I&C modernization projects, to establish contacts with other I&C modernization projects to exchange lessons learned, and to help in identifying good solutions and avoiding possible pitfalls.

1. INTRODUCTION

1.1. BACKGROUND

Nuclear power plants (NPPs) rely on instrumentation and control (I&C) systems for monitoring and display, for control, and for protection and accident mitigation. As seen in Figure 1, almost half of these nuclear power plants are at least 20 years old. A major concern in operating plants is their performance with respect to safety, reliability, and availability. Many nuclear power plants increased their availability factors by more than 10 percent over the last 10 years and are reaching respectable availability levels well above 80%. Modernization of I&C systems in nuclear power plants has been one of the important key factors in increasing plant availability. I&C systems will need to play an even more substantial role in increasing the availability of nuclear power plants to even higher levels in the future. This will require modernization of many of the existing I&C systems to those with better performance and increased functional capabilities.

Most existing I&C systems in nuclear power plants throughout the world were built with analog equipment and relays that were designed 30 to 50 years ago. This is true even for the plants that are considerably younger than 30 years old. A majority of the plants are still operating with a substantial fraction of this originally designed I&C equipment. To increase availability and enhance the safety, many utilities are considering the modernization of some or all of their I&C systems in their nuclear power plants. Digital systems will be the dominant technology for this modernization. Examples of this can be seen in Eastern Europe. It has been reported that modernization activities of some WWER plants have been successfully carried out. This represents one of the most difficult tasks performed by the nuclear industry in Eastern European Countries in recent years.

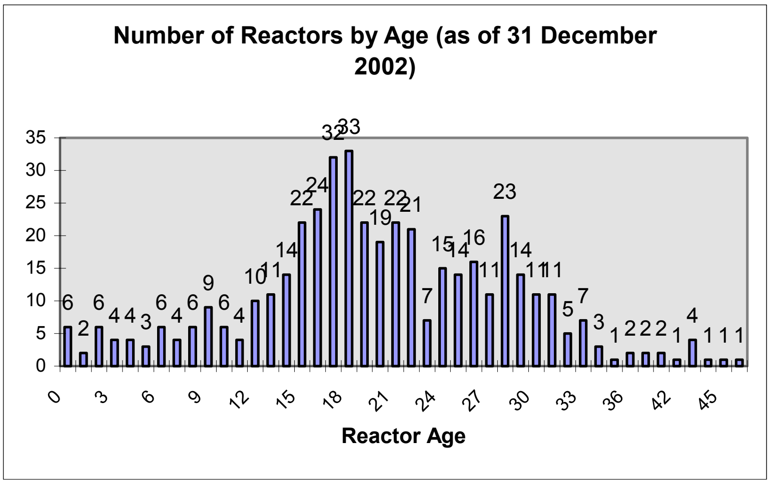

FIG. 1. Number of reactors in operation.

There are several reasons for considering the modernization of some or all of these I&C systems in a nuclear power plant. Obsolescence is a major consideration. This can result from causes such as lack of spare parts, lack of supplier support (or even the loss of the supplier to the nuclear industry), and the lack of functional capabilities needed to satisfy current and future needs. Aging of the I&C systems is another consideration which leads to difficulties such as degrading reliability and availability, increasing costs to maintain acceptable performance, and the lack of experienced staff for maintenance and engineering. A very important consideration to determine if a system needs to be modernized is its performance. If the system has a high failure rate, especially if the consequences of the failure are unacceptable or undesirable or unnecessarily challenge the protection systems, then it should be high on the priority list for modernization. In addition, the need for higher and higher reliability and availability may require the capabilities of new technology that are not possible or practical with the older technology.

I&C modernization is required for many plants due to the need for performance improvements or to address new safety requirements. License renewal, which adds at least 20 years onto the operational life of the plant, makes the likelihood of modernization even higher since the existing I&C equipment and supporting architecture will not provide acceptable service to the end of the extended life of the plant. Deregulation and competition have added additional pressures for improved operation, which in turn leads to a greater need for modernization to decrease operation and maintenance (O&M) costs and to increase performance of both the system and its user. Added functionality of new systems, such as self testing, self diagnostics, on-line monitoring, and fault tolerance and fault recovery, as well as increased accuracy allowing reduction in uncertainty margins, support cost reduction, increased reliability, improved performance, and enhanced safety.

During modernization project, there is the opportunity to standardize on types of equipment and processes. This can reduce maintenance training and maintenance activities as well as the amount of spare parts. It may also lead to fewer human errors since there are fewer types of equipment with their inherent differences. It can also facilitate the integration of systems and information.

Finally, the staff at many nuclear power plants is aging. This means that the people with the expertise on the existing systems are disappearing and it is difficult to find new staff with the expertise to support the older technology of the existing systems. In addition, it is very difficult to find young people who are willing to learn about and work on old technology. This is not the technology they learned about in school, and working with old technology is not considered a good path for advancement. Modern technology and interesting challenges are necessary in order to attract bright young people to the nuclear industry.

Due to the issues and needs discussed above, I&C modernization for most plants is necessary, and most likely will be necessary for almost all plants at some point during their lifetime. In fact, depending on the remaining lifetime of the plant, modernization may occur more than once. However, to perform cost-effective modernization programmes and to achieve the desired benefits requires good project management and good, well-informed decisions. For example, Nuclear Engineering International (NEI) pointed out that “The key lesson from all the VVER (WWER) upgrade success of a modernization project is hardly threatened by issues of a technical nature. Instead, what really plays a decisive role is whether tasks and people can be managed effectively using efficient paths of communication” [1].

This report is designed to provide guidance and good practices for effective management of an I&C modernization programme. This includes the determination of what systems should be modernized to address issues of obsolescence, staff reductions, and changing safety requirements; as well as the needs for reducing O&M costs, improving system and human performance, and increasing system functionality.

1.2. OVERALL OBJECTIVE

The overall objective of this report is to facilitate the cost effective implementation of new (most likely software-based) I&C systems in nuclear power plants. This is necessary to address obsolescence issues, to introduce new beneficial functionality, and to improve overall performance of the plant and staff. Non-nuclear industries have, in general, already made the change in technology from analog (hard-wired) to digital (software-based). The same technology, and accompanying techniques to implement it, is being introduced now into more and more nuclear power plants for both safety and safety-relevant applications. Effective management experience and lessons learned from these other industries need to be collected and used as appropriate for more cost effective modernization of I&C systems in nuclear power plants. However, the nuclear industry has some unique requirements that must also be addressed cost effectively.

To successfully implement new I&C systems, it is necessary that the safe operation of such systems in nuclear power plants has to be proven during the licensing process in order to gain the acceptance of licensing authorities, as well as acceptance in the plant itself. Effective management to meet the required high quality of the assessment of the nuclear power plant I&C systems within acceptable costs is needed.

1.3. SCOPE

The scope of this report covers all of the management activities related to modernization of I&C systems in nuclear power plants. It is written to support utilities, suppliers/vendors, architect engineers, consultants, and other third party groups participating in a modernization project. This report's scope includes the evaluation of all I&C systems to determine which can be successfully maintained at this time and which need to be modernized. This evaluation needs to be made periodically so that the decisions are appropriate for the current status of the systems and the plant's goals, objectives, and commitments.

The scope of this report includes two different approaches to I&C modernization. The first is incremental modernization of I&C systems over several outages with the intent to minimize the impact on the plant availability. In fact in many cases, the plant constraint is to perform the modernization activities within the planned durations of existing refueling outages.

This requires substantial management effort to co-ordinate the activities over the several outages, to effectively perform the modernization activities during the outage, to perform as much work as possible while the plant is at power, to plan activities and provide the necessary resources to make sure that they are completed within the outage, and to make sure that the plant is completely operable and performing as desired after each step of the modernization programme.

This latter is critical for two reasons. First, the plant must always operate safely and economically. Second, funding and other resources may change so that what was originally planned as an intermediate step in the modernization programme may become the final step, at least for long period of time if not for the rest of the life of the plant. In addition, this approach will almost certainly require intermediate fixes that will have to be later removed when more of the modernization is completed. These intermediate fixes will most likely increase the over all cost of the modernization, increase regulatory interactions, and increase training needs.

The second approach is to determine which I&C systems and infrastructure (networks, protocols, computing equipment platforms, process equipment platforms, etc.) need to be modernized and then shut the plant down for as long as it takes to accomplish the planned I&C modernization activities. This approach does not require the substantial management effort to co-ordinate the activities over many outages or to make sure that all of the systems continue to work together for successful plant operation during the intermediate stages of the modernization programme. However, it still requires substantial management effort to complete the modernization cost effectively. Due to the needs for high availability of the plant in most situations, this approach will probably not be used nearly as often as the incremental I&C modernization approach.

The scope of this report includes large, comprehensive modernization programmes that will modernize a large number of I&C systems, and small modernization programmes that will modernize a very few (perhaps only one) I&C systems, and all of the possibilities in between. The scope includes highly integrated systems and projects, as well as stand-alone systems and projects.

1.4. RELATIONSHIP TO OTHER WORK

The effective management of I&C modernization projects, which is the topic of this report, is closely related to several existing IAEA reports. These include reports on I&C systems and their modernization in nuclear power plants [2–5]. They also include reports on processes that are required during I&C modernization projects [6–12].

This report does not repeat the information provided by these referenced reports, but instead focuses on the management aspects and decisions related to I&C modernization projects. For more details on these other aspects of I&C modernization, readers should refer to the above reports.

1.5. READERS AND USERS OF THIS PUBLICATION

The readers and users of this report are expected to be managers of various levels who will be making decisions related to I&C modernization activities at the plant including: whether modernization is appropriate, enabling I&C modernization projects, providing the resources for I&C modernization, and managing the actual I&C modernization project. This report will help management develop processes to identify what systems can be maintained and which systems should be modified. It will identify management responsibilities during the project preparation and feasibility study phase, the project initiation phase, the project design and development phases, and the project testing, installation and operation phases. This report will also be useful to the team members of I&C modernization projects to improve their understanding of the management requirements and expectations.

1.6. SUMMARY/CONTENT OF REMAINING CHAPTERS

Chapter 2 describes the management leadership and support roles for an effective and successful I&C modernization programme. Chapter 3 describes the motivations that drive

I&C modernization and the types of planning required to move the I&C modernization projects forward. Chapter 4 discusses the project preparation activities, including the modernization feasibility study. Chapter 5 describes the project implementation activities needed to initiate the project and the associated planning including models for cooperation between the utilities, suppliers and third party contractors. Chapter 6 describes effective project management activities during the execution of the project. Chapter 7 gives lessons learned and experience gained from I&C modernization projects. Chapter 8 gives conclusions and recommendations. This is followed by the terminology used in this report. There are five appendices. One gives an example of a questionnaire that could be used for obtaining information for the proposed database described in appendix B. Appendix B defines the requirements for a database that could be put together to help provide information on I&C modernization activities at other plants.

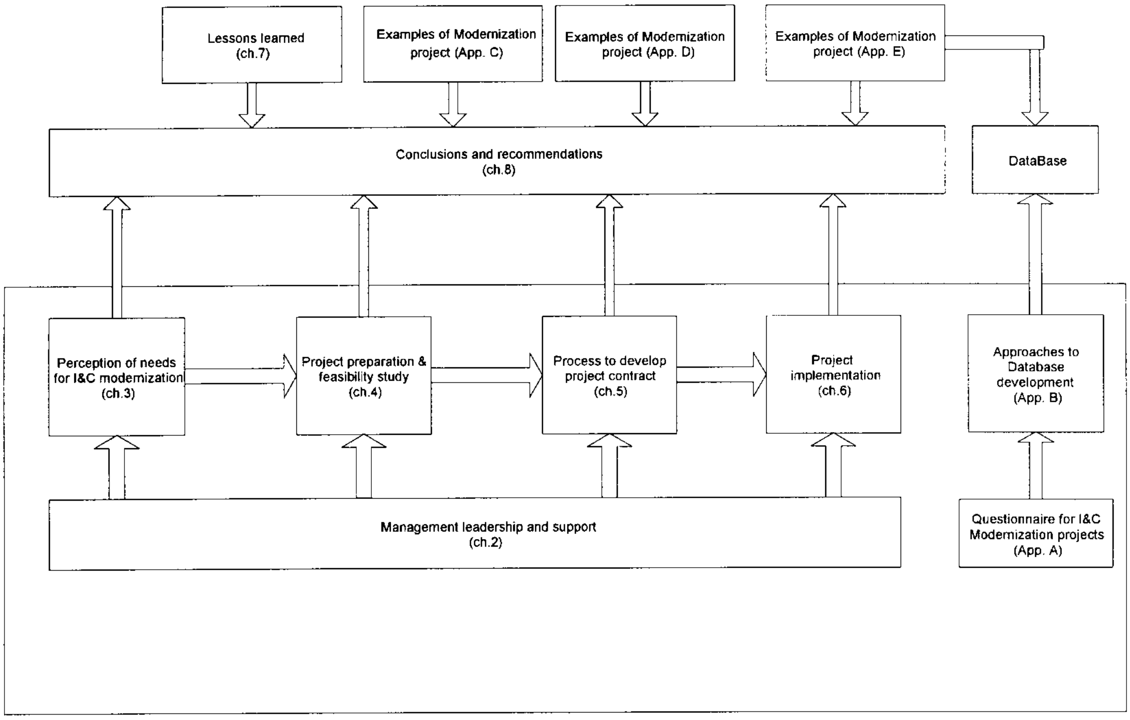

FIG. 2. Basic relational structure of the main text.

The others include papers on modernization projects at various nuclear power plants including some presented at the IAEA Specialists Meeting on Effective Management of Nuclear Power Plant Instrumentation and Control Modernization Projects Including Development of a Database in Garching, Germany 29 October–2 November 2001.

The basic relational structure of the main body of this report (Chapters 2–7) is shown in Figure 2.

2. MANAGEMENT LEADERSHIP AND SUPPORT

2.1. MANAGER RESPONSIBILITY

2.1.1. Management support

Good, knowledgeable, and actively involved management is essential for the success of I&C modernization projects. This must start at the top of the organization. It is important that there is a high level manager who understands I&C and its needs and concerns. This manager can act as a well-informed champion and sponsor for the I&C modernization activities. In most plants this has been a problem since very few members of upper management have started their professional careers in I&C. In addition, due to the talent and ingenuity of I&C engineers and technicians, I&C has not been a major problem for plants in the past compared to other areas such as steam generators, erosion corrosion, and active components such as pumps and valves. Due to obsolescence and the economic drivers for improved performance, I&C has now become a major concern for the plant. However, many I&C engineers have reported that it is difficult to get modernization projects started because there is not high level manager to help push the project forward.

Virtually all operating nuclear power plants will eventually depend on modernized I&C systems to maintain or improve availability, reliability, safety, and efficiency. This will need to be accomplished while minimizing operations and maintenance costs. The modernized I&C systems will allow the plant to take advantage of the on-line monitoring, self testing, self diagnostics, fault tolerance, information processing, improved human-system interfaces, and higher accuracy capabilities of the new technology. However, to make that happen effectively, preparatory work needs to be done. This preparatory work, which is done in response to the overall needs of the plant and not for a specific system only, requires the guidance and support of high level management.

2.1.2. Strategic planning

For most (perhaps all) utilities, it will be necessary to designate an I&C champion who is knowledgeable about I&C and who will be the guiding light for I&C activities. This champion must be sufficiently high in the management chain to be able to keep a focus on the long term goals, without being diverted by the day-to-day problems. Under this champion's leadership, strategic plans should be developed that will guide the transition from the present state of the I&C equipment in the plant to the future vision for the I&C equipment. This future vision must support the overall plant goals, objectives, and commitments.

These strategic plans for the modernization of the I&C systems in the plant may be done using one of two approaches. The first approach is the one where the plant does the strategic plan itself or with third party contractor support. Based on the results of the strategic plan, the plant creates detailed requirements and goes out for requests for bids to do the modernization work. After the supplier is chosen, the utility and the supplier iterate on the requirements to find the best way to meet the plant’s needs with the available equipment of the supplier.

A second approach is the one where the utility puts together some high level requirements for the plant. They then go out for requests for bids. The supplier does a detailed evaluation to determine how they can meet the plant’s high level requirements. The utility selects a supplier and then the utility and supplier iterate on the requirements to find the best way to meet the plant's needs with the available equipment of the selected supplier.

No matter which of the above approaches is used, there will probably have to be compromises since the supplier's equipment will most likely not meet all of the plant's requirements without substantial costs to modify the supplier's equipment. The goal of the iteration is to maximize the amount of requirements met with the minimum of additional costs for modifying the supplier's equipment, or at least to achieve a mutual understanding of the need for additional costs and/or the requirements not met. The second benefit of the iteration is that the supplier knows exactly what the utility wants and the utility knows exacting what the supplier will be providing. This eliminates unpleasant surprises that have frequently occurred in the past when a utility gives the supplier a set of requirements and the supplier then provides the product that meets the requirements as best as possible within the constraints of the supplier's equipment's capabilities and the financial resources available. The other possibility of a surprise is that the product does meet the requirements exactly but the cost of it increased substantially.

2.1.3. Plant I&C endpoint vision planning

The endpoint definition of the I&C systems, equipment, architecture, etc. (i.e., the future vision) at the end of the modernization programme for a plant is plant specific. It can range over a large spectrum of possibilities. At one end there could be one or more stand-alone projects without any attempt to integrate the systems or the information related to them. It could consist of a small modernization programme where only a few systems are modernized and they are done in a consistent manner. It could consist of a large, comprehensive modernization of all of the I&C systems in the plant. Or it could be anywhere on a continuum between these last two possibilities. Whatever the level of modernization, the new systems should be controlled and monitored in a consistent way, which means that the same look-and-feel for the operator should exist. This is true independent of which valve or other process component is to be maneuvered. To accomplish this, initial strategic planning is essential. Due to the importance of this common look-and-feel for the operator (and this also applies, when relevant, to engineering and maintenance staff) to reduce the likelihood of an error or lack of timely response, it may be desirable to put the same look-and-feel in the interfaces to the older equipment, when possible, even though the older equipment is not being modernized.

2.1.4. Design and implementation guidance

To reach the goal of uniform behavior from the operator's and/or maintenance staff's point-of-view, it is essential that during the first stage of a modernization, design rules are established to give the designers prerequisites on how to design and standardize the modernized I&C system. For example, consider the interfaces to control a certain type of pumps, fans, valves and so on. It is important to make sure that the control interfaces for each of these types of equipment are standardized during the modernization process.

It may be impractical to develop the detailed design rules for all of the proposed modernized systems at the beginning of the modernization programme. Therefore, it is important to develop a set of fundamental design rules that must be satisfied by all modernized systems. Then as a specific system is to be modernized, the fundamental design rules should be followed and supplemented as needed. For example, if new technology is available and beneficial for the system, then there will probably need to be new design rules related to the new technology. An example of this is that there may be design rules to satisfy current electromagnetic compatibility (EMC) testing requirements. However, if wireless technology is implemented that has frequencies outside the original EMC testing requirements range, new rules may be needed to satisfy the new requirements at higher frequencies. All new rules should be made common knowledge throughout the utility. It is also essential that the designers be trained on the new rules to make sure that they understand them and implement them correctly.

Decisions are needed up front on the level of standardization of equipment to be used for I&C systems. One approach is to standardize on the minimum number of types of equipment possible. This can make it easier for operations, maintenance, and training; as well as reduce spare parts requirements. This facilitates common interfaces and interconnections. An alternative approach is to not standardize on the equipment used for the systems, but rather to go for the best in class for each system. In this case, it is important to require that the systems conform to standardized interfaces and protocols.

It is critical to get the acceptance by the end user of the system. Involving the end user in the beginning phases of the project is a good way to do this. The person putting together the requirements specification should interface with the end user to make sure that the requirements reflect the end user's needs, desires, and capabilities. The same is true for the designer to assure that the system that will result from the design is what the end user needs and wants.

The additional functionality of digital technology and the integration capabilities of digital systems and information should be evaluated to determine if they are beneficial for the system. The often used practice of replacing an old system with a new digital system with exactly the same functionality may not be the best approach for the plant. Adding unnecessary functionality does not make sense. It adds to the cost and can potentially lead to errors. However, adding additional functionality that is needed or that can be used to do the job better should be done. An example might be to add task oriented displays that include all of the information needed to perform a particular task. It could also include information from other systems that might be affected during the task. Another example is to include self-testing and self-diagnostics capabilities to increase reliability. The impact of new functional capabilities should be thoroughly evaluated.

2.1.5. Monolithic versus incremental modernization strategy

The plant must determine whether it is more desirable to shutdown the plant for the required time to do the complete I&C modernization programme (monolithic approach) or to do the I&C modernization programme incrementally over several planned refueling outages (incremental approach). This will be a plant specific decision based on plant specific factors and requirements. The strategic plans developed must support the implementation approach selected by the plant. When the incremental approach is used, the strategic plans must allow incremental changes and upgrades on a system-by-system basis, but they must also ensure that the various systems function together on an integrated basis, that the data communication architecture can support the long term needs of the plant, that the plant standardizes on a limited set of selected platforms where it makes economic sense to do so, and that the plant staff and processes are adequately prepared. It is also critical to make sure that there are adequate people and financial resources for the programme to succeed. A frequent problem is that not enough people resources are available.

When the incremental approach is selected, a migration path (definition of the order of the systems to be modernized) should be developed. After the appropriate modernization activities (systems to be replaced and upgraded and new systems to be implemented to achieve the future vision) have been determined, the activities must be carried out in the correct order to maximize benefits, address urgent needs and requirements, and support the vision for the plant. This order will be determined not only by the I&C systems being modernized, but also by taking into account the interfaces to the systems, and concurrent existing projects which may impact the I&C systems. Relevant activities, such as operating and maintenance staff training, control room changes, and plant simulator upgrades for the modernized systems must be taken into account. The determination of the correct order will prioritize the modernization activities to achieve the plant vision. Based on these priorities, and the plant policies and internal and external requirements, a long term plan (migration path) is established to implement the decisions. This migration path needs to be flexible enough to allow for changes as may be required in the future.

For either modernization implementation approach, the strategic plans must take into account the digital system obsolescence cycle that is normally shorter than the obsolescence cycle of the analog systems in the past. The strategic plans should incorporate requirements/ approaches/ conditions that will more easily allow for future upward compatibility for the digital systems. These include defining a standard set of interface protocols for the systems, long term agreements for equipment and spare parts, and the architecture to facilitate future modernization activities.

2.1.6. Control room modernization planning

A critical aspect for an I&C modernization programme is the strategic plan for the control room. For both the incremental and monolithic approaches to I&C modernization of the plant, the endpoint vision for the control room and the operational concepts must be determined. The endpoint vision of the control room includes the configuration, the functional capabilities, the display types, the level of automation, types of electronic procedures, color and symbols to be used, alarm schemes and presentation, etc. of the control room. The operational concepts include how the plant is operated under normal conditions, how it is operated under abnormal conditions including loss of equipment or displays, how the operators are expected to interface with each other, etc. For both the endpoint vision and the operational concepts, it is critical that the human cognitive capabilities are considered and that good human factors practices are included. In the monolithic approach, it is assumed that the control room will go from its original state to the planned state in one step. The new control room may be a combination of analog and digital equipment and interfaces (hybrid control room), or it may be totally digital. In the incremental approach, the control room is modified over several outages so that at each step it will be a hybrid control room. After the last step in the incremental modernization programme, the control room may be either hybrid or fully digital. In either case, it is necessary to develop a migration plan for the control room to identify what is to be changed during each step. It is very important that the human cognitive capabilities and human factors knowledge is used to help determine the migration path. An example of guidance for control room planning is given in an EPRI report [13].

2.1.7. Strategic planning flexibility and expandability

The strategic plan, when the incremental modernization approach is selected, includes the endpoint visions and migration paths for the I&C systems and the control room. This strategic plan covers a planning horizon of several years, the number of years depending on the length of time for which the utility has selected to be the endpoint for the planning. The strategic plan needs to reflect the plant's goals, objectives, commitments, and resources. The plan also needs to reflect the existing condition of the I&C systems and control room. Since some or all of these are likely to change over the planning horizon of the strategic plan, it is essential to periodically revisit the plan and update it to reflect the current situation. For example, seven years into the twenty year planning period, the feedwater control system becomes highly unreliable and causes several plant trips. Originally, it was thought that this system did not need to be modernized. However, due to the new, unexpected problems with the system, it becomes very important to modernize the feedwater system as quickly as possible. Therefore, the endpoint vision and migration path in the strategic plan must be changed.

In order to minimize the impact on the plant when the conditions change, it is important to make the endpoint vision and migration path for both the I&C systems and the control room flexible and expandable. This means that the strategic plan, including the endpoint vision and migration path, is developed in a way that facilitates future changes in it. The objective is to accommodate changes in the plan to address new needs with minimal impact on the modernization activities already done, as well as future activities in the plan not modified by the new needs. This includes minimizing the need for rework and special interfaces.

2.1.8. Strategic alliances between the utility and the supplier

A new approach that is currently being tried by some utilities is to develop a strategic alliance between the utility and the supplier. This so-called Strategic Alliance Model approach (described in Section 5.6) to contracting I&C modernization activities shares the risks and the benefits between the utility and the supplier. This model places emphasis on joint planning and teamwork between the utility and the supplier from the beginning of the modernization programme to the end of it. It is changing substantially the way modernization projects are contracted, planned, and managed.

2.2. CORPORATE KNOWLEDGE AND STAFF RESOURCES

The I&C champion must also be the leader to ensure that adequate resources are available to successfully achieve the goals of I&C modernization projects. Financial resources are one part of that, but another aspect, that is critical and becoming harder to satisfy, is to ensure that adequate staff members, with the correct type of knowledge to perform the I&C modernization requirements, are available. In most plants, where I&C modernization is needed, the I&C staff is aging along with the systems and is either being promoted to other jobs or is retiring. The latter case is becoming more and more prevalent in the nuclear industry both for the utilities and the suppliers. In many cases, as these staff members leave, a substantial amount of the corporate expertise on the existing systems and their design bases disappears. Newer staff members do not have this same level of expertise, which hinders their ability to efficiently support I&C equipment and the modernization efforts in the plant. Hiring knowledgeable suppliers or third party contractors may not be a possible or desirable solution for three reasons. First, there may not be any knowledgeable suppliers or third party contractors for the plant systems. Second, there may be substantial competition for the supplier's or third party contractor's time making the price for them very high. Third, hiring suppliers or third party contractors to do the work does not add to the corporate knowledge of the plant and; hence, perpetuates the lack of knowledgeable plant staff. Therefore, it is important for management to develop programmes to capture and pass on the expertise of the departing staff before they leave the job. It is also important to make the job attractive enough to attract new staff.

When the modernization activities are planned and scheduled, management must make sure that adequate staff members with the correct knowledge and skills are available. This may require appropriate training courses and mentoring activities ahead of time to support the required activities.

Another concern with staff members is their performance as they are being asked to do more things in shorter periods of time. In addition, they are expected to do a wider variety of things. Outages, in general, are becoming shorter in length and for most plants the I&C modernization activities must be done within the scheduled outage time. This leads to longer working hours, which can lead to increased human errors if not managed correctly. Another aspect of the need to implement I&C systems without extending the planned outage time is that more work must be done while the plant is operating at power. Staff must be well trained not to make errors that could lead to an unanticipated trip of the plant. In some cases, the old and new system may be hooked up in parallel, which brings its own special circumstances and concerns.

The I&C champion must also develop a culture that all stakeholders (everyone who has an interest in the project such as users, systems engineers, maintainers, designers, trainers, etc.) of the project are represented in the project. This is essential for the success of an I&C modernization activity. For example, the buy-in (acceptance and ownership) by the plant operators is important for changes that impact how they operate the plant.

2.3. MANAGEMENT PLAN

A well-developed management plan allows the work to be done cost effectively with minimal risk. It describes the actions to be performed to achieve all specifications and requirements of the I&C modernization project. The main objectives of the management plan are to [10]:

- Meet objectives, specifications and requirements of the project,
- Assure that the project organization and the role of the individuals is doable and effective to achieve all of the project's objectives within the given constraints,
- Assure that the scope of all activities within the project (including reviewing, testing, training, etc.) is complete to achieve the project's goals,
- Ensure technical and professional qualification of the project team,
- Define activities to assure acceptance of the system,
- Define project management activities and management plan control from the start to the end of the project, and
- Ensure quality control and configuration control.

The management plan should include the following to meet these objectives:

- Project scope and objectives including management processes and interfaces,
- Project organization,
- Analysis and assessment processes for the project,
- Procedures to involve all of the stakeholders and gain their acceptance,

- Project schedules and resources,
- Quality control,
- Confidentiality practices,
- Metrics for acceptance,
- Risk management strategies,
- Resource planning and allocation,
- Training of staff for necessary skills,
- Technical interfaces between various groups on the project including the end users,
- Configuration control,
- Progress reporting, and
- End products.

3. PERCEPTION OF NEEDS FOR I&C MODERNIZATION

3.1. GENERAL GOALS, OBJECTIVES, COMMITMENTS OF THE PLANT

I&C modernization projects should be performed in the context of and in the support of the overall plant goals, objectives, and internal and external commitments. These commitments include those to licensing authorities, public, staff, and other stakeholders. The goals and objectives of the plant will be driven substantially by the utilities long term and short term business plans. The commitments will be established basically from external requirements and agreements. In the past, I&C systems have been modernized on a stand alone basis; that is one system at a time without consideration of the overall plant needs. Therefore, the modernization was accomplished by doing what was best for the specific system only, independent of its impact on other systems and other future modernization activities. This has led to several problems in the plant, even when the system itself has worked well. This approach has led to a proliferation of equipment types in the plant, increasing the need for training, staff, and spare parts. It has also led to islands of computing and information, which reduce efficiency and make integration of systems and information very difficult, as well as created unnecessary duplication of both functionality and data and the unnecessary associated work to maintain them. It can also lead to problems with maintaining consistent data since the same data may reside in several places.

High level management must establish the overall goals, objectives, and commitments for the plant. Then management must make these goals, objectives, and commitments known to the staff. Management must put into place plant specific guidelines, constraints, and processes to ensure that I&C modernization projects are done in a manner that is consistent with the plant goals, objectives, and commitments [14].

Examples of plant goals are to minimize the cost of producing power and to become a top performer plant in the world. Examples of plant objectives are to reduce the number of unplanned outages, to reduce the length of planned outages, and to increase plant availability. Examples of external plant commitments are agreements with and requirements from the nuclear licensing authorities and local governments (including satisfying the relevant laws), as well as with the public and the stockholders.

3.2. DEVELOPMENT OF PLANT SPECIFIC STRATEGIC PLANS AND GUIDELINES

3.2.1. Management Involvement

Management must authorize and support the development of plant specific strategic plans for I&C modernization, the development of plant specific guidelines and generic requirements to be followed by I&C modernization projects, and the establishment of plant specific processes to ensure that the I&C modernization projects are carried out in a manner consistent with these strategic plans and guidelines. These strategic plans, guidelines, and processes must all be consistent with the overall plant goals, objectives, and commitments described above. The development of these plant specific strategic plans (including feasibility studies) and guidelines requires substantial resources. Therefore, upper management must establish the need for them as well as the resources to develop them.

An important area for management guidance to the I&C modernization project is acceptable, consistent processes for determining both costs and benefits. Justification of a project is essential for getting approval to proceed. This is always a difficult activity, especially for the determination of the benefits. Guidance on what is an acceptable process to determine the benefits and the basis requirements to justify the proposed benefits would make it easier to determine them. The guidance would also help ensure consistency between projects so that it is easier for management to compare them and determine which to approve.

The strategic plans will establish what work needs to be done in the I&C modernization programme and the prioritization of the activities. The plant specific guidelines will establish how the work will be done. They can also be used for writing requirement specifications for I&C systems.

3.2.2. Infrastructure to support modernization

The infrastructure needed to support the modernization of I&C systems must be established so that it can support the plant goals, objectives, and commitments. This infrastructure consists of things to support the entire modernization programme over its expected life; such as the desired network configuration, amount and location of fiber optic cable, the types of computing platforms and process platforms that are acceptable to use, the acceptable set of protocols, and so on. This infrastructure should be designed such that the integration of systems is facilitated and it should put in place techniques to more easily support future modifications including those that may be required due to the faster life cycle of digital technology compared to that of older analog and relay technology.

Implementation of the appropriate infrastructure requires management guidance and backing since this is often a substantial cost effort, both in terms of determining the correct infrastructure and in implementing it, that needs to be part of the overall I&C modernization programme. This high level management perspective is often needed because it increases the cost of the first system implementation since the infrastructure has to be implemented as well as the system itself. However, having the infrastructure will allow future systems to be implemented more easily. It will also support system and information integration and remove islands of computation and information including unnecessary duplication of functionality and data.

3.2.3. Plant specific strategic plans and implementation guidance

An approach to reduce the cost and effort needed to develop plant specific strategic plans is to start with industry-accepted methodologies for these plans. Similarly, industry accepted guidelines, which in some cases may have been approved by the licensing authority, and regulatory generated guidelines can be used as a basis for the plant specific guidelines. Plant specific strategic plans are needed in several areas such as long term life cycle management that results in a feasibility study type plan, long term maintenance plans for systems that do not need to be modernized, modernization evaluation plans to determine the best way to modernize systems that need to be modernized, and the long term infrastructure plan to determine the correct networking, computing platforms, process platforms etc. to support the long term modernization plans.

Examples of methodologies to support strategic planning in these areas are given in EPRI reports [15–19]. Guidelines and requirements to support I&C modernization are needed in several areas such as licensing of digital systems, the process for developing requirements specifications, V&V, EMC testing, abnormal conditions and events analysis, evaluation and acceptance of commercially available digital equipment (or Commercial-off-the-shelf (COTS)), requirements for the qualification of process platforms for safety applications, and requirements for workstation architectures and interfaces. Examples of guidelines and requirements supporting I&C modernization in these areas are given in the EPRI reports [20 – 32]. Obviously, these are only one set of approaches that can be used.

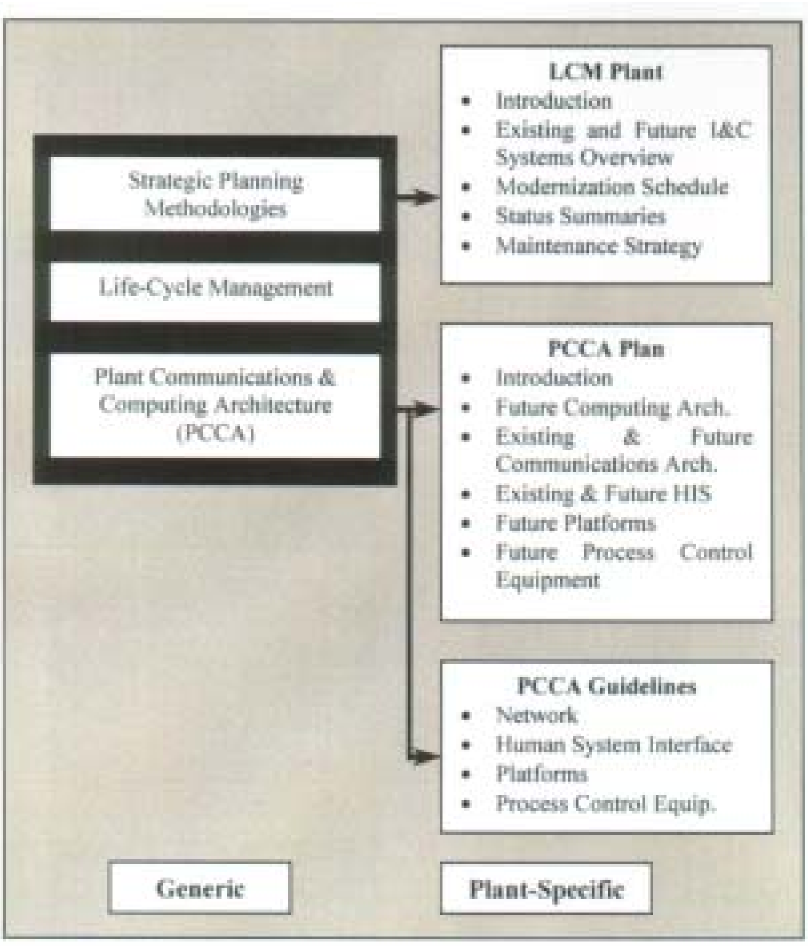

FIG. 4. Plant strategic planning relationships.

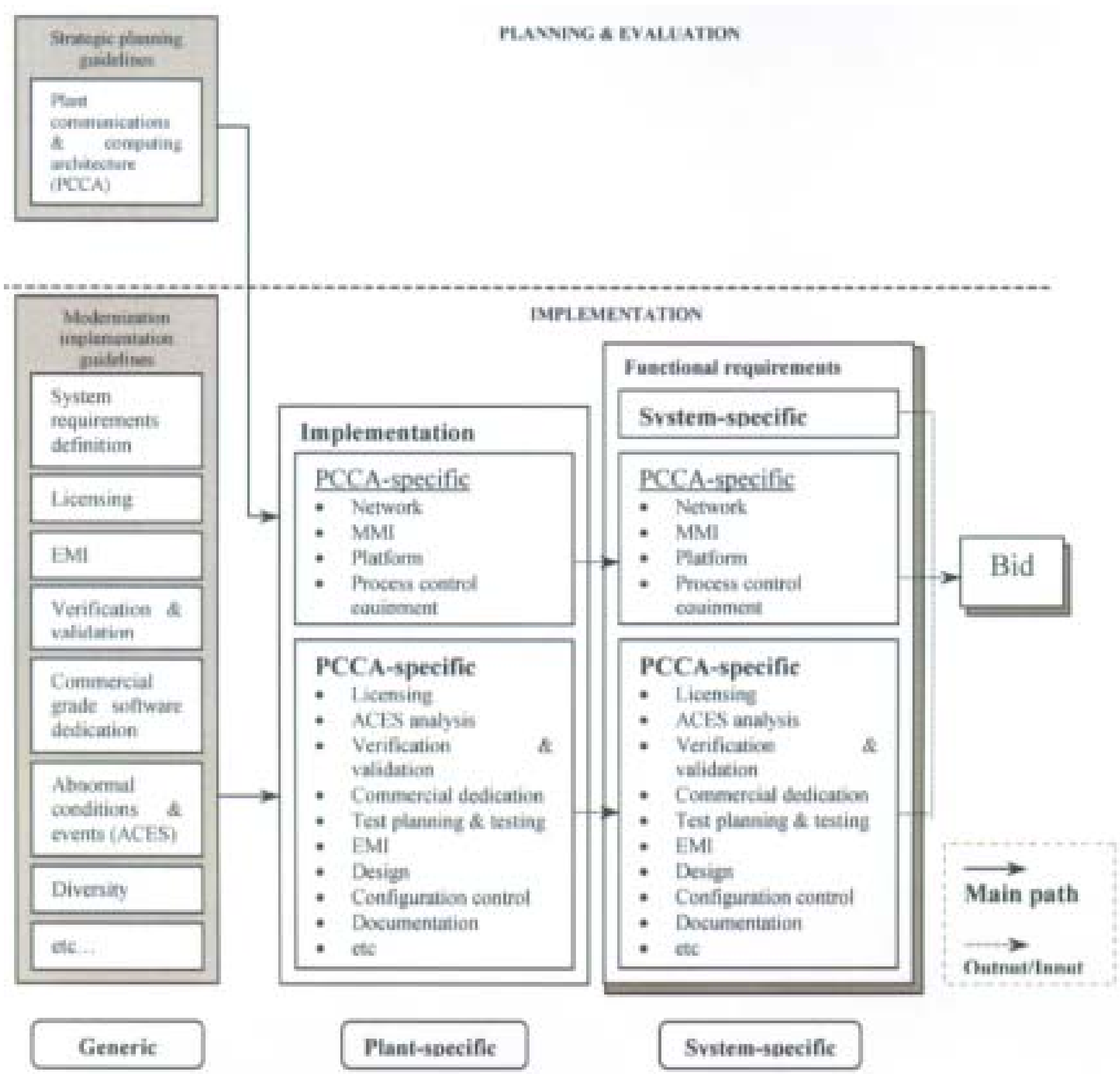

FIG. 5. Guideline and requirements relationships.

The relationship between the generic strategic planning methods, the plant specific plans, and the individual system maintenance plan or modernization evaluation report is shown in Figure 4. Figure 5 shows a similar relationship between generic guidelines and requirements, the plant specific guidelines and requirements, and the system requirements specification. Figure 6 shows the relationship between the generic evaluation methodology, the system specific evaluation report, and system specific requirements specification of system specific maintenance plan — whichever is the best approach for the system.

Even in the case where the utility provides only high level requirements and then sends out a request for bids, these plant specific guidelines and requirements are necessary. They are an integral part of the high level requirements since they define the acceptable way to do business in the plant. The supplier may take exception to some of them. However, it is then thoroughly understood by the plant and the supplier where these exceptions exist. It can be clearly determined if the proposed alternative is acceptable and should be used.

3.3. IDENTIFICATION OF ISSUES, NEEDS AND LIMITS WITH CURRENT I&C SYSTEMS

From the experience gained during nuclear power plant operation in the world, the following main drivers of I&C modernization can be identified:

- Aging of the equipment leading to failure rate increase, growing obsolescence problems including difficulties with spare parts procurement, increasing costs to maintain satisfactory performance and other problems with the operation and maintenance of plant systems (more detailed information is available in reference [33]);
- Need for functional extensions and enhancement to increase reliability and availability, to increase power output, to reduce likelihood of human errors, to meet new regulatory requirements (an example of this is the Safety Parameter Display System (SPDS) implementation), etc.;
- Deficiencies discovered in the I&C design by surveillance testing or by analysis of serious incidents and accidents (an example is the extensive modernization of RBMK control and protection systems after the Chernobyl accident).

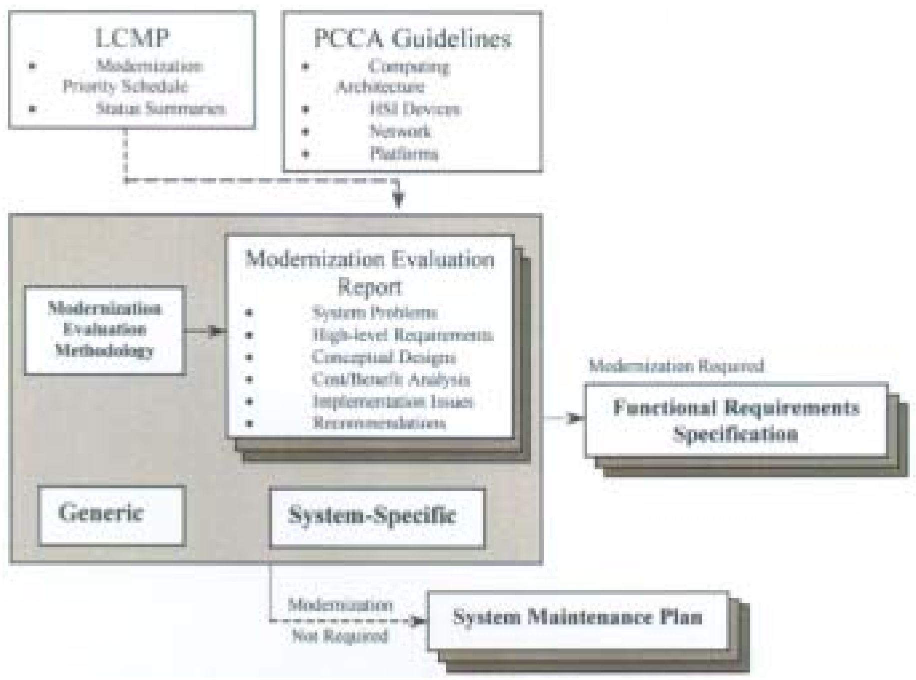

FIG. 6. Modernization evaluation relationships.

Before entering the modernization project, it is advisable to collect information on needs and limitations in the current I&C system. Such information can be found from the failures and incidents as collected by the event reporting and analysis system used at the plant. An effective system of event reporting and analysis can help identify and determine the significance of the failures caused by the aging of I&C systems and components. Other weaknesses can be identified from regular self-assessment of operational performance, including analysis of even small deviations from normal operation, see examples in reference [34].

All failures affecting safety functions, as well as failures causing trips or power reductions, should be thoroughly analyzed and prevented/removed as much as possible by the implementation of corrective measures. The nature of such failures (I&C or other equipment deficiencies, personnel errors, procedures inadequacy, etc.) must be identified to properly determine the corrective measures and make them effective.

To make the collection of operational experience efficient, plant managers are recommended to participate personally in the development of the plant's system on operational safety performance monitoring with the help of effective indicators, examples are presented in reference [35].

Many plants regularly analyze their operational experience feedback to develop plans based on the resulting assessments and forecasts that incorporated the feedback. Some of them have been very successful in using this feedback in the process of the decision making and some others have not been as successful (faced problems, carried extraordinary economical losses, etc.). This experience is very important for the plants that are still on the way of the decision making and for the plants that may face the same problem in the future.

Even in case of very reliable operation of the I&C systems, plant managers may find some significant capability or operational limits caused by the technology of the existing systems. This can also be a sufficient argument for starting the process of I&C modernization. For example, many units of different plants in the world (Comanche Peak, Olkiluoto, Paks, etc.) have significantly increased their rated power in recent years by achieving more accurate monitoring of important process parameters. Modernization of I&C through the use of modern digital technology allows this possibility, especially for those plants that are equipped by the I&C systems of the analog or limited digital designs.

3.4. FORECASTING PROBLEMS AND LIMITS IN THE NEAREST FUTURE

In addition to identifying current problems and limits with current I&C systems, the plant managers should also assess and attempt to foresee possible future problems and limits of the current I&C systems operation and maintenance. It is important to take into consideration in these assessments that the plant will be forced to continue to try to enhance safety, to increase reliability, availability and power output, to shorten outage time, and to reduce staff.

In general, it is not a simple task to make any adequate long term forecasts in the nuclear energy market. Besides pure technical issues there are many other aspects, like public opinion and political intention, which have to be taken into consideration. However, in some particular cases, such forecasts may be less difficult. For example, from market announcements it may be known that the commercial production of a certain type of I&C equipment, which is still being used in the plant, is going to end soon. In this particular case, it is very important to foresee coming problems with spare parts logistics, and increases in the cost of purchasing spare parts and maintenance. This will help define the remaining cost effective lifetime of the I&C equipment. This problem of the end of commercial production will occur sooner or later, and will lead to plant operation impacts with associated consequences.

This is an example of why plant managers should pay special attention to predicting problems that may need to be faced in the future from the current I&C design. This looking at future needs will help to get the modernization process started early enough so that the problem does not cause plant trips or equipment damage, or to provide the plant with the necessary amount of spare parts to maintain the current design during a pre-defined period of time.

3.5. BENEFITS OF ADOPTING NEW TECHNOLOGY

Modern digital technology has a wide variety of beneficial capabilities compared to analog technology. Therefore, in many cases doing a like for like replacement (just replicating the capabilities of the old system in the new technology) is not the best solution for the plant. When a new system is being implemented, the potential beneficial capabilities of the new technology should be evaluated to determine which are appropriate for inclusion into the system to achieve plant goals such as increased reliability, availability, power output, etc. The following provides a list of some of the important benefits that can be achieved with digital technology.

- **Measurement precision**: Digital instruments do not have the drift problems that are associated with analog instruments. It is also possible to use digital technology to more accurately measure parameters than was possible with analog technology.
- **Reduced equipment volume**: Digital technology has the ability to process a large amount of data in one processor enabling the reduction of the volume of the whole system.
- **Improved reliability**: Digital technology can be used to achieve higher system reliability, e.g., by including a redundant processor which is in a stand by state. In the case of a failure in the active system, the function of the system could be switched to the redundant standby processor with no interruption of the system function.
- **Simplification of fault detection**: Digital technology can incorporate self-testing and self-diagnosis for fault detection.
- **Complex function capability**: Digital technology can easily implement complex functions since software does not have the limitations hardware has since it is more versatile and does not require adding more and more components.
- **Adaptability and ease of modification**: Digital technology allows easy modification of existing algorithms and the incorporation of new capabilities in the system since the implementation is in software not hardware.
- **System monitoring capability**: Digital technology can easily incorporate self monitoring into a system so that it can observe its own performance.
- **Operator support**: Digital technology is easy to process all the data as long as the data are incorporated to the system so that modification of necessary information as appropriate to the operators is easily accomplished.
- **Installation ease**: Digital equipment is easy to be installed owing to reduction of number of cables through the uses of multiplexing, databuses, and fiber optics.
- **Self testing capability**: Digital technology can easily incorporate self testing functionality.
- **Simplification of cabling**: Digital equipment has a great advantage of reduction of cabling once all the necessary input are incorporated to the system.
- **Ease of system upgrading**: The system architecture of digital technology easily accommodates the further future version updates.
- **More attractive for young engineers**: Digital technology is current technology of interest to young engineers because they are familiar with it since it is the technology they learned about in school; therefore, it is very difficult to get new engineers to work

in nuclear power plants on analog technology which they do not understand and have no interest in.

- **Maintenance costs:** Maintenance costs for digital systems will soon be cheaper than maintenance costs of analog systems (price of digital technology going down, no offset setting, self-testing and self-diagnostics, etc.)

3.6. ISSUES TO CONSIDER IN TRANSFER FROM ANALOG TO DIGITAL TECHNOLOGY

Modernization of I&C will most likely involve a transfer from analog to digital systems, because of the advantages that can be obtained. There are still certain issues that should be understood in doing this transfer of technology in order not to introduce unnecessary problems in the modernization projects. Such issues are for example the following:

- **High development costs:** The development costs of new systems may be high due to V&V and licensing processes of software based safety systems that are expensive.
- **Software common mode failure risk:** Without suitable hardware and software architectures and proper development processes in the development of the new systems, there is a risk of introducing common mode failures through the software. This risk can be reduced through proper use of V&V and diversity.
- **Quantified assessment of reliability:** If a quantified assessment of the reliability is required for example for PSA purposes, it should be observed that it might be very difficult to come up with defendable reliability estimates for software based systems.
- **Retraining of operating and maintenance staff:** It should be observed that the new systems may introduce the need for new training and skills both in the operating and maintenance staff. On the other hand, these skills may be easier to find on the open market than skills in the old analog systems.
- **Absence of standards:** There is an emerging body of standards available for digital systems, but it may be difficult to match the old standards with the new ones. There also seems to be less international consensus among licensing bodies on how to treat digital systems [36].
- **Acceptance by regulatory bodies:** Experience has shown that national safety committees sometimes are reluctant about accepting that a computerized I&C system can guarantee safety.
- **Verification and validation:** Experience has shown that digital systems need a considerable amount of effort to ensure that they are working properly in all operational modes and that they are not exhibiting unintentional functionality in any operational mode.
- **Difficulty of identifying all possible defects:** Due to the complexity of digital software system, it is almost impossible to deliver a complete proof that they exhibit all intended and not any other functionality in the operational modes.
- **Short technological lifetimes:** Digital systems often exhibit rather short technological lifetimes. It may therefore be necessary to combat obsolescence more proactively when using digital systems as compared with the old analog systems.
- **Qualification of tools:** There are many computer based tools available for the design and V&V of digital systems. The benefit of these tools may, however, be reduced due to difficulty of proving that they are producing correct results.
- **Problems with staff acceptance and retraining:** The change of technology is sometimes considered to be very large and therefore it may be difficult to get

acceptance of the staff for the new systems. An early involvement of the staff in consideration does usually help in this regard.

3.7. DECISION TO INITIATE I&C MODERNIZATION ACTIVITIES

When growing problems with the continuation of the current I&C operation at the plant are reliably forecast, plant mangers must make the key decision to either start the modernization process or to maintain the current systems understanding the expected difficulties and anticipated increasing operations and maintenance costs to maintain acceptable performance.

The principle decision to initiate I&C modernization activities could be made based on the identification of the problems with current I&C system, from the expectation of problems in the future as a result of the plant manager's forecasts, or desired (needed) improvements for more cost effective operation. The decision to initiate the modernization activities has to be made by the managers after making a choice between modernization and further maintenance of the existing system by reviewing plant problems and needs.

An adequate assessment of the expected length of plant's remaining lifetime may have the crucial influence on the decision to be made. It is clear that in the extreme cases, the decision is obvious. For example, when it is definitely known that the unit will be shut down and decommissioned very soon there is no justification to modernize any of its significant systems, including I&C. On the other hand, when the lifetime of the plant is extended through license renewal, and the existing systems can not continue to support the plant, the necessity to modernize the systems sometime before the end of the plant lifetime becomes obvious.

When the decision on the modernization of a system is not obvious, the experience from the other plants that have performed I&C modernization activities, preferably obtainable from a well-structured and well-maintained database, would be valuable. This experience information would support making decisions on specific system modernization including cost/benefit analysis, design and selection of equipment, licensing requirements, qualification methodology, and project management. Operations and maintenance experience from other plants or other projects would be especially important for determining the goals of the new system, the scope of the project, and the system's design.

3.8. ADVANTAGES AND DISADVANTAGES OF INCREMENTAL AND MONOLITHIC APPROACHES

The utility must make a decision between an incremental modernization approach where the planned I&C modernization is performed incrementally during several normal length planned outages or a monolithic approach where the planned I&C modernization is performed all at once during one extended outage. Obviously, the ideal situation is when the entire I&C modernization can be done within one normal length planned outage. However, this is highly unlikely for major I&C modernization programmes and will not be considered here.

There are advantages and disadvantages with the both the incremental and monolithic modernization approaches.

The main advantages with the incremental modernization approach are:

- The outage lengths are not extended past the normal planned length if the I&C modernization were not being done, this way the I&C modernization does not result in lost availability and days at power with the resulting lost revenue
- Smaller steps in the modernization process reduce the economic risk due to less investment binding, less risk of problems that may inadvertently prolong the outage, and less licensing risk at each outage
- The smaller projects of each outage are easier to manage both for utility and supplier, scope and specifications are limited and time and costs more predictable
- Lessons learned from the modernization activities done in earlier outages can be applied for next outage, continuous improvements can be obtained for both utility and supplier
- Technology improvements over the period of the modernization programme can be incorporated when beneficial

The main disadvantages with the incremental modernization approach are:

- Temporary interfaces and interface systems will most likely be necessary to keep new systems compatible with old systems increasing the implementation costs of the modernization programme
- The management of the modernization programme is more complex since it goes over several outages, and must ensure that each intermediate step is fully operational and can be the configuration of the I&C indefinitely if the resources for the future steps are not available
- The management of the interactions between the various steps in the modernization programme require more effort and longer term planning
- Potential human errors during operation and maintenance as the configuration of the plant, the equipment, and human–machine interfaces keep changing after every outage throughout the modernization programme
- Equipment (hardware and software) may change over the extent of the modernization steps so that the level of standardization is less than desired
- Operations and maintenance training is increased since the systems, equipment, and configurations change several times during the modernization programme
- Licensing efforts are increased since the intermediate “fixes” and configurations must be licensed when appropriate

The main advantages with the monolithic modernization approach are:

- Since the complete modernization programme is completed in one step, temporary interfaces and interface systems are not needed decreasing the implementation costs of the modernization programme
- The management of the modernization programme is simpler since it does not have to consider intermediate steps and the interaction between them
- Potential human errors during operation and maintenance should be less likely since there is only one step change in the configuration of the plant, the equipment, and human–machine interfaces
- The same versions of equipment (hardware and software) are used for the entire modernization creating a high level of standardization
- Operations and maintenance training for the changes is needed only once during the modernization programme

- Licensing efforts only need to address the final configuration of the modernization programme

The main disadvantages with the monolithic modernization approach are:

- The outage length for the implementation of the modernization is longer than normal outages resulting in lost availability and revenue
- The one step modernization programme increase the economic risk due to larger investment binding and increased potential of problems that may inadvertently prolong the outage
- The licensing risks may increase since the changes are bigger; however, since there are no intermediate fixes which may be harder to justify, the risks may be smaller
- The larger project is probably harder to manage both for utility and supplier, scope and specifications are larger and more complex and the time and costs are potentially more predictable

There is no “right” answer as to which modernization approach should be used, it is a plant specific decision. The utility must determine which approach is the correct one for its plant. The advantages and disadvantages listed above should be considered. However, other plant specific issues need to be considered as well. For example, there may be regulatory requirements that must be met before the plant can operate, in this case all of the changes required to meet the regulatory changes must be done in one step no matter how long the outage is. Another example is that there may be an extended outage to replace or fix other problems. If this extended outage is long enough, and the resources (both people and finances) are available, then it may be most effective for the plant to use the monolithic approach when, without this extended outage, it would have been best to use the incremental approach.

3.9. CONSIDERATIONS OF I&C MODERNIZATION APPROACHES

According to the type of modernization, internal and external circumstances, and available resources, different alternatives should be considered for each modernization approach. The topics below should be considered related to various aspects of modernization.

Regardless of the modernization approach selected, it is important for the plant manager to ensure that:

- The approach of the modernization is clearly defined;
- A responsible project manager, having enough authority and power, is appointed;
- Personnel can be trained on plant simulators;
- All the aspects of modernization are being carried out appropriately; including formation of the favorable social climate;
- Adequate resources are committed to the project.

3.9.1. I&C modernization scope

- **Full scope modernization:** This approach includes safety and safety-related systems such as reactor protection system, process instrumentation system, and control and monitoring systems for the primary and balance of plant. This also may include modernization of field instruments and main control room. As the size of the scope is relatively wide, it may require a longer modernization period, incremental implementation over several refueling outages, extensive engineering effort, training, and cost.

- **Few to several systems modernization:** This approach is to replace or upgrade existing stand-alone systems, which do not interfere substantially with other systems. Examples of such systems are monitoring systems and control systems such as main feed water pump control and turbine supervisory and control system.

3.9.2. I&C modernization functionality

- **Like-for-like replacement:** In this case the new system has the same functionality as the old system. The new system would be comprised of modern technology, but the technology would only be used for implementing the same functionality as the system it is replacing. Some new capabilities may come automatically with the new technology such as redundancy or a different interface, but the basic functions are the same.
- **Replacement with functional enhancement:** Digital technology brings with it the opportunity to implement additional functionality into the system, frequently with little additional effort, when it is beneficial for the plant to do so. Due to the potential benefits of functional extensions or enhancements (such as reliability and availability improvements or increased power output), I&C systems should be modernized with extra functionality compared to the existing systems. The management should always evaluate the advantages of the additional functionality before making the decision on what functionality to include in the new system in order to maximize the benefits gained from the new system.

3.9.3. I&C modernization operation methods

- **Parallel operation:** This is to add the new system into the plant and run it in parallel with the old system, usually for one cycle, in order to make sure that the new system is working properly before removing the old system. The new system could replace the old system whenever such a need arises. Testing is quite effective in this case due to easy comparison of output signals from the both systems, using the old well-validated system as the reference source.
- **Backup operation:** A new modern system may be added to backup the existing system to increase reliability. The role of the backup system is to monitor the performance of the old system and take over control actions when a failure of the old system occurs. The new system could replace the old system whenever such a need arises. In addition, the experience gained during the operation of the new system could provide familiarization of operations and maintenance personnel to the new systems and enhance the reliability of the plant and HMI. The organization of parallel operation of new and old systems may cause problems, but may also give an additional opportunity for new system testing. The main problems from such operation are mostly related to possible unplanned reactor trips and power reductions due to latent weaknesses in the system design/installation or interface (difficulties with switching over from one to another system). That is why plant simulator use at the first stage of new system implementation seems to be the optimal solution for parallel operation of new and old systems (confirmed by Paks NPP and other plants experience [37, 38]).

4. PROJECT PREPARATION AND FEASIBILITY STUDY

The manager's role in the phase of project preparation and feasibility study would be to recognize the current status of the I&C systems of the plant, and to structure a concrete justification for I&C modernization for the systems that need to be modernized. This chapter introduces one effective way of evaluating existing I&C systems and for prioritizing I&C systems for modernization. A number of approaches and justifications for I&C modernization are also discussed.

4.1. ORGANIZATION OF PROJECT PREPARATION TEAM / MANAGER

It is highly desirable to assign a dedicated team for the project preparation and feasibility studies. The team will decide if they want to do the feasibility studies either in-house or have them done by a supplier or third party contractor. An alternative would be to put together high level requirements and go out for bids for the modernization project without doing feasibility studies.

In the case of not performing feasibility studies, the utility can select a supplier based on proposals which should be based on the supplier's review and knowledge of plant systems. Then the utility and the supplier then iterate on the final modernization plan and negotiate the contract price based on the finalized scope. Chapter 5 describes an example of the case of cooperation between utility and supplier from the early stage of contract.

In the case of performing feasibility studies, the in-house team and/or a supplier will be responsible for evaluation of existing systems, prioritizations of system implementations and schedule, identification of systems goals, evaluation of modernization alternatives, definition of internal resource requirements, and justification to obtain additional resources. To be more effective, the team may consist of experts in cost/benefit analysis and budget planning, as well as I&C experts capable of evaluating existing systems in terms of reliability and of assessing the up to date technology in the industry and current licensing requirements.

4.2. EVALUATION OF EXISTING SYSTEMS

The results of detailed evaluations of existing I&C systems in terms of obsolescence, reliability, failure impacts, licensing requirements, and costs would form the bases of I&C modernization projects. These evaluations would be more effective when it is done periodically by the utility staff, because the obsolescence may increasingly occur and the reliability of the I&C systems would start decreasing. A detailed analysis process such as in reference [18], provides a technical approach for identifying problems and for developing reasonable modernization alternatives.

The matrix with the format of Table 4.1 provides a good example to figure out the system status. It would be helpful if the system status can be visualized for the prompt perception of modernization needs by performing this type of evaluation. The items listed in the table are just examples so that the items to be evaluated should be chosen according to their importance to the plant considering the needs of each project. The project manager is required to choose correct evaluation items.

The names of I&C systems of the plant can be listed in the left column and the degree of obsolescence, failure rates, and the impacts of failures can be inserted into the matrix provided using the following simple guidelines. The degree of obsolescence could be classified as ‘Already obsolete’ (Red), ‘Partly’ or ‘Expected’ (Yellow), and ‘Not obsolete’ (White). This classification could be done in more detailed manner, including the impact of spare parts, supplier supportability, and maintainability. The degree of failure rates could be classified as ‘High’ (Red), ‘Medium’ (Yellow), and ‘Low’ (White). This also can be more precisely classified according to the utility’s margin of tolerance. The degree of impact of failures namely in terms of availability and safety could also be classified as ‘Spurious Trip’ or ‘Inoperability of Safety Systems’ (Red), ‘Power Reductions’ (Yellow), ‘Entry into Technical Specification (TS) Operational Limits and Conditions (OLC)’ (Yellow), and ‘No immediate impact’ (White). The impact on plant availability and safety could be based on the previous failure history at the utility or on the industry experience.

For a more in depth evaluation, it is desirable to have a plant specific Failure Modes, Effects, and Criticality Analysis (FMECA) of the systems important to plant availability and safety. This will identify critical components that would initiate plant transients or spurious trips when a failure occurs. The results of the FMECA would be one of the most valuable pieces of information not only for the maintenance planning, such as to develop or revise preventive maintenance programme, but also for developing the long term strategic plan for modernization.

Table 1 Example of System Status Evaluation

System	Obsolescence	Failure Rates	Availability Impact	Safety Impact
Reactor Protection	Not Obsolete	Low	No	OLC
NSSS Control	Already Obsolete	High	Trip	OLC
BOP Control	Already Obsolete	High	Power Reduction	No
TG Control	Expected	Low	Power reduction	No
Plant Computer	Already Obsolete	High	No	OLC
Annunciator	Not Obsolete	Low	No	OLC
Misc. Monitoring	Already Obsolete	High	No	OLC
Local Instruments	Partly	Low	Power Reduction	OLC
MCR Instruments	Partly	High	Power Reduction	OLC

As shown on the example matrix, it can be easily identifiable that Nuclear Steam Supply System (NSSS) control system would become the top priority in terms of availability aspects. And the modernization of the NSSS control system looks to be highly desirable by this result. To make a decision of modernization priority, the available technology, resources, costs and benefits, and external requirements should be considered. This type of evaluation would facilitate, with appropriate variations in the level of detail, the determination of the priority, scope, and strategic maintenance planning. This availability and safety evaluation of existing I&C systems would be most effective when it is done periodically to reflect the changes of failure rates, obsolescence status, and spare parts status. Reference [33] provides more specific issues regarding the aging and obsolescence of I&C equipment.

4.3. PRIORITIZATION OF SYSTEM IMPLEMENTATIONS AND SCHEDULE

Once the evaluation is finished a list of I&C systems that require modernization could be obtained. For the effective use of available resources, it would be desirable to have a prioritized list of I&C systems for modernization including the scope. Again the prioritization process should consider available technology, resources, costs and benefits, and external requirements as well as the impact of obsolescence, failure rates, and the impact of failures.

Once the prioritization is done, the identification of the modernization goals for each of the selected I&C systems should be performed considering functionality, reliability, and licensing requirements. The basic requirements of the system goals should include enhanced performance, user-friendly HMI, user inputs especially from operations and maintenance, preferred technology, and position of the licensing authority as well as functionality of existing systems and reduction of O&M costs.

For plants with relatively high reliability, as expected in newer plants, it still will be beneficial if a long term strategic plan is established just as it is for plants having reliability problems.

When there are no pressing needs to modernize a safety system early in the modernization programme, it may be advantageous to modernize non safety I&C systems first and then move on to modernizing safety systems. The risks of using digital equipment in safety systems will probably be reduced in this situation because the operations and maintenance staff would be well-trained and less stressful to use digital equipment due to the experiences gained from the operation of non safety equipment. This approach may be beneficial and effective in obtaining experience in I&C system modernization which would be of assistance for the effective management of I&C systems in the future. However, if there is an immediate problem with a safety system, then it should be addressed early in the modernization programme.

It is advantageous to have a concrete plan for a standardized plant wide I&C infrastructure, such as platforms, networks, and protocols. This plan, available in earlier stage of the modernization process, will prevent a number of different systems operating in a plant. This has been proven to be extremely inefficient in terms of ease of maintenance, spare parts sharing, flexibility of information sharing, not to mention the lack of consistent technology for the operations and maintenance personnel.

One of the tasks to be determined in this stage of project preparation is identification of target time-scale for the project. Factors associated with this task would be scope of the project, priority of the modernization, cost plans, and external and internal interfacing requirements and constraints.

4.4. PROVISION OF RESOURCE REQUIREMENTS

As a next step, it is necessary to define the resource requirements. This should include the definition of the required technology; supplier, engineering and installation work force;

training; and time and budget for the project. This should also include the evaluation of whether such resources are readily available within and outside of the utility.

It is important that the following requirements and constraints are well defined and satisfied:

- Functional (e.g. needed and desired functions)
- Physical (e.g. available rack and cabling space and ventilation)
- Technological (e.g. available technology and its capabilities and limitations)
- Economic (e.g. available resource and pay back period)
- Safety (e.g. Technical Specifications and regulatory commitments)
- Versatility (e.g. flexibility and expandability)
- Human related (e.g. levels of automation and types of interfaces)
- Rapid life cycle (e.g. lifetime of equipment and technology)

4.5. THE MIGRATION PATH

For the most frequent situation, where the I&C modernization activities are to be performed in an incremental manner rather than in a monolithic manner, a migration path should be determined. Relevant activities, such as operating and maintenance staff training and plant simulator upgrades for the modernized systems, must be taken into account. Based on the plant policies and internal and external requirements, a long term plan is established to implement the decisions. This plan will lead to a schedule for the modernization of the identified systems. It needs to be flexible enough to allow for changes as may be required in the future.

The modernization plan, which describes the migration path, has to consider the interface boundaries between the I&C systems and components as well as the interfaces with other plant systems and equipment. The migration path should describe as thoroughly as possible all of the necessary incremental steps required to reach the final vision for the I&C systems. The incremental steps may consist of a few large steps or several smaller steps depending on the utility’s goals and constraints. At every step in the modernization process, it is essential that all systems, components, and equipment satisfy their interface requirements and are operational so that the plant can continue to operate effectively. The plan should include time for validating and documenting each step of the modernization activities.

The plan should also take into account the reality that new and old systems will have to coexist and perform as required. This coexistence can lead to both technological and human interface issues that must be addressed. It will also have to take into account, that for some systems where only parts of the system are modernized, that new and old equipment in the system will need to work together to ensure that the new and old equipment portions of the system really do work together as designed. For example, the new equipment may have higher levels of accuracy than the older equipment that represents the other part of the system. These differences could lead to unexpected results and should be determined and compensated for before the system is declared operational. In addition migration plan for the control room and for various documents including operating procedures and operator qualification should be established.

The migration path should also identify whether it is advantageous to have the old and the modernized system running in parallel in the plant. This would be done to verify the proper operation of the latter system before it is commissioned for operation in the plant.

When several plants are to be modernized in the same manner, it is recommended to choose one plant as the lead plant for the modernization. This plant can be used as a test plant to validate the modernizations before replicating them on the other plants.

4.6. JUSTIFICATION TO OBTAIN RESOURCES

Well-structured cost and benefit analysis is the key to making various decisions in I&C modernization. While identifying the cost is relatively straightforward, it is often quite complicated to quantify such expected benefits as enhanced safety and reliability, and improved HMI, which actually are major objectives of I&C modernization. Nonetheless, it is important to account for such benefits when performing the cost/benefit analysis. Still it is important that management recognize that some benefits can not be quantified but are very important for modernization decisions. Other hard to quantify benefits of I&C modernization include the difficulty in attracting new staff to work on old analog technology and the increased scrutiny of the plant by licensing authorities due to decreases in reliability. Even though these are hard to quantify they are still very important to the plant and need to be factored into the modernization decision. These hard, if not impossible, to quantify benefits but can actually be strong drivers for modernization projects. In fact, experience shows that issues like these are, in some cases, the major justifications that enable the modernization project.

The information required for decisions to achieve management goals usually starts from the practical limits of I&C system lifetime, which forms the basis for the quantitative cost and benefit analysis. Reference [39] describes this process. Such goals or benefits as improved core performance, increased plant availability, less regulatory burden, and life extension would require, or could be based on qualitative assessment rather than exact numbers. It is, of course, possible that more exact estimation of the benefits with figures of high confidence could be obtained utilizing the project team and available financial data.

One of the activities in the feasibility study is to define the scope of the project and to allocate potential responsibilities to the anticipated organization that would consist of utility, plant organization and its staff, architect-engineer, any project coordinating body, suppliers and any consultancy or specialist.

The results of this feasibility study should also include a detailed time schedule as well as the most effective approach for the plant between incremental and monolithic implementation because it may be necessary to procure sufficient services and material in time to meet major milestones.

Project preparation and feasibility study would be one of the most important phases for the effective management of I&C modernization project. This is to evaluate existing I&C systems in terms of obsolescence, failure rates, availability, and safety impacts of failures to produce prioritized lists of I&C systems that require modernization. Identification of system goals such as functionality, reliability, and licensing would then produce lists of potential alternatives of modernization. Experience from other plants that have done I&C modernization would be beneficial sources to decide the utility specific approach. With this project preparation and the feasibility studies along with internal staff and financial resources requirements, it would then be possible to shape solid justification to obtain further needed resources.

5. PROCESS TO DEVELOP PROJECT CONTRACT

This chapter describes the I&C system modernization process and activities starting in the time period between the approval of the modernization by the utility and the signing of the contract with the selected bidder. This part of the process may substantially influence the price and implementation terms. Considering the purpose and aims of report, the process is not described in all details, but attention will be drawn only to the areas, where the most problems have occurred.

5.1. INTERACTION WITH LICENSING AUTHORITY

It is extraordinary important to understand the requirements and guidelines from the licensing authority. It is important for the utility to interact early and often with the licensing authority and to be cooperative in order to obtain the necessary statements and permissions in time. It is the interest of the utility to disclose licensing related information and to provide all necessary supporting material to the licensing authority in a timely manner. Only the atmosphere of confidence and full frankness provides the prerequisites for the seamless progress of the licensing process without unnecessary delays and unexpected costs for additional documentation or even for additional modifications of the equipment.

The early interactions with the regulator will also make clear any expectations as soon as possible that may be contrary to the utility's plans. In this case the utility will be able to address those expectations as early as possible and present the case for its plans to the regulator in order to determine if the plans represent an acceptable alternative.

5.1.1. Determine necessity of licensing authority approvals

The utility should analyze and know the applicable laws and decrees to be able to define all activities, documents and materials that require approval. Documents for information purposes to support the licensing process should be submitted to the licensing authority as soon as possible during the modernization project.

The necessary documentation to be approved must be submitted to the licensing authority in time and with the required form and level of depth to improve the likelihood of timely response by licensing authority. The submitted documentation must be compiled with extreme care and high quality as an apparently negligible insufficiency may cause unexpected delay or may even be a cause for rejection of the modernized systems.

5.1.2. Initial interaction with licensing authority for agreement on applicable standards

Considerable attention has to be paid to the codes and standards, which are intended to be used for the I&C system modernization. In this area agreement between the utility and the licensing authority should be reached. Good understanding and rigorous application of the required standards and principles leads to very good results and shortens the time necessary for the licensing process. Early interactions are profitable also for the licensing authority, as it can enter to the modernization process from the beginning in an active way and obtain the background for the safety evaluation of the modernized I&C system. Different forms of interactions may be done, ranging from the participation of the licensing authority in the discussions, audits at the suppliers, to submission of specially generated documentation, such as topical reports. Discussions of engineering solutions to address the following areas should be included in the interactive process between the utility and licensing authority:

- Isolation
- Independence
- Defense-in-Depth concept
- Diversity
- Redundancy
- Common Mode Failure(CMF)
- Fault tolerance
- Single and multiple failures
- Fail safe design
- Electromagnetic Compatibility(EMC)
- Level of automation
- Verification and Validation(V&V)
- Human–Machine Interface (HMI)
- Testing (Factory acceptance test(FAT) and site acceptance test(SAT), etc)
- Equipment qualification (EQ) (seismic, heat, vibration, humidity, etc.)
- Safety analysis and design correspondence (response time, setpoints, real time performance, etc.)
- Acceptance criteria

5.1.3. Safety case development

The safety case development (for example, safety report and other supporting documentation) is a continuing process which goes on throughout the entire project. The project manager must assign the responsibility for the document preparation and for the generation of individual parts of the safety case to the suppliers and engineering departments of the utility. Generation of the safety case is an important part of the project requiring appropriate monitoring. Timely generation and submittal of the documentation of safety case to the licensing authority are a necessary condition for the completion of the modernization in the scheduled time.

The following should be discussed and determined as minimum with the licensing authority:

- Identification of the applicable codes and standards for the safety case generation,
- Identification of the organizations which are developing the overall concept and performing integration for the utility,
- Identification of the chapters of the safety documentation that must be modified,
- Determination of the content and format of the safety documentation,
- Division of responsibilities between the compilers of the individual parts and assignment of a coordinator,
- Creation of control mechanisms and tools,
- Creation of a detailed time schedule, and
- Differences between original design basis and recent licensing requirements.

5.2. ORGANIZATION OF PROJECT TEAM

Experience shows that each important activity related to a modernization project requires good management. Best results are obtained by using appropriate project control. The utility should establish an executive project team and nominate a project manager. The project manager must be fully responsible for the whole project and have sufficient competencies to successfully carry out his responsibility. Experience has demonstrated that the project manager should report directly to the plant director. The project team and supplier are responsible for the creation and implementation of all procedures necessary for the work. Project quality documents, so called Handbook, should be developed for all activities related to the project.

The project team should be composed of experts in all of the necessary domains. The responsibilities of each project team member must be well defined. If staff outside the team are engaged to support the project team, priorities must be defined for them to avoid conflicts between their regular manager and the project manager. This group is also responsible to make sure that suppliers meet the conditions of the contract without additional cost or delay.

The utility must have engineering staff with the necessary skills to ensure the successful completion of the approved objectives during the creation of the specification, design, testing procedures, safety documentation, verification and validation of the correctness of the performed I&C system modernization.

5.3. BASIC DESIGN AND ENGINEERING

The utility requirements for the I&C modernization are collected in the basic design which should correspond with the related part of the plant design basis. The basic design should include the requirements for the new systems.

5.3.1. Design criteria

The utility should create design criteria and must also have a group to make sure that the supplier follows these design criteria in the project. The likelihood of the success of the whole project increases significantly when all stakeholders are involved in the project design criteria. The staff of the engineering, operational, maintenance, purchasing, and other departments of the utility are a major part of these stakeholders and create a powerful team for the I&C modernization effort. Such a team has all the prerequisites for creation of high quality and balanced design criteria for I&C system modernization. According to the experience from the I&C modernization projects, the biggest problems were in such cases, when the utility was not able to create a design criteria and/or was not able to control the implementation of the design criteria into the design documentation.

5.3.2. Design and engineering

Prior to the start of the compilation of the modernization specification and the design, the utility must have the relevant part of the as-built design documentation and the design basis documentation. This is a necessary condition for successful modernization of an I&C system. Deficiencies in the specification may have significant negative impacts on the budgets, completion dates, and performance.

The I&C system modernization design must consider basic design principles applied in power plant engineering. In particular, the design should incorporate basic principles listed in Section 5.1.2.

5.3.3. Interfaces to other systems

I&C systems have many interfaces with other systems. When designing the modernized I&C system, it is also necessary to consider and design all interfaces to systems effected by the modernization. These interfaces should be designed together with the design of the modernized I&C system. It should be the responsibility of the project manager to assure that this is done. Practically, each modification of the I&C system has certain impacts on the interfaced systems, such as:

- Heating, ventilation and air conditioning (HVAC): change in the dissipated heat quantity, modification of parameters (temperature, humidity, etc.),
- Electrical systems: modification of requirements for electrical power supply and its quality,
- Mechanical part: addition of tapping points, thermal wells for temperature measurements and
- Interface with other existing I&C systems.

5.3.4. Functional and task analysis of human machine interface (HMI)

It is necessary to prove during the design process and its validation in the safety documentation that all requirements for HMI are met and that they comply with the criteria for safe and reliable operation of a nuclear power plant facility. Verification and validation of the HMI design in relation to the functional and task analysis should include the requirements applied by the licensing authority.

5.3.5. Requirements

Quality and completeness of the requirements are a necessary prerequisite for the procurement contract and the successful design. All errors or omissions will cause problems. Requirements introduced after the contract signing are very expensive and may even impact negatively the schedule. It is recommended, after the supplier is selected, to have some clarification on the requirements between utility and supplier to finalize an acceptable set of requirements.

Generation of good requirements requires a qualified team (refer to section 5.3.1) and sufficient time. Guidance on the development of requirements is given in reference [6] and [21].

Time and money invested into complete and unambiguous requirements represent a good investment.

5.4. PLANNING

Planning is important for project control. Planning principles must be elaborated in detail in the contract; these include principles, procedures, evaluation periods, etc.

5.4.1. Cost and schedule

The price for each of the scheduled tasks of the project needs to be defined clearly. It is also beneficial to clarify the bases for the price calculation for the different items in order to simplify the handling of claims during implementation. In close relation to the task schedule, a payment schedule is to be prepared as well.

In case of modification in the execution or acceptance of any of the project tasks, this payment schedule is to be modified accordingly. The payment schedule must be linked to the network diagram (time schedule with detailed links between the depending activities). For the I&C system modernization project, the network diagram should be used as a control tool to keep the project on schedule and cost.

5.4.2. Quality assurance

A quality assurance (QA) programme is a necessity for each nuclear utility. The QA programme and its implementation must be part of the contract. It is recommended that the supplier create and submit the QA plan for the I&C system modernization project for approval.

5.4.3. Configuration management plan

It is recommended that the utility include the requirements for the configuration management plan into the contract. These requirements must be accurate and clear and should include all areas ranging from the project management to the form of the documentation and way it is created and maintained. Also it is important to be aware of software versions in configuration management plan.

5.4.4. Verification and validation (V&V) plan

The V&V plan should be part of the contract and include all the necessary V&V activities. Contents of the V&V plan should be agreed upon with the licensing authority. The V&V plan should contain all activities, including audits.

5.4.5. Human resources plans

Modernization of I&C systems requires sufficient human resources. This requires expert capacities both at the utility and the suppliers. When planning, this aspect should not be omitted or underestimated, otherwise timely completion of the modernization of I&C systems cannot be achieved.

5.5. SELECTION OF SUPPLIER

The listing of all supplier selection principles exceeds the scope of this report. Only basic principles that the high level management should support are listed here.

5.5.1. Identification of potential suppliers and preparation of invitation to bid

The potential suppliers must have a QA system approved for nuclear activities. Potential suppliers should provide references from similar projects with a detailed list of contact correspondences to enable the utility to get additional information. The utility should request the curriculum vitaes (CVs) of the supplier’s key personnel for the personnel qualification. Furthermore, the utility should have the right to approve the key personnel of the supplier.

The invitation to bid (ITB) is a very important part of modernization process. All of the requirements should be understandable and well defined. The ITB should include the following as minimum:

a) **Basic design** which includes all technical requirements (functionality requirements – including safety classification, environment and qualification requirements for all operation and design conditions, specifications, reliability requirements, life time, all design limitations, etc.).
b) **Draft of contract** with all important conditions (warranty, payment schedule, contract law, force majeure, penalty, time schedule for modernization, codes and standards, condition for new license, scope and quality of documentation, installation limitations (if any), spare parts, training of maintenance and operation personal, special tools and equipment, software license and software documentation, service requirements, etc.).
c) **Evaluation methodology**.
d) **Rules for bid** (form, date, time, place, reasons for exclusion, etc.).

It is recommended to organize meetings with all bidders during the bid preparation period. During such meetings, additional questions from the bidders should be answered by the utility. The answers and questions of one bidder should be sent to all other bidders.

5.5.2. Evaluation of bids

The selection of the supplier should be carried out according to previously defined evaluation methodology. The criteria should be not be changed or modified during the tender procedure. It is recommended to separate the evaluation of the technical and the commercial parts of the tenders. (Refer to the detailed guidelines in reference [40].) The bidder should submit all technical documentation for the conceptual study of how the plant can be modernized with their systems. These documents are especially important for the design of all linked I&C systems.

5.5.3. Detailed interaction with selected bidders

The tender may be organized in one step, where the supplier is selected during a single tender session, or in more steps, where two or more bidders proceed to the next “round”.
In this case the rules for the second round should be defined clearly. The tendering process with two rounds can be beneficial since it provides a chance to make the requirements clearer. Also the utility can assure itself that the supplier that is finally selected understands all of the requirements.

5.6. CONTRACTS

The contract must be profitable for both parties. An unbalanced contract will pose problems during the entire period of its performance. Traditional contracting defines working and interface relationship methods that sometimes suffer from a lack of openness, communication, and a low level of trust between utility and supplier. While the utility tends to seek the lowest possible price while maximizing its benefits, the supplier seeks the highest possible price to maximize profits.

In order to be the lowest evaluated bidder, the prospective supplier often bases his bid on a minimal "assumed scope," rather than the "actual scope" which may be in the best interest of the utility, hoping to later improve profitability by aggressively managing the project to maximize scope changes. The lowest-priced evaluated supplier most often is awarded the contract.

Many latent problems do not become evident until the contract has been signed. Even when a common language has been found, it soon becomes obvious that there are many different ways to deal with a technical issue, depending on whether the problem solver is concerned with satisfying the utility need or applying a minimal solution. Moreover, a lack of knowledge about the specific systems of a plant can lead to a non optimal decision.

5.6.1. Methodology of contract

Before launching any development of software based I&C systems, the utility should make sure that the potential supplier completely understands the necessities for the modernization project. This approach also helps ensure that the supplier is capable of bringing answers to the utility and has the capacity to assure its logistic support. There are two kinds of approach for the contract between the utility and the supplier.

- One is progressive contracting. Two successive contracts are included:
    - First contract: to establish the technical specifications of the system,
    - Second contract: detailed design, manufacturing and installation, and commissioning to realize the system.

The progressive contracting approach can refine the objectives and requirements and supports better understanding between the utility and suppliers.

- The second approach for contracting is the alliance model. This model was developed for those projects that are long and complicated and have difficulty in defining the work scopes. The basic philosophy is to share the benefits and risks between utility and supplier. Sharing of profits and losses can be formalized between the supplier and the utility on the basis of target cost which consists of the direct cost plus overhead cost in the project.

- Key principles of the alliance model are as follows;
    - Establishment of a "virtual" project team, comprised of the most qualified personnel of both organizations from a variety of disciplines
    - Alignment of participants' business objectives to ensure project risks and rewards sharing
    - Key performance indicators must be related to the project and defined for the total performance
    - A steering committee, comprised of utilities and supplier executives, that monitors the project and provides authorization and guidance
    - An "open-book" cost accounting approach that ensures all real costs are mutually monitored
    - A risk/reward principle previously agreed upon provides the incentive for continually improving performance

- Benefits of alliance contract model are as follows;
    - More efficient use of resources
    - Organizational energy more focused
    - Improved communication and efficiency between utility and supplier

- o Likelihood of conflict and litigation reduced
- o Project is well defined and remains "on target" or better.

5.6.2. Agreement on the final requirements

In the course of the contract negotiation the utility should make sure the following:

- The supplier has fully understood the requirements and the delivery scope.
- The supplier is able to fulfill its obligations within the required time.

The scope of responsibilities must be clearly defined in the contract. The supplier and the utility should understand them in the same way. Also these should be discussed to clarify the requirements and scope.

5.6.3. Documentation requirements

All requirements for documentation including scope of supply and schedule should be specified in the contract in detail. The requirements must be comprehensive and unambiguous. It is recommended to attach examples of the documentation that is to be part of the supply. The following must be part of the supply as a minimum:

- Design documentation (drawings, manufacturing documentation, etc.)
- Operation and maintenance documentation (specifications, manuals, calibration data sheets, calculations, etc.)
- Quality assurance/quality control and equipment qualification documentation (equipment and component test protocols, FAT, SAT, etc.)
- Software documentation including software requirements, system and application program software, software modules (library modules), databases, etc.
- Installation procedures
- As built documentation

5.6.4. Cost and delivery schedule

The payment and supply schedule must be part of the overall network diagram of the project. The payment schedule should be prepared in such a way that a substantial part of the price should be paid only after the completion and acceptance of the work. A good payment schedule is an effective tool in the hands of the utility to make sure that the supplier hands over high quality work in time.

6. PROJECT IMPLEMENTATION

6.1. INTRODUCTION

This phase goes through different tasks from the detailed design activity to the commissioning one. This phase, which has to fit into the schedule of a running plant is particularly critical due to three major concerns: short time outages, some activities to be performed during operation, must lead to an effective operation and maintenance of the plant. Therefore, the phase requires very detailed schedule and organization. The Utility must be aware that, at this point, it may be difficult to reverse, especially after starting the I&C system dismantling.

6.2. SPECIFIC TOPICS ABOUT THIS PHASE

6.2.1. Human resources

The success of a modernization project is essentially determined during the previous phases (strategic plan, modernization specification, basic design, and relations with the suppliers and the licensing authority). However, according to the modernization size, it may be necessary to set up a specific organization, including maintenance and operating staff participation, and to organize all tasks in relation to the plant operational schedules, in order to succeed.

The project team could be divided into three groups. The first group would co-ordinate and do project follow-up with the supplier. A second group would work with HMI and its V&V, and procedures. The third group would adjust the interface in the existing I&C as a consequence of the new equipment. The last two groups could be set up together with the supplier. The benefit for the utility is to gain critical know-how for future design, operation and maintenance on site. The supplier gets valuable operational and plant experience when designing the new I&C equipment.

This project team could be the previous one (chapter 5), completed or modified with people that will be directly involved with the system in operation and maintenance. This team must have skill enough to provide a system, in time and that will be accepted by the utility and by the licensing authority.

For a major or critical project, or to keep the knowledge on-site, the project manager could set up the project team as an Integrated Team (**IT**) working in project mode, with shared responsibilities between utility and supplier and clearly identified in an organization chart. The IT manager might be a member of the power plant staff. The project manager could also associate an independent consultant, for specific aspects like Human Factor Engineering.

6.2.2. Schedule and work plan

In case of an incremental modernization, it is necessary to have an overview of the final integrated I&C system while considering each modernization step. The plant management has to ensure that the project team keeps this overview in mind, during the project, particularly in case of introduction of new technology (improvement of the offer).

This could be done by specific meetings with the project team during the detailed design phase, for each step of the modernization, in relation to the criteria identified in the long term strategic plan and experience gained from previous steps.

A main constraints to be mastered to succeed in a modernization project is the limited availability of the plant (generally only during the plant outage) for the integration and the on-site tests of the system (SAT & Commissioning), as defined in the contract.

The project is usually split into main activities from design to commissioning. Some of these activities can be realized in parallel for time saving and others must be done sequentially.

A detailed schedule describing these activities, including the utility's resources and the critical dates, has to be provided to management for each project or sub-project. The project manager and the plant manager have to agree on this schedule and work plan within the context of the constraints of the power plant (operation and safety). This is particularly critical for the installation activities during power operation.

The project team should perform project specific audits of the suppliers work process to gain an understanding of their processes and the outcome of those processes. This is an important part in the QA/QC of the project, but it also is a way to verify information from status reports and technical meeting.

The plant management has to make sure, from the beginning, that project's QA programme details all the follow-up and control procedures of the various activities. Defining and using Key Performance Indicator (KPI) [1]should be useful for monitoring the different sub projects. These KPI could be gathered in a dashboard to reflect the progress level of the project.

6.2.3. Interaction with stakeholders

6.2.3.1. Interaction with licensing authority

It is important to keep the licensing authority informed of all tasks of the modernization project (before the submission of the safety case), in order to anticipate problems regarding the qualification or acceptance process in case of safety or safety-related functions and to lower the licensing risks and costs. The plant management has to ensure that the project team has a dedicated person to interface with the licensing authority during the design and implementation process, and that a formal basis of the interaction has been established (list of documents, report to the project team, schedule…) to help ensure regulatory compliance.

A list of reports, generated by the utility project team or the supplier project team, to be submitted to the licensing authority has to be agreed to at the beginning of the project implementation. Reports on software life cycle, equipment qualification, system reliability, design of the individual I&C systems, detailed design, manufacturing process, result of installation and commissioning tests are examples.

In case of incremental project, the licensing authority may pay special attention of the compliance of each new development with the design criteria generated at the beginning of the project. The plant manager has to ensure that no important deviation has occurred from the beginning of the licensing process particularly in the case of an incremental modernization, otherwise, license renewal is needed.

Hereafter are presented major topics areas to be considered for review by the inspector. The list is not all inclusive and should be interpreted as potential major focal points of the inspection.

- Determine the full scope of the digital I&C system upgrade.
- Verify that the as-installed digital modification is in accordance with the SER, design drawings and licensee commitments.
- Verify that maintenance, surveillance, abnormal operating, emergency operating, and alarm response procedures have been updated, and correctly reflect the new system attributes

[1] Example of KPI: ratio between estimate and actual costs for each task, technical assessment of tasks in progress.

- Verify that plant drawings, the Safety Analysis Report, and other relevant documentation have been updated to reflect the updated system.
- Verify that the operators and technicians have been adequately trained, and have an understanding of the system commensurate with their responsibilities. Verify the training, qualifications and experience of the engineering staff or supplier personnel involved with the digital system.
- Verify that post installation configuration management procedures and controls are in place, and are followed.
- Review any hardware and software failures that have occurred to determine if they were properly resolved or if there are system weaknesses that require correction.
- Verify that follow-up testing and post-installation testing were performed according to licensee commitments and manufacturer recommendations.
- Verify that setpoints and related uncertainty terms have been adequately evaluated and revised to reflect the new system, and have been accurately installed in the software.
- Verify that indication and/or annunciation for system bypass and failure, as specified in the SER is correctly installed and understood by the operators and technicians.
- Verify that the handling and storage requirements of spare system parts are consistent with manufacturer and licensee requirements (periodic power-up, battery life, etc.).
- Verify that the as-installed user interface is in accordance with the SER and design drawings.
- Verify changes in control room HMI so the new interface it not misleading.

6.2.3.2. Interaction with plant

This concerns mainly the design that deals with the hardware manufacturing, the system architecture, the software implementation and the installation in the existing plant. Therefore, the project team needs to be involved very early to do reverse engineering to recover the current system's design basis and in the reviews of all the documents issued during this activity. The manager must be aware that these activities may be needed for the continuation of the project and the preservation of the power plant operational condition for the next years.

The project manager has to ensure that the design of the system allows future modifications during the lifetime expectancy of the plant, without major impact on the operation.

For each activity of the project, the project team and the supplier have to meet periodically according to the project schedule, or immediately for major problems, in order to identify and report problems to management. The plant manager must be quickly informed of all problems that may have an impact on the planned outages, on the project team's workload, on the regulatory compliance, etc. Setting up a steering committee and using the KPIs should be helpful for the information of the plant manager.

For the various reasons mentioned above, we highlight the major role that the plant manager must assume during this phase, being involved at the very beginning and remaining informed of major events during the project.

6.3. DESIGN PHASE

The design phase consists of three different steps: conceptual design, system design and detailed design. The conceptual design can be done either before or after contract signing

(Chapter 5). In case of a modernization of a stand-alone system, you are more likely to go through the three steps in a single iteration. But in case of a larger project with several I&C systems interacting, you have to iterate several times the different steps. The plant manager must be aware that this iteration can be time consuming, and should therefore monitor the suppliers' actions to get early warnings in case of a delay.

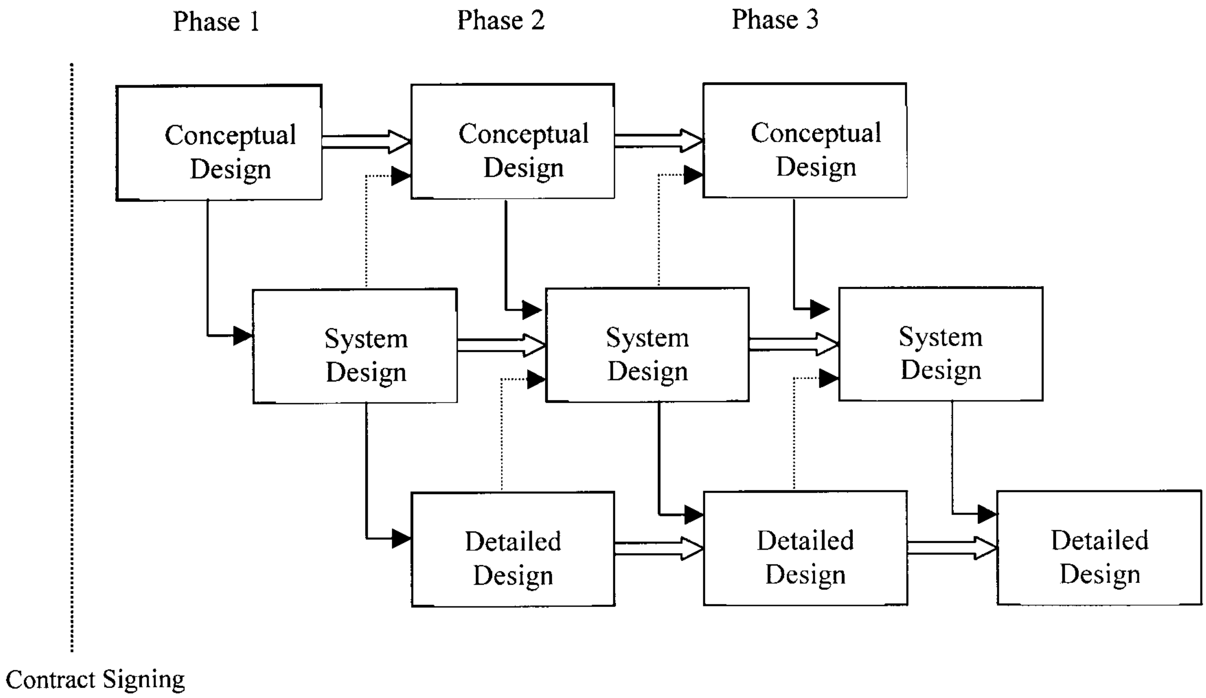

FIG. 7. Diagram of the I&C systems design showing phases of the development and feedback from the utility.

If considering a step-phased approach it is necessary to precisely define the limits of each scope of the supply, taking into account the possible necessity to modify some part of the system which has been previously modernized. You may also consider a temporary solution until the final scope of supply is delivered.

Even if there is no changes intended in the I&C functionality, the transition from analog to digital system cannot be a simple one to one transformation of I&C structures. One must consider the behavior and potential new failure modes of digital technology, such as common cause failure due to software.

The key activities during this phase to be performed can be divided into four groups mainly performed by the supplier:

The conceptual design results give the main architecture of the I&C systems and the guidelines for the different team involved in the system design. The goal is to provide the same technical solution for the same kind of problems. By reviewing the conceptual design document, the utility will have early idea of the final system that will be installed in the plant. During the conceptual design the supplier also specify how the contract requirements will be verified. Even the Licensing Authority may have an interest in the result of this phase.

The system design gives the guidelines for the detailed design activities. During the system design phase, you may identify problems which impact the conceptual design. As a result, you may have to revise the conceptual design documents. During the system design you also specify how the requirements included in the contract will be verified during FAT, SAT and commissioning on a system level. The acceptance criteria are also defined during this activity. The utility should continuously monitor the supplier design process or even review the most critical system solutions.

Detailed design activities (design diagrams, design walk through, design document, development plan, database design/ER diagram, etc.). The utility has to monitor the progress of this phase but usually has no interest in the technical results.

All the information concerning the existing I&C system and remaining detailed information about the project requirements, are provided by the plant team during technical meetings.

During the system design and the detailed design, both the utility and the supplier have to evaluate the impact on the existing I&C system: every disconnected signal in the exiting plant has to be evaluated and necessary steps taken so the remaining and the new equipment works together. As this is time consuming and costly activity, it should be well prepared before the outage. The amount of interfaces to the existing power plant should not be underestimated so you might consider changing the scope of the new systems.

Special care should be given to HMI design for the control room interface: The plant management should consider the plant's human factors guidance (NUREG 0700, NUREG 0711, IEC 964) [41– 43]. The use of simulator with HMI capabilities, very early in the project, to validate the interface and functions (alarm management, procedures, etc.) is highly recommended. If you involve experienced operators from the nuclear power plant you can benefit from their knowledge and get an acceptance for the changes in the interface. Close interactions between the utility and the supplier on the HMI would give the most confidence in the results and will provide efficient training for the utility staff that will later be responsible for the operation and maintenance of the new system.

In the V&V process of the HMI, you might have to use the old simulator to create a baseline. By performing the same scenarios in the upgraded simulator you can evaluate the impact of planned changes on the HMI. Care should be taken to reduce the possibility of the operators remembering the execution of the scenarios in the old simulator as to not void the tests.

During the **integration activities**, when you merge the hardware and software together, it is possible to see the results of the detailed design for the first time. Integration activities give the utility a possibility to evaluate the product and in a dialog with the supplier make the last modification concerning the functions and the interface of the system.

6.4. TESTING AND ACCEPTANCE

6.4.1. Acceptance criteria and test procedure for factory acceptance test

The goal of the factory acceptance tests (FAT) is to assure that the system correctly implements all the specifications as defined in the contract, prior to be sent to the plant. They cover the validation of the systems (hardware modules, connections, basic software, racks, etc) and the validation of the associated tools (configuration tool, etc). In case of safety and safety-related functions, the approval of the licensing authority may be required.

This is one of the most important phases of the project: it is the last chance to solve any problem concerning the system, in a context more favourable than on the site. Therefore, the more closely the utility is involved, the more confident it will be with the system and the easier the integration on site will be.

To ensure the quality and completeness of the tests, a test plan has to be established by the supplier. This test plan shall be prepared to identify and define the organizations (overall and specific), activities, resources, and planning processes deemed to be necessary. This plan must include a list of acceptance criteria; it has to be established by the supplier according to the specification of the individual components (hardware and software) and to the system requirement specifications, including the qualification and licensing requirements if appropriate. The project team must approve this plan, including the list, before the testing.

The project manager has to assure that all the necessary actions are taken by the project team to verify the consistency of the requirements to be tested. For example, the supplier could provide a matrix of compliance.

System FAT may have to be performed on the complete system with the full system configuration data or on a representative subsystem. In order to reduce the test effort on site, it is important to test the integration of the new system with systems similar to those in the plant as much as possible. The utility has to take care of that most of these systems can be simulated so that the supplier has the appropriate interface conditions.

The test schedule must be issued in advance to allow the project team and the licensing authority (if appropriate) to participate or to witness these tests. The test reports should be signed by the utility for acceptance of the system to be delivered to the plant. The plant manager has to ensure that the project team member responsible for the testing has the authority to approve or reject the results and to require re-testing.

6.4.2. Acceptance criteria and test procedure for site acceptance test

The goal of the Site Acceptance Tests (SAT) is to verify the configuration of the system, to perform complementary tests for the untested functionality during the FAT (specific interfaces, etc), and functional testing of the system installed in the plant but without impact on the process (no connection to actuators).

A list of acceptance criteria has to be prepared by the supplier according to the system requirements specification taking into account the results of the FAT. The criteria that are concerned are mainly those permitting to assess the good integration of the entire I&C system in the plant environment (isolation, redundancy with the global architecture, EMC, behaviour of the system when a loss of power occurs, interfaces management, diagnosis, etc). Each test procedure, describing items to be tested and specifying the acceptance criteria and the test environment should be issued for review. The acceptance criteria must be accepted by the utility before the testing.

The SAT plan, the utility's resources and the constraints on the operation and the planning of the site installation have to be agreed upon by the utility.

6.4.3. Test procedure for commissioning

The commissioning testing concerns the functional tests of the system connected to the process and the other I&C systems. It includes final operational testing, tuning of process parameters, and validation of long term performances of the system.

- The commissioning testing phase contains several steps. During the execution of these steps, license authority will review test results and witness actual tests before allowing utility to proceed further. Commissioning test results are one step in the licensee authority final approval of the modernization. The commissioning phase is finished at the end of a sufficient period permitting to validate the long term performances of the system.

6.4.4. Plant simulator for system testing

The utility should make the plant simulator available to the supplier to support design, testing the system's functions, analyzing characteristics, and tuning dynamic performance.

6.4.5. Usage of full scope simulator for V&V

The full scope simulator is also an excellent tool for showing the usability of the operator interface. The V&V of the operator interface will be influenced by the status of the procedures and the operators training level.

The simulator can also be used for development and testing of different procedures.

Moving from analog system to digital system may be challenging for most of the utility staff, especially when modernization impacts the control room. Therefore, this could be a source of problem during the initial operation period and a factor of benefit reduction.

The development of a representative system for early testing by the operator and maintenance staff is strongly recommended. This will allow the operators to verify that they are able to handle the functions, and that the HMI is usable and useful [37].

6.5. TRAINING

6.5.1. Training identification

A major concern in modernization projects is the ability of the utility staff to operate and maintain the new system after the modernization. The plant manager must be aware that the introduction of a new technology will likely impact his operation and maintenance staff. Some staff may be unable to accept such a change depending essentially on age, skill or education level.

It is highly important to define, as soon as possible, a staff management plan describing the existing organization, the future organization and to identify the path to reach the new organization. Some staff could be trained to adapt themselves to new technology; other staff must be assigned to new functions. Managers should be aware that the required technical skill set may not exist or be available within the utility, and new staff recruitment may be required.

Such recruitment should be done early, as the chosen candidate is likely to require additional training.

6.5.2. Training plan

Timely and well organized training of the utility staff is very important for implementation, commissioning and later, for operation and maintenance. The plant manager has to be sure of the availability of this staff during these training activities.

A training plan, which effectively identifies the training required to all utility staff, (technical support, maintenance and operation) should be established early in the project. It is important to identify the proper timelines at which training should occur. Technical support staff should be trained as early as possible to gain knowledge on how the new upgrade will interact with remaining systems, to update system documentation and provide technical assistance during the planning of system installation. Maintenance staff training should be initiated in sufficient time to allow effective participation during the FAT; their training should be completed well before SAT and commissioning. For operation staff training, availability of an upgraded simulator and operation procedures may be required; this would require that the simulator upgrade be done well ahead of planned plant installation.

To effectively produce a training plan, supplier documentation, training scope and schedules should be provided early. Supplier may provide training at their facilities, on-the-job training at the plant or a combination of both. Supplier can sometimes limit the number of attendees to training session; in this case, managers should choose individuals whom can communicate effectively to pass on acquire knowledge to remaining staff. Planning for these internal training sessions should be considered in the overall training plan.

6.5.3. Simulator upgrade

The full scope simulator, available on most plants for operator training, will likely need to be updated to reflect the changes on HMI, system characteristics, and the control concept.

In the case of a step-phased project, the utility must be aware that the skills of the operator have to be proven on the new system and also to be maintained on the current plant configuration.

Managers should be aware of four potential simulator upgrade paths for step-phased projects:

- Simultaneous migration to plant modernization configuration
- Addition of full scope simulator corresponding to modern configuration while maintaining previous simulator configuration
- Dual mode simulator capable of switching between upgraded and existing functionality (difficult)
- New partial (part-task) simulator for upgraded functionality only

Training strategies will largely be based on simulator upgrade path chosen.

6.6. SYSTEM INSTALLATION

6.6.1. Installation strategies

Three types of installation can be considered:

- Installation during plant operation,
- Installation of part of the system during power operation with the remaining work done during plant outage
- Installation during plant outage

A risk management study can help management select the appropriate strategy.

Special care should be taken when upgrades are done during plant operation to avoid disturbances. Such disturbances can potentially lead to unplanned shutdowns, increasing the overall cost of the modernization. Proper identification of interfaces and affected safety system, power consumption of new equipment and the affect of the new equipment on existing systems are vital to the success of the upgrade.

6.6.2. Installation planning

Prior to the installation, the supplier has to develop an installation plan taking into account the existing environmental (process, other systems and other supplies) and plant operational mode (plant operation or outage). The installation and possible dismantling plan should include a detail schedule of planned activities. It should also identify the required interface conditions of the remaining system to prevent inadvertent equipment operation. The planned activities have to be approved by the utility before the installation can proceed.

If the upgrade is done during plant outage, the installation plan must take into consideration outage activities. Certain activities may need to be closely co-ordinated to be carried out efficiently.

Dismantling plan should carefully identify the interfaces between replaced and remaining systems. Impact analysis on the remaining system should be carried out to mitigate potential problems. Early identification of these problems will reduce installation time during outages.

When modernizing the control room, a temporary operator panel gives you a possibility to remove a large part or all of the panels and cabinets in the control room for the purpose of making installation easier. By performing specific actions and doing temporary installations, the utility might be able to reduce the number of safety functions that needs to be supervised by the temporary operator panel.

A change in the need of supervised safety function has to be approved by the licensing authorities. This can be done by analysis of the situation and writing a temporary safety specification for use during the modernization of the control room. It is also beneficial to add important service functions to the temporary operator panel.

6.6.3. Installation execution

During plan execution, it is important to constantly review and adjust activities to forecast potential delays. Problems encountered during execution may affect not only current planned activity, but also other pending activities.

Interaction between the utility and the supplier are important during this phase. Installation staffs are managed by the supplier, who should interface directly with the utility representative to provide regular progress reports and contingency plans when installation changes must be contemplated.

6.7. SYSTEM DOCUMENTATION

The quality of the system documentation is an essential part of the quality management system. The system documentation should be updated as the project moves forward and should reflect how the initial requirements translate into system features. In this way, appropriate traceability functionality will be asserted. As the project has more than one stage (see Fig. 6), there is an obvious need to maintain the system documentation during the design and later into the implementation phase. Consequently, tools and methods should be considered that would facilitate this process. A flexible solution would also form the basis for an efficient maintenance strategy even after the project completion.

Modern quality management methods put an emphasis on quality assurance of the development process and not only the quality assurance of the end product itself. This means that the development process itself must be documented, and there must be qualifications how the development process resulted in an end product of acceptable quality.

This focus on the development process suggests that computerized tools should be used. Various categories of tools, such as Computer Aided Design (CAD), Computer Aided Software Engineering and software modelling, already exist. These tools will typically result in systems documentation such as code listings, 2D, 3D and isometric drawings. Some of the CAD tools are object oriented in the sense that they will be able to store a collection of attributes together with the individual plant components (like component characteristics). Other pertinent data may also be associated such as supplier data, spare parts in stock. Some advanced systems even have the possibility to initiate procurement using eCommerce technology.

One should also consider the association between the CAD tools and more overall system documentation such as the designed safety function. This association should show explicitly how the safety function is asserted by the involved systems and their components.

Other types of more generalized systems documentation exist:

- Function of the Structures, Systems and Components (SSC);
- Fundamental processes that satisfies a function;
- Basic safety margins to be included in the design
- Interfaces with other structure, system and components (SSCs), including mutual dependencies;
- Events and fault scenario expectations; Feedback from the system testing (deviations reports).

All these types of abstracted functionality are eventually implemented by the given design. It should be documented why the given design accomplishes the abstracted functionality. It is an obvious advantage to have a “living document” rather than paper based documents during the project and also in the maintenance to follow. A computerized check of possible consequences of a subsequent plant change is thus possible.

Operational and maintenance documentation should be available before the beginning of the SAT in order to be used and validated during installation and commissioning.

This documentation must be understood by the utility team. It is a major way to learn how the plant will be operated and maintained with the new system.

6.7.1. Configuration management plan

The Configuration management plan must be initiated very early in the project implementation and must be seen as an integral part of the quality management, see reference [44].

Configuration management is a necessity since no project can be run without modifying previous partial design solutions and revising decisions made at the earlier stages. The challenge is thus to keep a consolidated and consistent view on the current state of the plant design.

6.7.2. Final, as built documentation

As-built documentation should include as a minimum: system block diagrams, wiring diagrams, equipment lists, architecture, device deliverance schedules and system training & maintenance manuals. In order to be of benefit to the owner/operator of the systems, the as-built documentation needs to reflect the "as commissioned" state of the system.

Most of the documentation is delivered by the supplier and therefore, and may not be consistent with the utility’s. Integration into the existing documentation hierarchy in the plant has to be considered, very early, if needed.

This final documentation should contain sufficient detailed information to permit contracting with third party for the system maintenance in case supplier is no longer in business.

A preliminary version must be available before the commissioning phase starts and updated at the end of the commissioning.

6.8. OPERATING EXPERIENCE AND ERROR REPORTS

Feedback on modernization activities should to be organized from the beginning of the project to capitalize the useful data during the development of future system (cost, duration, problems) and the operation (benefits, problems step).

There is a common practice among licensing organization to require a validation of the planned changes in simulator environment before the changes are implemented in the plant. This will be a main source of operating experiences for both system correctness and usability. In those cases where the operator interface are being affected by the changes in the instrumentation and control, it must be established that the new interface be safely used by the operators, and would not lead to operator errors. It is considered an advantage to have the training simulator changes available as early as possible since the operator experiences may be used to influence the design process. However, formal validation test should be put relatively late in the project when final design is available, otherwise licensing authorities may require new test due to substantial changes made after the formal test was run.

6.9. MAINTENANCE MANAGEMENT

Considering investments engaged in the modernization, the expectation is that the new system has to last till the end of life of the power plant and therefore, the high level management would have to define a long term strategic plan for maintaining the efficiency of its modernized I&C system.

6.9.1. Elements to be considered by the manager

New digital I&C systems certainly have the advantage of being easily adaptable to new functional requirements — if skills are still available — but they have the drawback of having a short market lifetime. Indeed, new systems evolve faster and become obsolete very quickly.

The plant manager has to face choices: on one hand, it is not possible to change its I&C system each time a new product is introduced and on the other hand, the plant will be soon be operating with an “old” system for which maintenance cost will rise quickly (external cost, knowledge, hardware, etc.). It is therefore necessary to define and implement projects, which aim at long range maintenance planning and timely replacement, in order to prevent situations of technical obsolescence and supplier skills.

For these reasons, it is important to define appropriate maintenance concepts in order to adjust the I&C system to current situation if both market context and technical conditions change.

6.9.2. Maintenance management plan

It is important to implement software and hardware version management during the project.

Two methodologies are available:

- To freeze at a given version.
- To follow the commercial evolutions.

6.9.2.1. Freeze at a given version

The advantage of freezing is that the I&C system will be homogenous but the problem of freezing at the initial version is that the system will be “old” when the last modernization step occurs and components may have to be purchased very early in the project. The project team may have to define the amount of spare parts that will be needed regarding the expected lifetime, if it intends to keep this version up to the end. Freezing at the final version will assure availability but may require retrofitting and re testing the previously installed systems.

For Safety class system, considering the licensing cost, only absolutely required changes should be implemented.

6.9.2.2. Follow the commercial evolution

The advantage is that the system will be up to date when the last modernization step occurs but the manager has to take the qualification effort for each version into account (Identification of modifications, importance and impact). The I&C system will be heterogeneous with the risks of incompatibility, lack of inter-operability and high maintenance cost. The manager should think about the long term maintenance plan in advance and once the overall new I&C system is implemented and operational, the utility will have to issue it as an official document.

If the strategy is to maintain the new I&C system, with some necessary update, the manager has to make sure that the characteristics of the system (standard, interfaces, architecture, etc.) will allow him to follow, if necessary, the evolutions of the product, without (or with few) effect on the availability of the production and on the licensing authority acceptance. Even if each new product is "card-to-card" compatible, regression tests will have to be performed (performance tests) and documentation must be updated. At any time, the manager should be able to freeze at a given version.

A plan of continuous technical improvement should be a good opportunity to maintain the knowledge and skills (internal and external). This plan is crucial for the long term performance of the plant. Indeed, these new I&C technologies, usually based on software, impose a constant application (training for skill maintenance), unlike hardwired technologies.

Whatever the strategy, a long term agreement with the supplier may be needed.

7. LESSONS LEARNED AND EXPERIENCE GAINED

7.1. PROJECT PLANNING

- When it is decided that incremental approach will be used for the modernization programme, it is important to have a migration plan for the control room as well as the I&C systems. There needs to be an iteration process between them to achieve the final migration plans.
- Ease of implementation or design is not the only critical aspect to determine order and scope of projects. Other aspects such as need for replacement should be used to define the order and scope of modernization. Examples are:
    - obsolescence,
    - aging
    - plant reliability, availability
    - productivity needs,
    - physical layout,
    - ergonomic requirements in the control room
    - new requirements from regulatory bodies
- Beginning modernization with isolated I&C systems, having a mixture of control and monitoring capabilities, is a good way to gain project experience.

- Coordination between the different, simultaneous modernization projects is necessary but has to be handled carefully.
- Inadequate planning or resources (time, money, people) may mean that the upgraded system will need to be replaced again to fit into the overall plan.
- It may be an advantage to maximize the standardization of I&C platforms. If a standardized platform is selected, it is important to build first the infrastructure in the plant to which new systems will be connected successively.
- Long term agreements with the suppliers are helpful to assure long term availability of spare parts, replacements, and technical support.
- It is advantageous for the operator interfaces in the MCR to use same human–machine interface principles (look and feel).
- It should be determined at the beginning with the supplier how the documents for the new system will be integrated into the existing plant documentation hierarchy.
- The approaches of the supplier and the utility to the modernization contract are different due to their different interests. This has resulted in some negative experiences in the cooperation. It is important to establish guidelines at the beginning of the project for solving potential conflicts.
- The early involvement of the licensing authority is a key point to reduce the licensing risk and cost. In the case of a large I&C modernization project, it can be beneficial to create a project specific licensing plan and agree on it with the licensing authority.
- There can be advantages for having different suppliers do a feasibility study over how the plant can be modernized with their equipment to clearly understand how they would satisfy the current requirements and how the concept can be extended to support new needs in the future.

7.2. PROJECT ORGANIZATION

- All stakeholders (operator, maintenance person, designer, etc.) of a system should participate in the modernization project to make sure that it satisfies their needs as best as possible. This is an important aspect for making the system as good as possible and for getting acceptance of all of the staff who interface with the system.
- It is important to make sure that all members of the project team understand the goals, objectives, guidelines, and basic contract terms for the modernization programme, and after the modernization decisions are made, it is essential that they all work together in the same direction to implement these decisions.
- There must be an adequate number of plant staff with proper level of knowledge and expertise to support the project. It is important that there are not too many projects scheduled that the plant staff cannot give adequate attention to all of the projects.
- Some staff members may have to be assigned full time to the project, and if so they should be released from regular duties.

7.3. PROJECT EXECUTION

- Utility knowledge of the plant and operational experience provides valuable input for I&C modernization activities.
- The new system should support the plant’s naming conventions for pumps, fans, measuring points, and so on. If new naming conventions need to be added, it is important that only a single responsible person or group is allowed to assign names for new signals and objects.

- Even though the supplier is responsible for the design and qualification of the system, the utility still needs to have a clear understanding of the system and perform independent verification.
- When software based systems are installed, the staff has to be aware of version identification, configuration control, and compliance to appropriate standard and requirements

7.4. HUMAN–MACHINE INTERFACE DESIGN

- The migration strategy for the main control room has to be carefully planned because I&C modifications have a strong impact on both plant operation and operator training.
- In the modification of the control room if a complete section of control desk/panel or a complete operational task is modernized at once, it is easier for the operator to operate the plant and the likelihood of human errors is reduced.
- If human cognitive capabilities and human factors engineering practices are not considered, there is a potential for increased human errors with the new systems and interfaces.
- It is difficult to get good results from the requirements specification for the HMI only; therefore, the HMI design should be an iteration process between the supplier and the utility, preferably using a prototype of the interface or, at a minimum, using screen pictures.
- Changes in the control room often lead to discussions with the licensing authority about whether the operators need to be re-certified before they can operate in the new control room. The changes also lead to discussions about the amount of verification and validation required for the HMI.
- A formal control room modernization process has to be established to identify the activities of the operators in the modernized control room in order to satisfy safety and productivity requirements.

7.5. STAFF TRAINING

- Changes in I&C technology require new skills such as understanding of computer networks, maintenance of digital systems, screen display design, etc. This change in skills must not be neglected and appropriate training must be done.
- Modernization of the control room will require operator training. There needs to be a way to train the operators on the new control room before it is operational. Yet at the same time, the operator must keep up his training on the existing control room. This could require the use of additional simulators, either part scope or full scope.
- During design of the new I & C platform or systems, it is very desirable to have the plant staff work directly with the supplier, perhaps at their site. This is the best training and education the plant engineering and maintenance personal can get and when the system comes to the plant, these people are very familiar with the equipment.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. CONCLUSIONS

Modernization of I&C systems in older nuclear power plants is becoming an important issue. This has been necessitated by obsolescence, aging equipment, increasing failure rates, need for additional functionality and/or improved performance. Many nuclear power plants are achieving higher availability factors and higher level of safety by adopting well planned modernization programmes. Due to the issues and needs discussed in this document, I&C modernization may actually become necessary during the plant lifetime more than once.

Establishing the need and requirements for the new I&C system is the most important phase, which should result in a set of complete and unambiguous requirements specifications. These have to be based on a clear picture of the current plant conditions. Various paths may be taken based on the needs. It is important that all stakeholders including the licensing authority take part in this phase.

Even though upgrades to I&C equipment could be treated in isolated manner, it is concluded that a formal, well planned approach to I&C modernization is highly recommended. This long term approach, which involves all stakeholders from the utility, design centers, and regulatory authorities, should be based on long term vision and take into account plant performance data, experiences in other similar plants, and evolving I&C technologies.

Project preparation and feasibility study are to be performed in manners that evaluate the system status and available resources. Based on evaluation results, lists of I&C systems that require modernization would be available. The quantitative and qualitative benefit analysis is necessary to form the solid justification of the modernization projects.

Entering an I&C modernization project needs commitment from the senior management. It is important that the project is seen in connection to a long term strategic plan of the plant. Only by ensuring adequate financial and human resources the goals of the I&C modernization project can be brought to a successful end.

Before entering an I&C modernization project it is advisable to define a staff management plan describing the existing organization, the future organization and to identify the path to reach the new organization. Some staff could be trained to adapt themselves to new technology, other staff must be assigned to new functions. Managers should be aware that the required technical skill set may not exist or be available within the utility, and new staff recruitment may be required. Such recruitment should be done early, as the chosen candidate is likely to require additional training.

Designing a new I&C system typically consists of three different steps: Conceptual Design, System Design and Detailed Design. It is necessary to define the limits of each step to take into account the possible necessity to modify parts of the system that have been previously modernized. Producing system documentation is an essential part of the project, which should be updated as the project moves forward. A test plan including HMI is another important part of the project.

These general conclusions are reflected in the more detailed recommendations below.

8.2. RECOMMENDATIONS

8.2.1. I&C system modernization management

- It is important to have a high level manager who understands I&C systems and its needs and concerns and who will act as a well informed champion and sponsor for the I&C modernization activities.
- A plant life-cycle management programme should be used to evaluate the need to modernize an I&C system in the context of plant goals, requirements, and constraints.
- Management must ensure that adequate financial resources and human resources with the appropriate skills are made available to achieve the goals of the I&C modernization projects.
- Management should develop the normal approach that all stakeholders of the modernization project are represented in the project.
- Management should make sure that there are adequate utility resources and appropriate skills to perform the utility portions of the modernization project.

8.2.2. Needs, requirements and preparation of specifications

- A clear picture of the current condition of the existing I&C systems is needed for a basis for modernization decisions. Identify the problems and limitations with the existing plant I&C systems.
- Determine the needs and desires of the utility and identify problems and limitations of the supplier's system to meet the needs and desires.
- The endpoint vision and migration plans should be developed in a manner that is flexible and expandable to allow for changing conditions such as goals, requirements, constraints, and technology; and should be reviewed periodically for potential changes.
- A strategic plan identifying the vision of the endpoint configuration of the plant's I&C system and the main control room needs to be defined at the beginning of the modernization activities.
- Plant specific design and implementation guidance should be developed and used for requirements definition and other aspects of the modernization project.
- Comprehensive and unambiguous requirements are a fundamental condition for a successful project. Attention should be placed to special conditions such as plant start up and abnormal conditions and events. It is necessary to provide sufficient time for the creation of these requirements.
- All stakeholders of the system should take part in the creation of the requirements specification.

8.2.3. I&C modernization project preparation

- Management decisions on how requirements are developed, monolithic versus incremental modernization, level of standardization, and type of relationship between the utility and supplier must be made at the beginning of the modernization programme.
- For incremental modernization, a migration path needs to be defined to identify the order of I&C systems to be modernized and the order of control room changes.
- Acceptance criteria should be prepared for the evaluation of the bids to select the supplier.
- All contractual requirements must be correctly, completely, and clearly formulated in the contract.

- The utility should generate a payment schedule, which will motivate the supplier to hand over the completed work in time and with high quality.
- Procedures for adjustments of the scope of supply should be part of the contract.
- The utility should evaluate the scope of modernization towards the number of interfaces to the existing plant and consider changing the scope and new system to reduce the number of interfaces.

8.2.4. I&C modernization project implementation

- The configuration management plan must be initiated very early in the project and must be seen as an integral part of the quality system to be delivered by the supplier.
- The utility should have resources for working side by side with the supplier during design, installation, and commissioning to acquire the essential knowledge for operating and maintaining the systems.
- It is important for the utility and the supplier to work together on the modernization programme to best determine how the supplier's equipment can best satisfy the utility's needs.
- Project audits should be done on the supplier to make sure that contract obligations are fulfilled.

8.2.5. Tools, methods, procedures and documentation.

- Before modernizing the main control room, establish a reference base line measurement using the simulator for the pre-modernized control room in order to verify that the changes have not negatively affected plant operation.
- Use updated simulator to provide input into and validate operator manuals for the I&C modernization.
- Tools and methods to facilitate the processing of project documentation should be used.
- Operation and maintenance manuals should be available before the start of the site acceptance testing and associated training needs.
- Tools and methods should be used to maintain the I&C system over its whole life cycle.
- The final documentation should contain sufficient detailed information to permit contracting with a third party for the system maintenance. The utility should have an agreement to use this documentation with third parties.

8.2.6. Licensing

- A list of documents, subject of approval by the licensing authority must be created and it is helpful to have agreement between utility and licensing authority about completeness of this list.

Appendix A

QUESTIONNAIRE FOR I&C MODERNIZATION PROJECTS IN THE NUCLEAR POWER GENERATION SECTOR

Guidelines to interview plant/project managers with modernization projects experiences

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THE QUESTIONNAIRE

The purpose of this report is to provide guidelines to interview plant and/or project managers and engineers on their experience with I&C modernization projects in nuclear power plants (NPP).

This guideline is structured around the following axis:

- The environment and the objectives of the modernization project
- The strategy used to manage the I&C modernization project (by following the different phases of the project)
- The technical solution chosen and its characteristics (technology, capacity, dependability, …)
- The return of experience of such a project

GENERAL INFORMATION AND PROJECT OBJECTIVES

N°	Title	Question	Answer	Remark
1.0	Utility information			
		Name		
		Number of units (nuclear, fossil, hydro)		
		For each Nuclear Power Plant:		
		Location		
		Type	AGR/ BWR/ ABWR/ALWR/GCR/ GCHWR/ HTGR/ HWLWR/ LGR (RBMK)/ LMFBR/ LMGMR/ PHWR/ PLWBR/ PWR/ VVER…	
		Number of loops		
		Total power	MW(e)	
		Date of construction (start, end)		
		Date of Operating License issue		
		…		
		Other information		
1.1	Power plant characteristics			
		Name		
		Type		See above (1.0)
		Number of loops		
		Total power	MW(e)	
		Type of operation	Base-load, load-follow…	
		Reactor supplier		
		Other information		
1.2	Power plant history			
		Date of construction (start –end)		
		Date of first operation		
		Plant license expiration date		

N°	Title	Question	Answer	Remark
		Were there significant events during the plant life which have consequences on the I&C renovation process?	-	Including license renewal, change of supplier…
		Other information		
1.3	Plant organization			
		General organization of the plant	name, size, functions of the different departments	Attach a plant staff organization scheme
		Contact references	Name/ Function/ Address/ Fax/e-mail/…	For further discussion
		Is there an Engineering Department within the utility? If yes:	Yes/No	
		What are its size and functions?		
		What are its competencies?		
		Where is it located?	On site, in a central service…	
		Is there an entity (department, service, ..) in charge of I&C in the plant? If yes:	Yes/No	
		What are its size and functions?		
		What are its competencies?		
		Is there a Safety Authority representative on Site?	Yes/No	
		Other…		
1.4	Reporting system			
		Information available periodically		
		Incidents on I&C systems		
		Spurious actuation, or erroneous information		
		Reporting of the information to the Safety Authority or governmental services	Periodically, on request…	

N°	Title	Question	Answer	Remark
1.5	Classification system			
		Classification levels used	Number, names, and meaning of the different safety levels	With reference to IEC 1226 or IAEA systems
		Equipment Qualification system	Number, names, and meaning of the different classes. Standard…	K1, K2, K3 at EDF
1.6	Previous (or current) I&C Systems	Description of I&C before the modernization project with the name of each supplier		Attach an architecture drawing whenever possible
		Main I&C systems:		Precise name, functions, and safety levels
		Operator stations		
		Back up panel		
		Protection systems		
		Control systems		
		Information systems		
		Test system		For periodical tests…
		…		
		Secondary I&C systems		
		Pollution measurement		
		…		
1.7	Project objectives	Objectives at the origin of the project		Complete with quantitative data when available
		To decrease the maintenance costs of the I&C		
		by ensuring spare parts off the shelves availability	Deciding/Important/Minor/Without impact	

N°	Title	Question	Answer	Remark
		by reducing the purchase costs of the spare parts	Deciding/Important/Minor/Without impact	
		by decreasing the number of system maintenance periodic operations (testing, calibration, …)	Deciding/Important/Minor/Without impact	
		by decreasing the mean duration of the system maintenance periodic operations (testing, calibration, …)	Deciding/Important/Minor/Without impact	
		by decreasing the number of system maintenance curative operations	Deciding/Important/Minor/Without impact	
		by decreasing the mean duration of the system maintenance curative operations	Deciding/Important/Minor/Without impact	
		by rationalizing the I&C architecture	Deciding/Important/Minor/Without impact	
		by ensuring availability of competent personnel (within and outside the utility)	Deciding/Important/Minor/Without impact	
		by ensuring a better knowledge of system	Deciding/Important/Minor/Without impact	
		by reducing the cost necessary to maintain the engineering or manufacturing tools	Deciding/Important/Minor/Without impact	
		Other…		
		(1) To decrease the maintenance costs of the process equipment If yes, precise on which equipment: …	Deciding/Important/Minor/Without impact	By allowing a better regulated control, better monitoring, and by decreasing equipment mechanical solicitation
		(2) To increase the plant output		
		by reducing mean plant outage duration	Deciding/Important/Minor/Without impact	

N°	Title	Question	Answer	Remark
		by reducing the time necessary to restart the plant	Deciding/Important/Minor/Without impact	
		by reducing the number of plant trips	Deciding/Important/Minor/Without impact	
		by allowing the plant to operate at a higher output rate	Deciding/Important/Minor/Without impact	
		Other…		
		(3) To decrease the plant operating costs	Deciding/Important/Minor/Without impact	e.g. by operating the plant with a reduced staff
		(4) To improve the confidence of the general public (opinion) in the plant safety	Deciding/Important/Minor/Without impact	National or international opinion
		(5) To motivate the plant staff	Deciding/Important/Minor/Without impact	Give the average age of the present staff
		(6) To cope with new process requirements		
		by adding new functions	Deciding/Important/Minor/Without impact	
		by extending system capacity	Deciding/Important/Minor/Without impact	
		(7) To answer Safety authority demand		
		Plant specific requirements	Deciding/Important/Minor/Without impact	Describe the scope of the demands
		New Safety Referential	Deciding/Important/Minor/Without impact	Describe the origin (Europe requirements…) and the scope of the demands

N°	Title	Question	Answer	Remark
		(8) To improve control or supervision of the process by the operators	Deciding/Important/Minor/Without impact	Precise the scope
		(9) Others	Deciding/Important/Minor/Without impact	Describe which one(s)
		How were these project objectives: defined, and characterized (technically and financially) ?		Describe the method used to assess the objectives (possibly different depending on the objectives retained)
		Worth (technical and/or financial) assigned to these objectives		Describe the values given to the objectives
		Was there a return of investment required, and how was it assessed?		
		Trends taken into account (in terms of technology, future requirements, company organization, …)		
1.8	Project constraints	Main project constraints taken into account:		
		Plant outages planning		
		Room available for system hardware and cabling		
		Utilization of existing hardware (cubicles, cables…) or software		
		Links with other systems		CAD tool…
		Safety Autority concerns with respect to HFE (Human Factors Engineering) activities?		

N°	Title	Question	Answer	Remark
		Standards applicable to the project (including HF standards)	International: IEC/AIEA US: IEEE/NUREG/CFR/ANSI/ISA German: RSK/KTA UK: BSI/Interim Standard Canada: AECB Russia: OPB /PBY/GOST/OTT	Detail those applicable
		Budget		
		Others		
1.9	Modernization project summary	Description of the plant I&C after the modernization project		Attach an architecture drawing whenever possible
		Main I&C systems:		Precise name, functions, and safety levels
		Operator stations		
		Back up panel		
		Protection systems		
		Control systems		
		Information systems		
		Test system		For periodical tests…
		…		
		Secondary I&C systems		
		Pollution measurement		
		…		
		Cable		Wireless, fiber optics, halogenfree
		Sensors and actuators		Smart sensors…
		Number of plant or units concerned by this renovation project		
		Renovation project status and/or planning		

N°	Title	Question	Answer	Remark
		Were there other solutions envisaged, and if yes, which ones?		ASIC based component…
	And then for each system covered by the modernization project	Main characteristics of the system:		This part of the questionnaire shall be duplicated as many times as there are different systems covered by the modernization project
		Name		
		Function		
		Safety level		
		Equipment qualification level	Standards…	K1,K2,K3
		Origin of the system	Off-the-shelves/Adapted from existing system/Completely specific for the plant	
		Supplier		

RENOVATION PROJECT

This part of the questionnaire should be adapted to the project phasing adopted by the concerned utility. It consists of:

- questions applicable to all phases of the project (2.0),
- and questions specific to each phase (2.1 and +)

The order in which questions are asked and answered within a given phase can be freely altered.

The questions shall be answered as follows depending on the project status:

- If the phase has not yet started or is in progress: then the answer shall correspond to what was (or is) forecast during project initiation phase
- If the phase is already completed: then the answer shall correspond to what was actually reached at the completion of the project

In this questionnaire, a project is called a “progressive renovation project” when the renovation is carried out in different steps, i.e. when the plant is operated with different I&C configurations at different moments of times.

N°	Title	Question	Answer	Remark
2.0	For each of the life cycle phase	Description		Name and brief content of the phase
		Status	Not started/In progress/Completed	
		Main tasks carried out		
		Companies involved and their missions		
		Plant staff involvement		
		Constraints		
		Risks		
		Resources:		
		Human resources (internal & external)		
		Hardware/platforms		
		Computer-based systems and tools		
		Total or partial reliance on external resources or competencies		It is of special interest to identify the subjects where reliance on supplier was total
		Location of the team (on site, at the supplier's…)		
		Costs		
		Internal		
		External		
		Time schedule		
2.1	Project initiation/Feasibility study	Describe the decision process between the first identification of the need for a renovation, and the decision to invest in a renovated I&C system	Benefits vs. cost analysis… Time, cost…	Consulting support, plant team…
		Who took the decision of the renovation?		

N°	Title	Question	Answer	Remark
		Level of involvement of the different actors (plant management, maintenance, operation, I&C team, Safety, …)		
		Other?		
2.2	Project organization	Main participants (in terms of organizations, department, persons) to the renovation project		Including Human Factors resources
		Was there a specific team put in place for the renovation project? If yes, was it located on the plant or somewhere else?		
		Was it made of plant staff only, or from other origins (consulting, supplier…)?		Describe the co-operation model
		How were the persons participating to the renovation project chosen?		
		What types of HFE (Human Factors Engineering) activities were performed during design development to ensure:		
		compatibility with operational needs?		
		compatibility with human capabilities?		
		consistency between advanced and conventional components of the HSI (Human System Interface)?		
		Was there any external cooperation for the renovation project (such as EPRI, AIEA, OECD, WANO, other plant…)?		
		Means to motivate the project staff during the lifetime of the project?		

N°	Title	Question	Answer	Remark
		Were there any constraints given to your plant by a central department (I&C, engineering, purchase department, Safety, …) of your organization?		
		Were there any Quality Requirements imposed		
		Any "local" participation of the system supplier (if the system supplier is from another country)?		
		Other?		
2.3	Definition of the system requirements - specification	On which basis was the requirement specification written?	Blank sheet, existing system, previous experience, suppliers documentation…	
		Any computer-based tool used? If yes which one?		
		Involvement of the supplier		In the basic or detailed design
		Involvement of the safety authority?		
		Were there significant evolutions of the specification during the project life? If yes, on which subjects, and for which purpose?		
		Other information?		
2.4	Definition and planning of the renovation project phases	Different phases of the renovation project, with the description of the: ❍ order in which the different parts of the system (or the different systems) are installed ❍ order in which the other connected systems to are linked and commissioned		This part of the questionnaire is to be detailed mainly in case of a progressive renovation project, where the system(s) is (are) installed, commissioned and operated progressively by sub-sets

N°	Title	Question	Answer	Remark
		Reasons behind the phasing of the project		Specially with reference to the project objectives and constraints defined on page 65 (plant outages …)
2.5	System and supplier selection	Method used:		
		to identify potential system manufacturer or supplier		Criteria for pre-qualification
		to assess their technical and commercial proposal		Precise the main criteria which were considered deciding
		to select between the different manufacturers or suppliers	Open bid/negotiation/…	Technical & financial evaluation
		Any requirements on local supply?		
		How did you ensure system and system supplier lifetime expectancy?		
		Any pre-qualification of the supplier and/or its system? If yes, what was the objectives and the content of this pre-qualification		Use of Return of experience, Specific tests...
		Other criteria		
2.6	Configuration			
		Tools used for the system configuration		Precise mainly the origins (system supplier, plant …)
		How were the configuration data (process and operation) provided	Functional drawings, files…	
		Language(s) and/or standard(s) used for configuration		

N°	Title	Question	Answer	Remark
		Main differences in this phase (in terms of tools, procedures, libraries used, tests, levels of independence, …) with a configuration that would have been performed in a conventional industry		
2.7	System development	Part of the system which existed (off the shelves) and part of the system which was developed specifically for the project?		Only when applicable (i.e. for systems which are not off-the-shelves)
		Any specific development rules imposed to the development teams (in terms of programming tools, methods, levels of independence,…)?		
2.8	Verification and validation			
		Purpose and extent of the Verification and Validation activities, including HFE evaluation activities.		Describe what specific problems were encountered
		Any standards or guidelines used for the V&V activities		
		Any V&V activity with a formal level of independence		
		Involvement of the Safety Authority in the V&V activities		
2.9	Installation and commissioning	Extent of the tests performed during installation and commissioning		Mainly with respect to the interconnected systems and instrumentation
		Impacts on the plant operation (outage, slow down)		
		Impacts on the I&C operation (system outage, systems de-connections, …)		

N°	Title	Question	Answer	Remark
		Extent (content and duration) of the preliminary works necessary before the plant outage(s)		
		Impact on the non renovated systems		
		Duration(s) of the plant outage(s) required for the installation and commissioning of the renovated system		
		Others		
2.10	Documentation	Involvement of the plant owner in the document definition and supply?		Precise if plant standard was applied
		Other		
2.11	Qualification	Involvement of the Safety Authority in the Qualification process?		
		Safety Authority guidelines to conduct the renovated system qualification.		
		Who was in charge of the qualification tests and analyses?		
2.12	Training	Any training before the system was ready for installation		Precise the staff concerned by the training
		Was there a dedicated test platform for maintenance training…?		
		Other		
2.13	Simulator	Is there a simulator?		
		Is it a full scale or full scope simulator or other?		
		What are its functions: training, test platform, …		
		What were the consequences of the modernization project on this simulator?		

N°	Title	Question	Answer	Remark
2.14	Operation	Was there any change in the operation such as:		
		Level of automation?		
		Computerized procedures?		
		Advanced alarm systems?		
		Assessment, diagnosis and planning aids?		
		Advanced user interfaces (control and display) devices?		
		Other?		
2.15	Temporary operation in case of a progressive renovation project	Main differences (if any) with the "permanent" operation phase		
		Were these differences foreseen during project definition?		
		Was there a period where the plant was operated using a combination of old and new control equipment		
		How was it managed in terms of priority assignment, coherency management, space allocation, …		
		Was there temporary equipment necessary during this period (for example back up panels, …)		
		What was your strategy in term of software and hardware version management?		Precise if the first installed version was maintained
		Other?		
2.16	Maintenance	Extent of your spare parts inventory (related to the renovated system)?		
		Type of warranty (duration, extent, response time) given by the supplier?		

N°	Title	Question	Answer	Remark
		Any specific arrangement with the system supplier to ensure long term system maintainability?		Such as supply of source code, specific access to system experts, …contract over 10-20 years…
		Other?,		
2.17	System evolution	In case of a prolonged project: either because it is a progressive renovation project or because the system is installed on different plants progressively		
		What was the strategy used to cover hardware and software of the commercial products evolutions		
		What were the extend of the non regression qualification tests		
		Other?		
2.18	System modification	Have you experienced a modification of this renovated system, since the end of the commissioning?		
		If yes, of what kind?	Hardware, software…	Describe the motivation of the modification (software release...)
		Was there any difficulty in this modification?		Adaptation of the programmes…
		Did you perform regression tests?		
		Other?		

RENOVATED I&C SYSTEM

For most of the characteristics described here, three answers are expected:

- the former value before the renovation project
- the value expected at the beginning of the project (during system specification phase)
- the value actually reached at the completion of the project (when applicable and available)

Depending on the system, and the objectives retained for the renovation project, the system functions and their characteristics shall be more or less studied in this part of the questionnaire. In particular, for the points which are directly related to the project objectives, detailed values or characteristics shall be examined. This part of the questionnaire shall be duplicated as many times as there are different systems covered by the renovation project.

N°	Title	Question	Answer			Remark
3.1	System functions					
		Main functions of the system	1)	2)	3)	
3.2	System description					
		System architecture	1)	2)	3)	Attach architecture drawing if available
		System technologies (hardware technology, communication networks, engineering tools, …)	1)	2)	3)	
3.3	System justification	On which basis were the system architecture and technology defined?				
		How were the renovated system limits and/or breakdown (for progressive renovation purpose) defined?				Precise in particular the objectives of this definition
		Any diversity study performed? If yes, precise objectives and content				
		How was the single failure criteria studied and taken into account?				
		Was there any specific human factors/ergonomic studies performed? If yes, briefly describe objectives and content				
		How was the potential future obsolescence of renovated system taken into account?				
3.4	Performances					
		Installed capacity (eg. number of logic and analog inputs and outputs, and/or number of internal variables, or number and/or elementary function blocks)	1)	2)	3)	
		Extension capacity	1)	2)	3)	Precise whether it is an equipped or non equipped spare capacity

N°	Title	Question	Answer			Remark
		Main response times	1)	2)	3)	Different response times can be given depending on the system missions
		Accuracy	1)	2)	3)	Different accuracies can be given depending on the system missions
		Time tagging accuracy	1)	2)	3)	Different accuracy can be given depending on the system missions
		Any worry during project development on the system performances? If yes, which ones?				In terms of capacity, accuracy, response times,
3.5	System configuration capacity and user-friendliness	Kind of modifications enabled by the system	1)	2)	3)	The different possible types of modification (addition of I/O's, internal computations, additional peripherals, new functions, …) should be identified before the interview
		For each type of modification,				
		system capacity to do it on line or not?	1)Yes/No	2)Yes/No	3)Yes/No	
		operator authorization to do it on line or not?	1)Yes/No	2)Yes/No	3)Yes/No	
		duration (to prepare, to carry out, and to test)				
		Any tool, mechanisms to control modifications brought to the system?	2)	3)		
3.6	Integration capacity (in an existing environment)	Any requirement(s) on separation with other existing systems? If yes, how are they ensured?	2)	3)		
		Description of the impact of the renovated system on its environment in terms of:	2)	3)		
		mechanical structure	2)	3)		
		civil works	2)	3)		

N°	Title	Question	Answer			Remark
		ventilation/heat removal	2)	3)		
		power supply	2)	3)		
		cabling	2)	3)		
3.7	Integration capacity (in a changing architecture for progressive renovation projects)	System particular features which ease (or on the contrary which make it more difficult) the system integration in a changing architecture?	1)	2)	3)	
3.8	Dependability	Any requirement(s) on single failure criteria? If yes, how are they ensured?				
		Any monitoring of the MTBF of the different components of the renovated system?	3) Yes/No			
		Significant differences of MTBF between specified and actual values	2)	3)		
		Any observed case of spurious actuation or incorrect information displayed?	3) Yes/No			
3.9	Extension and evolution capacity	System particular features which ease (or on the contrary which make it more difficult) the system extension and evolution?	1)	2)	3)	
3.10	Compatibility with existing standards	Standards with which the system is compatible	2)	3)		Mainly communication standard
3.11	Obsolescence	Means used to ensure that the system has a sufficient lifetime	1)	2)	3)	The means linked to the system (choice of components, of tools) are described here. The means linked to the project are described in page 79.
3.12	Qualification easiness	System particular features which ease (or on the contrary which make it more difficult) the system qualification?	2)	3)		In terms of tools available, methods used to develop it, design features, …
3.13	Environment	Was there any particular environmental constraints (seismic, temperature, vibration…)?				

N°	Title	Question	Answer		Remark
3.14	Impact on interconnected systems	What was the impact of the renovated system on the interconnected system?	2)	3)	Describe in particular those which were not identified initially

RETURN OF EXPERIENCE

For the characteristics described here, one to three answers are expected among:

- the former value before the renovation project
- the value expected at the beginning of the project (during system specification phase)
- the value actually reached at the completion of the project (when applicable and available)

N°	Title	Question	Answer			Remark
4.1	Project costs					Internal and external costs should be distinguished
		System definition, and project follow-up	2)	3)		
		System purchase	2)	3)		
		System configuration	2)	3)		
		System qualification (hardware + functional)	2)	3)		
		Installation and commissioning	2)	3)		
		Training	2)	3)		
		Maintenance	2)	3)		
		Total	2)	3)		
4.2	Project worth	with reference to the technical and/or commercial benefits of the following objectives				This can be established by using the project objectives identified in page 65
		objective 1	1)	2)	3)	
		objective 2	1)	2)	3)	
		…	1)	2)	3)	
		objective n	1)	2)	3)	
		Were there other benefits obtained which were not planned at the beginning of the project	1)	3)		Also with reference to the types of objective listed in page 65
4.3	Time schedule					
		Between first identification of a need and the decision to invest	2)	3)		
		Between the decision to invest and the coming into force of the contracts with the system suppliers	2)	3)		
		Between the coming into force of the contracts with the system suppliers and the system ready for delivery to site	2)	3)		

N°	Title	Question	Answer		Remark
		Between the system ready for delivery to site and the end of the commissioning and test	2)	3)	
4.4	Impact on Plant organization	Has the renovation project any consequence on your organization:	3)		Consequences can be: outsourcing increase of internal competencies staffing modification modification of limits of responsibility between departments
		on plant operation staff			
		on maintenance staff			
		on plant management			
		on I&C department			
		on engineering department			

N°	Title	Question	Answer	Remark
5.1	Return of Experience	In case you have a similar project to manage in the future:		All aspects (supplier selection, co-operation, choice of systems, strategy…)
		What would you avoid repeating?		
		What would you control more effectively?		
		What would you keep?		
		What problems have been encountered, or what potential problems could be encountered, in operation and maintenance of the hybrid HSI?		
		Other?		
5.2	How to succeed?	Any general or specific recommendations?		For example: what can be proposed or implemented to facilitate operation and maintenance of the hybrid HSI (redesign or modification of HSI components, staffing, training, procedures...)?

Appendix B

APPROACHES TO DATABASE DEVELOPMENT

1. INTRODUCTION

As mentioned in Chapters 3-6 and 7-1 it could be very helpful to use the data previously accumulated by other NPPs in the field of I&C modernization. This data can be helpful in doing a more realistic assessment of the task, in understanding the advantages and disadvantages from the planned modernization. Possible difficulties arising from the modernization can be detected and timely eliminated by undertaking the necessary precautions (early elaboration of the needed preventive measures). The database (DB) of modernization projects could be also helpful for finding similar tasks that were implemented with the best benefits for the utility, to decide on the modernization approach and to select well experienced suppliers.

That is why a regular collection and international exchange of such data would be beneficial for many utilities.

The following sections are written assuming that a relational database is used for the implementation. It does not mean that this option is the most appropriate for DB users from all points of view, however, such selection gives more possibilities to structure the data, to describe possible DB functions and data flows.

Significance of such DB usage for the managers could be very high, provided the content of the DB is adequate and sufficiently comprehensive. It is expected that it would be difficult to get data for this database with appropriate quality and the level of details. The IAEA responsible officer will have to determine if the potential users want to develop and populate such a database. There are many published documents, reports and papers describing good practices and lessons learned from NPP I&C modernization activities that could provide information for the DB [1, 34].

For example, in papers [1, 34] and in Appendix C, users may find interesting information on WWER I&C modernization implemented by Framatome ANP (former Siemens) at many NPPs in Bulgaria, Finland, Hungary, Slovakia and the Ukraine. One of the key conclusions from this experience, which could be taken into account by the plant managers, is the following: the success of the modernization projects strongly depends on social climate at the plant (traditions, culture, etc.). It means that favorable social climate should be prepared (or confirmed) before making a final decision on the modernization.

2. DATABASE STRUCTURE

The database is suggested as a supporting tool for the modernization project teams and the utilities. The DB structure has to support the users and be oriented on data processing optimization (including the data input and presentation). It should be as simple and transparent for the users as possible within the frame of the task to be solved.

In spite of the fact that exact DB structure can be defined only after the DB requirements development, the following several main groups (not necessarily DB formal tables) of required data can be identified earlier based on the objectives listed above and EDF questionnaire attached in Appendix A (see also Fig.1):

- NPP data, including internal management structure;
- I&C system data, including safety categorization and operational experience;
- Organizational and chronological data on the modernization fulfilled;
- Main data on the modernization projects implemented;
- V&V data (specially separated from the previous group due to independent significance of the lessons learned);
- Supplier data;

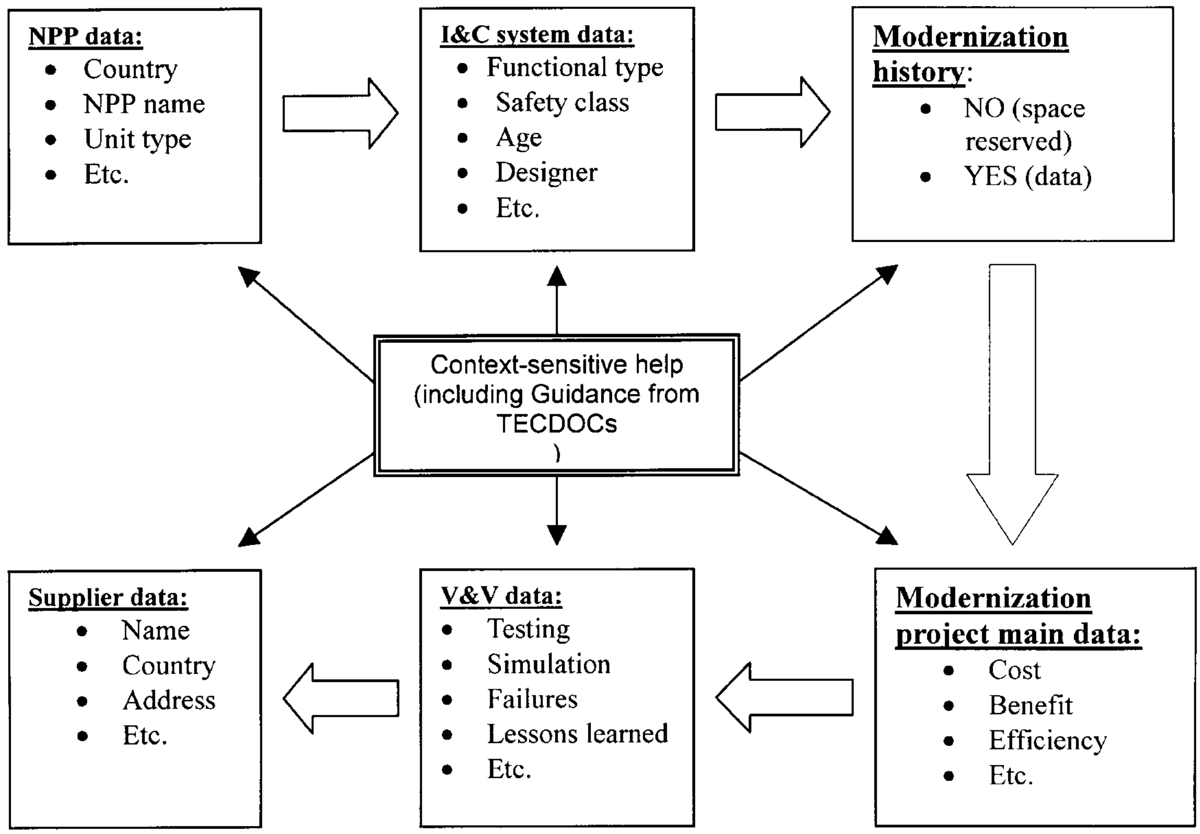

FIG. 1. Simplified DB structure (with an example of possible data flow while selecting the appropriate contractor).

Filling in the general data on NPP into the DB could be done independently from the rest of the modernization data and even in advance. An example of the more detailed content of the first group of the DB data ("NPP data") is shown in Table 1. The content of the other groups of the data can be preliminary assessed from the EDF questionnaire attached in Appendix A.

Table1. NPP data (example)

Field names of the DB table "NPP data"	Comments
Country	All Member States can be included in DB
NPP Name	DB should contain built-in pop-up menu with all names of NPP in the world
IAEA Code	Can be taken from: IAEA Nuclear Power Reactors in the World, Reference Data Series №2
Unit Number	From: IAEA Code, see above
Unit Type	From: IAEA Code
Construction Dates	From: IAEA Code
Date of Commissioning	From: IAEA Code
Main Technical Data	For each unit type technical data could be taken from other IAEA DBs and Guidebooks
Main Control Room layout or views	Important to assess man-machine interface before and after modernization
Operational Performance	Capacity factors are available for almost all the Units and could be used to assess efficiency of I&C modernization
Organizational Structure	At least simplified organizational diagram is needed
Type of operation	Base-load or load-follow operations have to be indicated
Event Reporting and Analysis System	Reporting off-site/on-site, reporting criteria, root causes analysis with problems revealing, etc.
Significant events, caused by I&C deficiency	Forced I&C modernization has to be identified
Utility Data	From IAEA and national documents
Other data	Optional

Fig. 1 also shows one possible data flow while selecting an appropriate supplier with the help of the DB. First, the users can find in the DB all units of similar type and then assess which I&C systems have been already modernized on each of them. Upon selecting the most interesting systems (from the view point of the modernization plans) and learning modernization history of these systems, the users can get the main data on the modernization projects implemented: costs, benefits, modernization approach (incremental or monolithic), etc. Special attention shall be paid on V&V results and the lessons learned from the modernization implementation. This helps to avoid many possible difficulties at the earliest stages of the modernization. Finally, comparing the results of modernizations implemented at similar type units, the users can help identify the most successful projects and the most appropriate supplier(s) for their modernization tasks. In co-operation with these suppliers a plant specific plan of modernization can be developed.

Figure 2 presents an example of the DB screen, reflecting the DB main menu bar and the window showing some data from the DB table "NPP data".

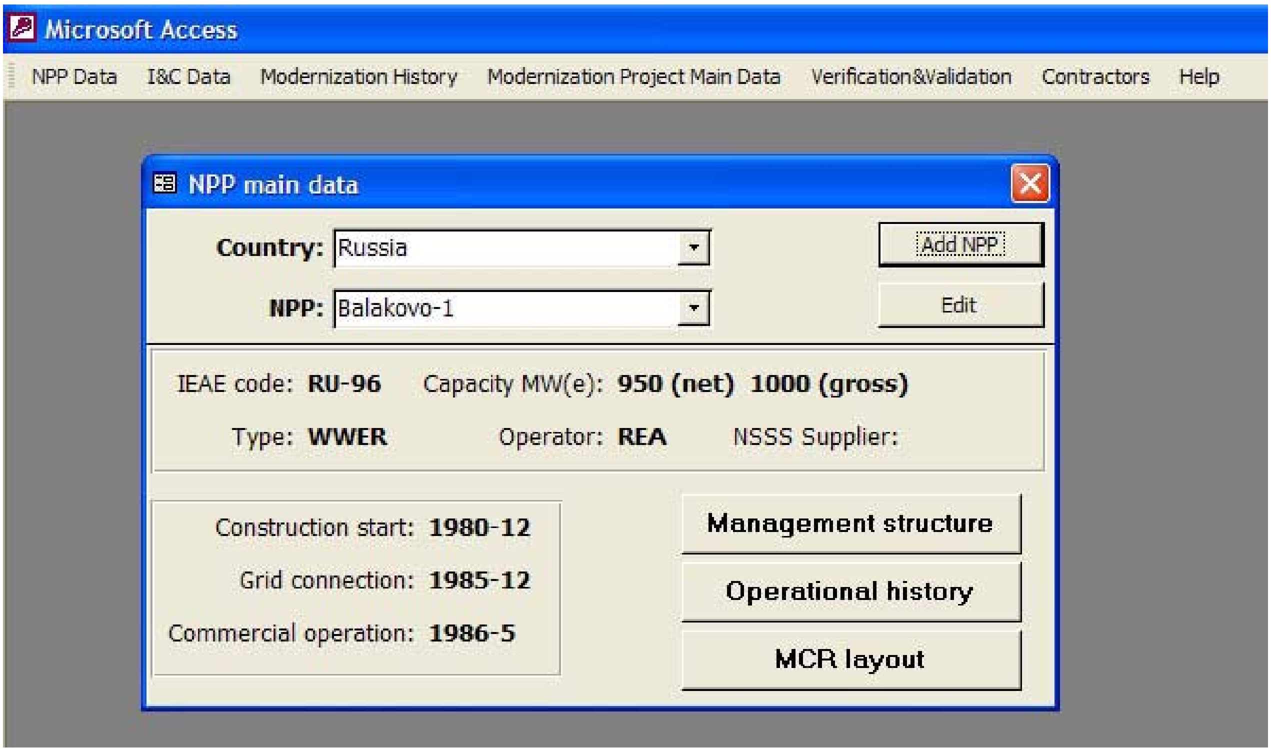

FIG. 2. An example of the DB main screen.

The user can get more information from the DB by selecting corresponding button, for example:

- Management structure;
- Operational history (performance);
- Main Control Room layout.

3. DATABASE FUNCTIONALITY

Database functionality usually depends on the main objectives of the DB and potential users' preferences. As a minimum, the DB should have the following functionality:

- Computerized input of all needed information (usage of built-in pop-up menus, check and radio-boxes, built-in guidance or questionnaire etc.);
- Data pre-specified processing (ratings and other calculations, trending, etc.);
- Present information in the form of different charts and tables;
- Searching the information by keywords;
- Filtering of information;
- Printing of reports in various form;
- Batch export/import of the data;
- Capability to be integrated on Internet;
- Context-sensitive help to the users;
- Access control for both retrieval and modification.

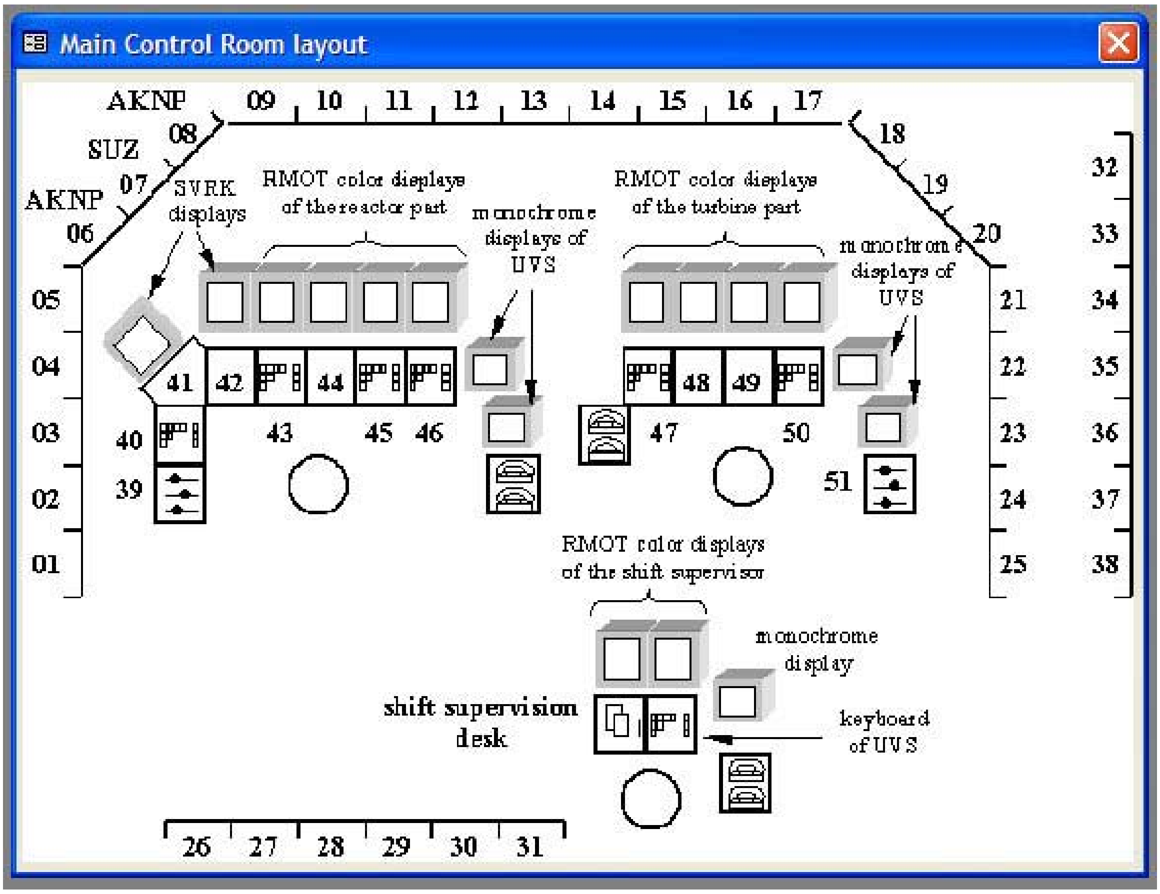

FIG. 3. An example of the DB screen with MCR layout of WWER-1000.

The built-in help would include:

- User’s manual;
- Any relevant IAEA documents.

4. MAIN TECHNICAL REQUIREMENTS FOR DB IMPLEMENTATION

From the first general assessment of the development objectives and potential users, the following main technical requirements could be listed:

- Designed for use on personal computers;
- Utilize COTS;
- Multi-users operation, including Internet;
- Compliance with the TECDOC contents;
- Openness for further development;
- Flexibility for easy modification and expansion;
- Internationally acceptable user-friendly interface;
- Using SSL for Internet access.

5. COLLECTION OF THE DATA

There are three main ways of the data gathering and input into the DB, all of them could be used for the data collection:

- Centralized input;
- Decentralized input;
- Combined input (combination of the first two options).

First way is to distribute specially prepared questionnaire (an example is presented in Appendix A) and then to use the answers for centralized input by a single organization. The second way is to develop the DB first and distribute it (or make it accessible on the Internet) for decentralized data entry. The third one is to allow both of the above options for information input.

Appendix C

EXPERIENCE IN REFITTING IN THE FIELD OF SAFETY INSTRUMENTATION AND CONTROL

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Abstract. In the last few years comprehensive modernizations and retrofittings of safety I&C in various nuclear power plants were carried out by the Framatome ANP using the digital automation system TELEPERM XS. Thereby it has shown that the very positive experience with digital automation systems in other industrial areas can also be applied to safety systems in nuclear power plants. A precondition of this is that the specific requirements of nuclear technology have been sufficiently taken into consideration in the development and qualification of the system platform. Through a comprehensive generic qualification, additional approval efforts and risks can to a large extent be avoided. The cost benefits of digital technology can also be made use of in the safety I&C and the tendency to use standard instead of special devices promises further cost benefits for the future. The simplifications to be expected for periodic tests and maintenance work have been confirmed by all projects. Field experiences have also shown that the theoretically determined very high reliability of safety automation systems TELEPERM XS is even surpassed in practice

Introduction

For more than twenty years digital automation systems have been dominating nearly all areas of industrial automation. The reasons for this are to be found in the system-immanent qualities of the device technology which allow a cost-effective, space-saving and low-maintenance solution of any automation task. At the same time the spreading use of the PC as a working tool led to a fast accumulation of know-how and experience in dealing with digital devices.

Despite their obvious superiority there are only few digital automation systems used in nuclear power plants. This is especially true for safety instrumentation and control (safety I&C). One reason for this is that in the last few years no new plants have been erected which are known to be an important impulse for innovations. Another reason certainly results from weighing the chances against the risks of a new device technology. The introduction of a new technology in safety- and availability-relevant fields of nuclear power plants results in a series of questions for which final answers will be found only after this technology will have undergone a field test.

This refers to

- effort and risks of the approval procedure,
- costs and lower space requirements as against the existing device technology,
- acceptance by the operating personnel and effects on the operation of the plant,
- periodic testing and maintenance,
- reliability within the operation of the plant.

In the last few years comprehensive modernizations and retrofittings of safety I&C in various nuclear power plants were carried out by the Framatome ANP using the digital automation system TELEPERM XS. The field experience thus gained forms a solid basis to be able to answer the questions mentioned above about the control system TELEPERM XS also from the field aspect.

Approval

The generation of software is generally thought to be extremely failure-prone. Therefore computer-based safety I&C systems are thought to require an especially high amount of verification efforts within the approval procedure and that this can also bear considerable risks. This fact was especially taken into consideration during the development and qualification of TELEPERM XS. Thus the generic qualification not only comprised the hardware but also the entire system software and engineering tools. Consequently, the subject "software qualification" is now almost irrelevant for the individual approval procedure. Furthermore, in addition to the individual components all TELEPERM XS safety-relevant system features as well as the engineering processes during the project management were included in the generic qualification. This results in a high degree of certainty about which documents are to be set up during the project management, which verifications have to be presented and how these are to be documented. The aim of all these measures was to safeguard that the approval of a safety control system with TELEPERM XS device technology does not require more effort than the approval of a comparable hardwire system.

The experience with successfully completed approval procedures in different countries confirms that this aim has almost completely been reached. Up to now neither project delays nor considerable additional expenditures have arisen from approval procedures of TELEPERM XS projects. As a matter of experience, however, the first approval procedure in a given country requires a certain increased effort. The use of computer-based devices leads to a new evaluation of some safety-relevant features. Thus, failures will have wider effects but the importance of random failures will clearly decrease due to the additional monitoring mechanisms. The practical implementation of this new evaluation requires the accumulation of additional know-how in the approving authority. However, worldwide increasingly more intensive communication between the approving authorities leads to an intensive exchange of experience so that this aspect is unlikely to play any part in the future development.

Costs and Space Requirements

The higher integration level of digital automation systems allows implementing a given scope of automation tasks with considerably less hardware than that required for hardwired device technology. Based on the assumption that the costs for the installation of a switchgear cabinet for electronics in the plant are approximately the same for both technologies, the reduced amount of hardware will proportionately result in reduced costs and space requirements. The amount of hardware for safety systems is not only determined by the scope of safety functions to be implemented but to a great extent by the combination of faults to be governed, since these will result in independence and redundancy demands. Since the combinations of faults to be governed are independent of the device technology used, cost and space advantages of digital technologies for safety I&C can only in parts be used for the benefit of greater reserves.

Experience with previous projects has shown that reductions of space requirements from 20% to 40% for medium and larger projects are realistic. Due to the infrastructure required for all projects, very small projects (amount of hardware in hardwired device technology is clearly less than one switchgear cabinet for electronics) might even require more expenditure in extreme situations than hardwired device technology.

Overlaying the effect described is a further cost advantage of digital technology which in the future will clearly gain importance. Whereas in the past an especially developed device technology was used for safety tasks in nuclear power plants TELEPERM XS is based on industrial standard devices. The major field of application of these devices is conventional automation. A variety of costs are arising from the manufacturing of electronic products which are independent of the number of components produced. Since these costs must also be covered by the products this leads to higher prices for those products which are manufactured in small quantities. The turnover and thus the costs for industrial standard products – and among these ranges TELEPERM XS – is nearly independent of nuclear technology, since this only covers a very small part of industrial automation. On the other hand the declining market for nuclear technology and the partly outdated production procedures lead to a continuous and partly dramatic increase of production costs for special developments. This tendency has been observed for some years now and will even gain importance in the future.

Operation of the Plant

The features immanent in digital technology offer a variety of possibilities to simplify plant operations. Examples are the implementation of more intelligent automation functions or the graphic display of the state of the plant by means of pictures. Whether and to which extent these options are used, very crucially depends on the concepts of plant management. Previous experience has shown that there have been very different customer requirements which have mostly been met.

Plants in which the operator is very actively participating in the plant management usually like to keep the plant management concept unchanged. The reason for this is usually that a change of the plant management concept will necessitate a considerable amount of training and that substantial acceptance problems by the operating personnel have to be expected. In the majority of previous TELEPERM XS projects the existing plant management concepts have therefore been maintained which from the technical aspect has not presented any problems. The chances of an improved processing of information have in most cases been used in addition to the conventional instrumentation. Previous experience has shown that this information has been accepted in very short time in all nuclear power plants.

Especially for new plants there were customer requirements for unlimited use of the new device technology and adaptation of the concepts of plant management to the altered technical potential. Respective concepts were already coordinated with the customers but up to now there has been no field experience to rely on.

Periodic Test and Maintenance

With respect to periodic tests and maintenance work digital automation systems are expected to offer essential simplifications as against hardwired devices. Due to the implemented self-monitoring measures nearly all faults will be detected and signaled spontaneously. As a consequence the tests can be limited to such functions which are not covered by self-monitoring. Furthermore the central service facilities allow a fast localization of faults so that the necessary repair work can be carried out straightforwardly thus considerably reducing the related effort.

To which extent these features will reduce the scope of test and maintenance efforts very decisively depends on the respective efforts related to the comparable product. In this respect there are considerable differences between the systems. Some plants, for example, officially require that large parts of the hardwired I&C be tested periodically every four weeks. Since these inspections are usually performed as manual tests (without automatic testers) this requires an enormous effort. Other plants are already utilizing automatic testers for the hardwired I&C, considerably reducing the effort. With these facts in mind any statements on absolute savings can only refer to individual situations.

Previous experience with TELEPERM XS projects have shown that due to comprehensive self-monitoring periodic tests of computers and communication connections can be completely dispensed of. The scope of testing is therefore limited to the measuring channels and the switchgear interfaces. Since the measuring channels are to a large extent also covered by self-monitoring, a clear reduction of the inspection frequency can often be agreed upon with the approving authority.

Reliability

Within admissible interpretation the reliability of safety systems is verified by means of probability analyses. Hidden random failures are largely excluded as a consequence of comprehensive self-monitoring measures with positive effects on the reliability characteristics. The smaller amount of hardware also leads to lower failure rates with further positive effects on the reliability characteristics.

Previous analyses have shown that safety systems in TELEPERM XS device technology have a reliability ten times higher than that of hardwired systems of equivalent structure. At first these analyses were based on theoretically determined failure rates of the individual components. Field experience from retrofitting projects have provided sufficient information to statistically verify these theoretical values by practical experience. As a result the actual failure rates turned out to be two to four times less than expected on the grounds of the theoretical analyses. Already with hardwired devices the experience has been that theoretically determined failure rates are by trend too high.

Furthermore, probability analyses were based on the assumption that safety control systems — even with low probability — could commonly fail due to configuration and manufacturing faults (common cause failure). The assumed probabilities were taken from technical literature and experiences with safety-relevant systems from other industrial fields. Again practical experience has shown that these values are by far too conservative. Up to now a common failure of several components has not been observed in any of the projects.

Summarizing, it can be said that the very positive experience with digital control systems in other industrial areas can also be applied to safety systems in nuclear power plants. A precondition of this is that the specific requirements of nuclear technology have been sufficiently taken into consideration in the development and qualification of the device systems. The cost benefits of digital technology can also be made use of in the safety I&C and the tendency to use standard instead of special devices promises further cost benefits for the future. The simplifications to be expected for repetitive inspections and maintenance work have been confirmed by previous projects. Field experiences have also shown that the theoretically determined very high reliability of safety control systems in TELEPERM XS device technology is even surpassed in practice.

Appendix D

EXPERIENCE FROM SUCCESSIVE MODERNIZATION OF INSTRUMENTATION & CONTROL SYSTEMS OF FORSMARK 1&2

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Abstract. Successive modernisation performed during several normal outages or one major modernisation during a prolonged outage is a question discussed at many Utilities nowadays. There are of course advantages and disadvantages with both the approaches. Modern control systems based on programmable equipment and networks also involve taking a comprehensive view of the plant concerned in order to achieve a control system that works properly from both the technical and ergonomic (control room environment) points of view. It is also important to be able to handle the new possibilities created by introducing a new control system into a control room in such a way as not only to effect functional improvements but also make the best possible use of the operating staff's previous experience. The end goal of a modernisation is to reach a completely upgraded power plant with integrated controls. As the plant after the complete I&C upgrade are to be controlled and monitored in a consistent way, which means same look and feel for operator, whichever valve or other process component that are manoeuvred, initial planning is essential. The I & C modernisation at Forsmark 1 and 2 is presented as well as the goals with the modernisation, general key success factors and specific lessons learned.

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1. PLANT I&C MODERNIZATION IN GENERAL

1.1. PROJECT MODERNIZATION APPROACH

Successive modernisation performed during several normal outages or one major modernisation during a prolonged outage is a question discussed at many Utilities nowadays. There are of course advantages and disadvantages with both the approaches.

The main advantages with one major modernisation during a prolonged outage are that temporary hybrid solutions are avoided in the Control Room and for the control equipment. Consistency in system versions, both hardware and software, is reached easily.

The main advantages with successive modernisation performed during several normal outages are:

- No prolonging of any outage, economical and logistic reasons
- Minor modernisation each outage gives less economical risk due to less investment binding, less risk of problems that may inadvertently prolong the outage
- Minor projects are easier to manage both for utility and supplier. Scope and specifications are limited and predictable.
- Lessons learned can be applied for next outage. Continuously improvements for both utility and supplier.

Which path that is most economical is hard to tell. Theoretically, the "one outage modernisation" seems more economical due to less temporary solutions and over-all shorter project duration, but gained experience seems to show the opposite.

Forsmark choose the successive modernisation path due to two main reasons:

- Utility main experience is to operate and maintain the Nuclear Units. Their organisation is not set up nor trained to execute major complicated modernisation projects. To do so anyway would create an enormous economical risk not defensible.
- Prolonging of outage is not economical defensible.

Forsmark has decided that the sum of outage periods for one unit may not exceed 73 days in 5 years, which in average means two short outages of 10 days followed by one long of 20 days (fuelcycle 12 months).

1.2. PHASED IMPLEMENTATION APPROACH

Important aspects of control system modernisation in existing plants include being able to carry out staged replacement so as not to lengthen ordinary shutdown times for overhauls, which imposes special requirements regarding the joint functioning of different systems during the modernisation period.

Modern control systems based on programmable equipment and networks also involve taking a comprehensive view of the plant concerned in order to achieve a control system that works properly from both the technical and ergonomic (control room environment) points of view.

It is also important to be able to handle the new possibilities created by introducing a new control system into a control room in such a way as not only to effect functional improvements but also make the best possible use of the operating staff's previous experience.

When defining a strategy, one needs to take different aspects into account. Our assessment is that the plant has been operated and maintained in such a way that no compelling technical reasons exist for a forced exchange of limited equipment. This means that there are good possibilities for a planned integration of new equipment into the working situation of the operation and maintenance teams.

This gives the opportunity to set up a common long run vision how your control room and control system infrastructure would look like in 20 years. From that you would be able to derive a strategic plan how to reach the vision, meaning continuing modernisation step by step.

When an I&C platform is chosen, a long term agreement with the supplier is necessary, specified with certain criteria. The fact that a platform is chosen should be used inside the organisation to force everyone to act accordingly, cause any choice of equipment outside the platform, will cause problems in the long run for maintenance and operational staff.

From a technical point of view the order in which the replacement is done is not the only critical aspect. Other aspects such as need for replacement due to ageing, physical layout, ergonomically requirements in the control room or new requirements from regulatory bodies should be used to define the order of replacement.

Utility management may not urge for modernisation until it is a crisis. That gives short planning and time schedule, all steps are rushed through, supplier may be able to handle it, but utility people are overruled, ending up in uncomfortable solutions. What is done is done. It is necessary to plan ahead to reach proper time schedule.

As a start, it is important to build the infrastructure in the plant, to which new modernised systems will be connected successively. Important issues are setting the operator interface in MCR, using same interface for controlling the process and for the process plant computer. The investment may seem heavy, but with the perspective of a 20-year modernisation plan, it is cost beneficial.

For the organisation, successive learning is advantageously. Peripheral systems with good mixture of controlled components and monitoring are good training objects, like Radwaste Control system or Condensate Clean Up system. If modernisation is postponed due to lack of decision, you may end up with availability problem of safety systems or RPS, causing spurious trips with great production losses. To start modernisation with RPS, one of the most complicated systems, should definitively be avoided.

1.3. KEY SUCCESS FACTORS

General

The end goal of a modernisation is to reach a completely upgraded power plant with integrated controls. As the plant after the complete I&C upgrade are to be controlled and monitored in a consistent way, which means same look and feel for operator, whichever valve or other process component that are manoeuvred, initial planning is essential.

To reach the goal of uniform behaviour from operator as well as maintenance view, it is essentially that as the first stage of a modernisation, design rules are established, giving the designers prerequisites how to design and standardise the modernised control system.

Example, type circuits in the analogue equipment to control a certain type of pumps, fans, valves and so on. Assure that these type circuits are converted to type circuits in the new digital I & C system.

However, design rules should be developed successively, matching the successive modernisation. To develop all design rules up front modernisation, probably ends up that you never get started. Try early to state fundamental rules that shall be fulfilled in the new equipment. Also, the utility organisation learns how to use possibilities with digital systems, why the design rules may have to be adapted as the modernisation pass on. When new rules are established, make sure that these rules are spread in your organisation and to the supplier. Do not forget the training part, not until the designer understands the rules, he is able to follow them.

Operation and Control Room

A key issue for success is getting the acceptance from operational staff, in designing Control Room and Soft Control Displays. Some important factors are:

Modernize complete section of control desk or complete operational task. Follow Operational Instructions and cover all steps, preferably on same screen. Operators hate situations where both screen and mimics have to be used, especially if the information is geographically separated or contradictory. Avoid split visions!

Use the benefits of integrated digital systems, giving operators increased values. Like task-oriented pictures, like important information from other process systems that might be effected during the operational task, like during surveillance testing, peripheral system parameters may be effected.

Operational people need to participate in the modernisation tasks. Participating operators must have confidence by the rest of the team. All the team has to feel participation.

A formal Control Room modernisation process has to be established, which is usually required by authorities, to secure the work of the operators in the modernised control room.

In Forsmark, the process is called "Manfred", and main checkpoints are:

- Don't forget anything in the new design that existed in the old.
- That all the new are needed or useful for operator.

Staff and Organisation

During the whole modernisation period the modernisation goals and the role of each group in the organisation must be very clear.

- The board is responsible for the investment decision and long term commitment
- Management must be prepared to take unexpected economical or strategically decisions with short notice during the travel.
- Make sure all members of the organisation are prepared and heading in same direction
- After Modernisation decision are taken, shut the mouth of opponents
- Organise for quick implementation of lessons learned
- Digital I & C mean that you will introduce new responsibilities in your organisation. Prepare for development of new competencies, like know how of computer networks, personal and tools to handle and make fault detection of fibre-network and components.

Projects

During the successive modernisation many separated projects will be performed, for different outages, but occasionally, also many project for a specific outage, in case several systems are modernised at same time. Some important issues are:

For each project, people from utility have to be assigned to the project, full time, released from regular duties. If not, regular duties will be prioritised and the effort for the modernisation will start to late, which means utility will end up with a solution they do not like. Conclusion, if **you do not put effort in the beginning of a modernisation project, you would have to suffer for the next 20 years**.

People from utility that has to be assigned to the project are operational people and engineering staff (primary designer and maintenance engineer). Use hired people to do regular duties, good investment for future.

Co-ordination between the different successive projects is necessary but has to be handled carefully. With too much co-ordination the progress may stop. Setting up an organisation group responsible for co-ordination could be a solution, but its responsibility has to be balanced with other groups in the organisation.

2. EXPERIENCE FROM PLANT I&C MODERNIZATION IN FORSMARK 1&2

2.1. BACKGROUND

At 1994 the situation at Forsmark 1 and 2 was

- The Process computer designed around 1980 must be replaced as the Norsk Data (Norwegian Computer), the supplier of the process computer went out of market.
- The data acquisition system DS8 of the Process computer was utilised at its full extent.
- The control rod manoeuvring system was beginning to malfunction, system must be replaced.
- The old analogue I & C equipment still works but with a great amount of maintenance. Specially on the turbine side. Many components were obsolete.

The plants would at 2000 be at "half-time" of there planned lifetime. Forsmark staff realised that the old analogue I & C equipment needed to be replaced.

2.2. STRATEGY

Forsmark started the following investigations

- Control Room Philosophy and Design study.
- Conceptual studies for replacement of all analogue I & C to digital I & C were ordered from different suppliers.

As a result of these studies the following major requirements where established:

- The number of different MMI´s should be kept as low as possible. The operators request was one single MMI concept in the MCR (Main Control Room).
- Create one platform for all future digital I & C, comprising both non safety and safety equipment.
- Create a good maintenance situation.
- The whole platform should be built in such away that it shall not fail to perform its functions due to any single failure.
- The process computer should be an integrated part of the new I & C platform, same MMI for control and PPC.
- All changes shall be made within the fixed outage periods.

Any other method then successive modernisation was not worth to discuss with the Forsmark management.

The reason for this was economy and the hazard with huge projects.

Forsmark has adjusted its organisation during the twenty years of operation to maintenance, smaller modernisation projects and operation of the plant. Subsequently Forsmark does not have people or organisation to handle huge modernisation projects.

2.3. REALISATION OF THE PLATFORM.

As a result of our requirements and the lack of standards among Control system, one supplier for the entire modernisation of the I & C equipment had to be chosen. And subsequently a modernisation agreement had to be established with that supplier.

Late 1995 a contract with ABB covering design and installation of the new I & C platform and corresponding changes in the simulator was established.

2.4. CONCEPTUAL I & C PLATFORM FROM WESTINGHOUSE IN FORSMARK 1 AND 2 ENVIRONMENT.

The conceptual structure from Westinghouse (former ABB Atom) is shown in Appendix 2.1 and the integrated concept at Forsmark 1 and 2 in Appendix 2.2.

In short the structure seen from the process level is:

- Control networks (field bus), used for the data transfer between controllers.
- Information network, to support the Operator stations (I&C MMI) and the process computer with process data. The process computer also acts as a server for process data to the upper networks and communication server for the specialist systems.
- MCR-network-A, connect specialist systems to the Operators MMI. The network ends in a firewall to protect all underlying systems.
- Forsmark base network, connects all administrative systems and office PC´s. The PDB (Process Data Bank) is connected as a gate between the MCR Network-A and the Forsmark base network.

The goal, one single MMI for the operator has been reached in a satisfactory way. This has been achieved by the usage of a MMI concept from the I & C supplier and by the use of X11 / Motif for interfacing of the specialist systems to this concept.

2.5. GOALS IN THE FORSMARK 1 AND 2 INVESTMENT PROGRAM 2000.

- Create one platform for all future digital I & C, comprising both non safety and safety equipment.
- Replace the process computer as an integrated part of the new I & C platform, same MMI for control and PPC.
- Replace and integrate the Control rod manoeuvring system into the platform
- On the turbine side, the long-term goal is to replace all old analogue I & C equipment. Another goal is to upgrade from two to three channel turbine protection.
- On the reactor side, the plan is to replace old analogue I & C when and where forced to due to poor performance.

2.6. STATUS IN THE REPLACEMENT YEAR 2001.

During the years 1996 to 2000 the following has been done

Year	Appendix	Text
1996	2.3-2.4	"Minor" changes in the MCR to create space for more screens.
1996		Installation of two new battery backuped electrical nets just for computers and Network equipment.
1996	2.5	Installation the MB300 network for connection of OS (Operator Station) to Controllers.
1996	2.6	Platform design principals
1997	2.7-2.8	Replacement of the plant process computer
1997	2.9	Replacement of the control rod manoeuvring system
1997	2.10	Replacement of the analogue two channel turbine protection system. New system three channel.
1998		Replacement of the TIP (Transfer In core Probe) equipment for calibration of LPRM detectors. New mechanics from Siemens and monitoring and control through existing AC450 controllers.
2000		Replacement of turbine control system
2000		Replacement of turbine process controllers
2000		Replacement of equipment for Condensate Clean Up system
2000		Replacement of reactor recirculation main drives and its control.
2000		Introduction of big screen presentation in MCR through Barco projectors connection to OS
2000		Introducing S800 equipment for cheap collection of information data points.
2000	2.11 2.12	Total system configuration 24 AC450 controllers 22 AC110 controller / S800 60 S100 data acquisition units 40 S800 data acquisition units 11 Advant Operator stations 3 Big screens 2 TFT screens inserted into panel

2.7. LESSONS LEARNED AND EXPERIENCES.

Valuable experience was made during the modernisation of the MCR computers and the I & C equipment. Some of the lessons learned are listed below

- Let different suppliers do a conceptual study over how your plant can be modernised with their equipment. The study shall clearly show how they solve your requirements today and how the concept can be extended in the future.

This gives you a better understanding of the supplier's equipment and his way of integrating the equipment into your environment.

- For example with this better understanding of the concept do you have existing cable ways in the plant for this?
- MMI, this is a complicated part and opinions varies a lot from plant to plant. However here is some advice's
  - If you earlier have a graphical MMI. Use that as the base for the requirements concerning what tools and base picture elements that the new MMI should have. Think in terms what basic picture elements do you need to create wanted picture contents. What kind of dialogs do you prefer.
  - The design of pictures for a system is an iteration process between the supplier and the customer at a live system. Our experience is that it is impossible to get a good result only from specifications.
  - Try to understand the problems and limitations with the MMI that the supplier has. Normally the MMI / Graphical editors from the big suppliers of I & C are very poor in functionality.
- Changing from analogue to digital I&C will imply that maintenance people will take over work that previous was done by computer people. This change must not be neglected.
  - Are these maintenance people educated for this.
  - Are there any old rules that they need to be aware of, for example in our case an old rule was to set the Operators need in focus. Is this automatically clear for maintenance personal? At Forsmark NO.
  - Are these maintenance people aware of that they in a project are responsible for everything from process interface to operators MMI. At Forsmark NO.
- Modernisation of equipment often leads to increased redundancy and new solutions. Make sure you have a clear picture of how this new solution will effect the operator. Otherwise you will end up with a mess produced by the programmer. For example you must have rules / visions on how to supervise and handle alarm from a three channel control system. State the rules, otherwise the programmer will do it for you.
- Your plant has a naming convention for pumps, fans, measuring points and so on. Make sure that this will be applied also in the new system. If new naming conventions needs to be added, take care of the questions at an early stage. An advice is that no one else but a single responsible person or group of persons on the plant shall be allowed to assign names for new signals and Objects.
- Your plant has a documentation structure. How shall documents for the new system be integrated in this hierarchy. Discuss with the supplier how to handle new type of documents.
- Don't imagine that anyone outside your plant has more knowledge of the plant than proven. The vendor had the knowledge at the time the plant was built, but what is the status today? Don't underestimate your own knowledge.
- A new "IT infrastructure" is installed that must be handled. …versions, configuration control, compliance…..
- Specially in the case when going forward with successive modernisation, beware of different versions of operating systems, otherwise you will be trapped in a never ending

upgrade situation. If an upgrade is absolutely necessary make sure in the contract that the supplier is responsible for upgrading the whole platform.

- During design of the new I & C platform, Forsmark had three persons participating in the Westinghouse project during 2 years. This is the best training and education your maintenance personal can get and when the system comes to site these people are directly familiar with the equipment. Don't miss this chance.
- Start writing your own work-procedures with the system before and at delivery. There will never be an opportunity again with that amount of changes in the system.
- Use simulator personal in the project to produce user documentation and to train the operators. The idea is to get a documentation that is used when training operators in the future not only a one shot project training.

Appendix E

MODERNISATION OF THE COMPUTERISED INFORMATION SYSTEMS (CISS) AT THE TIHANGE NUCLEAR SITE

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Abstract. Seven NPPs are presently in operation at the Belgian Doel and Tihange nuclear sites. The CISs implemented in those plants – both at the origin and during already performed modernisation projects – were up to now "tailor made" systems. Obsolescence problems with CIS at Tihange unit 2 led to a global re-assessment of CISs at all Tihange units and associated simulator. It was decided to open the door to systems implementing proven standard hardware products and software packages. A global replacement strategy covering also the long-term maintenance of the system was adopted. Licensing discussions had to occur beforehand to agree on the software safety classification and associated requirements to be taken into account for the modernisation. Tihange units 2 and 3 are now equipped with a new CIS. New CISs installation and commissioning had to fit in the foreseen plant outage periods and inconveniences for operation had to be limited to a minimum. CIS modernisation at unit 1 and at the simulator is to follow in 2002.

1. BACKGROUND

1.1. THE TIHANGE NPPS

The private Utility Electrabel owns almost 95% of the 16.000 MW installed electricity production capacity in Belgium. Tractebel Energy Engineering as Architect/Engineer of Electrabel is in charge of all construction and modification projects related to both conventional and nuclear Electrabel power plants.

Electrabel operates seven NPPs of PWR type in Belgium. They amount to almost 6000 MW electrical output capacity and ensure some 57% of the country's electricity consumption.

Commissioning of those plants occurred respectively in 1974/75 for Doel 1/2 (two loop twin units), 1975 for Tihange 1, 1982 for Doel 3, 1983 for Tihange 2 and 1985 for Tihange 3 and Doel 4.

Those seven NPPs are located at two different sites: the Doel site situated in the northern part of Belgium (nearby the town of Antwerp along the river Schelde) and the Tihange site in the south (near Liege along the river Meuse).

The three units at Tihange site are three loop units each rated around 1000 electrical MW. A full scope simulator – basically the replica of unit 2 – is also implemented at the site for operator training purpose.

1.2. THE CISS AT TIHANGE SITE

1.2.1. Actual CIS at Tihange unit 1 (see fig. 1)

When commissioned in 1975, Tihange unit 1 was equipped with a CIS featuring a limited number of analog and digital inputs. This system was mainly devoted to data logging of events/alarms, edition of reports and acquisition/treatment of In-Core neutron flux and temperature signals RIC ("Relevé InCore") function. It was complemented by a non-computerised temperature scanner that allowed monitoring of selected Thermocouples and RTDs installed on the process.

During the first ten-year safety revision of the plant (1986-1987), the CIS and the temperature scanner were already replaced by a more suited CIS showing:

- Extended number of analog and digital inputs;
- Improved treatment capabilities;
- User friendly HMI implementing full graphic colour screens in the Control Room and in the Technical Support Centre.

1.2.2. Previous CISs at Tihange 2 and 3 (see fig. 2)

Both plants were equipped from the origin (respectively 1982 and 1985) with CISs allowing:

- Acquisition of process relevant analog and digital inputs;
- Presentation of information (via semi-graphic colour displays) to the operators in the Control Room;
- Archive recording and file export on tape.

Data loggers independent from the CIS were implemented to monitor digital informative signals originating from the emergency Reactor Protection/Engineered Safety Features Actuation Systems (CPW) that are located in the second level of plant I&C (intended to cope with external accidents – e.g. airplane crash).

Specific Data Acquisition Systems scanning a limited number of analog signals (250) at a high rate (20 samples per second) were used during commissioning to record the main plant parameters during the large transient functional tests (SCRAM, load rejections,…). Those systems were still in use as perturbography triggered by SCRAM or turbine trip.

1.2.3. Actual CIS at Tihange full-scope simulator (see fig. 3)

One of the two ENCORE (GOULD) computers of the simulator runs a stand-alone replica of the Tihange 2 CIS. This simulated CIS is linked to the process simulator itself via:

- Shared « data pool » as far as the process variables are concerned;
- «Service signals» for simulation mode (freeze, slowdown, accelerate), time synchronisation,…

2. TRIGGER TO MODERNISATION OF CISS AT TIHANGE SITE

Support for CIS in unit 1 is contractually guaranteed up to 2005 through contract with original manufacturer Belgian ACEC. I/O cards/front-ends of AC132 series and display generators PPE-G are proprietary ACEC made equipment. A specific subcontract with Digital secured PDP11 computers support.

Upgrades of the CISs in Tihange 2 & 3 occurred in 1997:

- SOLAR 16/65 computers were upgraded (implementation of new and more powerful CPUs, replacement of cartridge disks by double access static ones -allowing to open the system to the external word;
- Number of digital inputs at Tihange 2 was brought to the same level than in Tihange 3 (4096 → 6144);
- Software in both units were totally uniformised.

Those upgrades were aimed to allow extending support possibility from the manufacturer up to 2010. In 1999 however, obsolescence problems with AYDIN display generators in Tihange 2 imposed to reconsider globally the problem of CIS perennity in Tihange 2 and 3 units and in the simulator.

A cost/benefit study was performed by TEE to identify the best-suited solution to be adopted. It came out that replacing the CISs treatment/HMI level while maintaining the inputs acquisition level was the best alternative.

It appeared also advisable to opt for a global and homogeneous replacement at the 3 units and at associated simulator considering the aspects of:

- Cost of actual CISs annual maintenance contracts;
- Burden of training and maintenance for the different systems;
- Operators training on simulator with up to date CIS simulation.

3. THE TIHANGE CISS MODERNISATION PROJECT

3.1. REGULATORY FRAMEWORK

At initial design and construction of the plants the CISs were considered as non class 1E because all information provided by the CISs was also made available in parallel on hardware devices to the operators in the Control room (signalling lamps, indicators, recorders).

As a consequence:

- All input signals originating from class 1E systems are through 1E isolation devices ;
- Electrical power distribution to the system is from redundant non-class 1E sources.

See fig. 4 for integration of CIS in the I&C structure of Tihange 2 & 3 and links of CIS with the other plant I&C systems.

At the very beginning of the CISs modernisation project, Licensing discussions took place with the Belgian Safety Authorities in order to reach beforehand a consensus about the system classification to be taken into account and the associated relevant requirements to be laid down. An analysis was performed in order to identify the CIS functions that could impact safe operation of the plants.

3.2. TECHNICAL/COMMERCIAL PREREQUISITES

It was decided to limit up to a maximum specific « tailor made » developments and to open the door to the use of proven standard market available hardware products and software packages.

Limits of the modernisation were also evaluated in order to cope with obsolescence of some other plant information systems. This led to integrate in the new CISs project the replacement of the:

- CPW (second level Reactor Protection/ESFA Systems) data loggers in Tihange 2 and 3;
- Data Acquisition Systems in Tihange 2 & 3 and in the simulator;
- In Core linked computer (RIC) in Tihange 3;
- Alarm handling systems in Tihange 1, 2 and 3.

Along with call for bid for the CISs themselves, proposals for 10-year maintenance (integrating maintained acquisition level) were asked for in order to evaluate the bids on the total cost of the project.

3.3. PROCUREMENT PHASE FOR THE PROJECT

Procurement activities for the project occurred according the relevant EC procedures for Service Contracts.

Announcement in the Supplement to the Official Journal of EC raised interest of 15 companies. After analysis of the received pre-qualification files, 6 companies were taken into account for participation in the call for tender stage that occurred early 2000.

Call for bid was for:

- The CISs systems in units 2 and 3 as basic scope intended for contracting in 2002 at the latest;
- The CISs systems in unit 1 and simulator as options intended for contracting in 2004 at the latest;
- The long term (10-year) maintenance of the systems.

Competition was tough and first contract was finally placed with the Belgian manufacturer Macq Electronique in September 2000 for Tihange 2 & 3 at around 600.000 EURO per unit. See fig 5 for new CISs structure.

Associated maintenance costs (inclusive maintained acquisition equipment) will be at no more than 20% of actual CISs maintenance costs.

3.4. ACTUAL STATUS OF THE PROJECT

CIS replacement in Tihange unit 2 occurred in June-July-August 2001 along with the outage for steam generators replacement (63 days); Tihange 3 replacement followed during normal outage of the plant in September 2001 (3 weeks).

For Tihange 1 and the simulator, the contract will be placed before end 2001 with both implementations foreseen in 2002 (during the September outage for Tihange unit 1).

4. MAIN FEATURES OF CISS REPLACEMENT AT TIHANGE 2 & 3

4.1. AVAILABILITY OF THE CIS

CIS replacement works had to be performed so as to fully fit within the plant outage activities and planning.

The CIS is a useful tool for the operator and the test teams even in plant shutdown conditions. As such, unavailabilities of the system had to be kept as low as possible.

Smooth and almost bumpless switchover to the new CIS was achieved by:

- Pre-outage preparatory cabling/mechanical works on site mainly for Tihange 3;
- Automatic import of existing databases (points, algorithms, displays) of old CIS in the new one; this allowed to limit site validation works to a minimum and to benefit from data validation built up during both commissioning tests and 20 years of operation of the plants;
- Extensive in-factory functional testing of the new CIS;
- Quasi-parallel working of old and new systems taking advantage of their master/slave configuration.

4.2. THE RIC FUNCTION AVAILABILITY

The RIC function which is integrated in the CISs performs the acquisition of the In Core neutron flux and temperature signals. This function gathers all the information of one In Core campaign in files that are in turn sent tot TEE to allow for periodic core calculations. After outage, the availability of In Core and RIC is mandatory in order to validate the new core and to allow full power plant operation.

As In Core is not available during outage, validation of the new RIC function had to occur prior to the stop of the plants for outage.

As RIC function was one of the CIS functions identified as more important for safety, exhaustive tests occurred to validate new RIC interfaces with In Core and new RIC results by comparison with old RIC ones.

REFERENCES

[1] F.-R. Hilbert and M. Martin, The Secret of VVER Upgrade Success, Journal of Nuclear Engineering International, p.14, April 2001.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Modern Instrumentation and Control for Nuclear Power Plants: A Guidebook, Technical Reports Series No. 387, IAEA, Vienna (1999).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Modernization of Instrumentation and Control in Nuclear Power Plants, IAEA-TECDOC-1016, Vienna (1998).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Advanced Control Systems to Improve Nuclear Power Plant Reliability and Efficiency, IAEA-TECDOC-952, Vienna (1997).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Computerized Support Systems in Nuclear Power Plants, IAEA-TECDOC-912, Vienna (1994).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Specification of Requirements for Upgrades Using Digital Instrument and Control Systems, IAEA-TECDOC-1066, Vienna (1999).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Verification and Validation of Software Related to Nuclear Power Plant Control and Instrumentation, Technical Reports Series No. 384, IAEA, Vienna (1999).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment of Computerized Control and Protection Systems, IAEA-TECDOC-780, Vienna (1994).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Issues for Advanced Protection, Control and Human–Machine Interface Systems in Operating Nuclear Power Plants, Safety Reports Series No. 6, IAEA, Vienna (1998).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Solutions for Cost Effective Assessment of Software Based Instrumentation and Control Systems in Nuclear Power Plants, IAEA-TECDOC-1328, Vienna (2002).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Software for Computer Based Systems Important to Safety in Nuclear Power Plants Safety Guide, Safety Reports Series No. NS-G-1.1, IAEA, Vienna (2000).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Instrumentation and Control Systems Important to Safety in Nuclear Power Plants Safety Guide, Safety Reports Series No. NS-G-1.3, IAEA, Vienna (2002).

[13] ELECTRIC POWER RESEARCH INSTITUTE, Nuclear Power Plant Control Room Modernization Planning, EPRI 1003569 (2002).

[14] Kaneki NARIKUNI, Kazuhide TOMITA, Kyushu Electric Power Co., Mitsubishi Heavy Industries, Ltd, " How to Lead the I&C Modernization Project Example of Genkai 1&2" 31 March – 5 April 2003, Helsinki, Finland.

[15] ELECTRIC POWER RESEARCH INSTITUTE, Instrumentation and Control Life Cycle Management Plan Methodology, EPRI TR-105555, Vols. 1&2 (1995).

[16] ELECTRIC POWER RESEARCH INSTITUTE, EPRI-lite: An Equipment Reliability and Obsolescence Evaluation Tool, EPRI 1003103 (2001).

[17] ELECTRIC POWER RESEARCH INSTITUTE, Instrumentation and Control Maintenance Plan Methodology, EPRI TR-106029, Vols. 1&2 (1996).

[18] ELECTRIC POWER RESEARCH INSTITUTE, Instrumentation and Control Upgrade Evaluation Methodology, EPRI TR-104963, Vols. 1&2 (1995).

[19] ELECTRIC POWER RESEARCH INSTITUTE, Plant Communications and Computing Architecture Plan Methodology, Revision 1, EPRI TR-104129, Vols. 1&2 (1994).

[20] ELECTRIC POWER RESEARCH INSTITUTE, Guideline on Licensing Digital Upgrades TR-102348 to Reflect Changes to the 10 CFR 50.59 Rule, EPRI 1002833 (2002).
[21] ELECTRIC POWER RESEARCH INSTITUTE, Requirements Engineering for Digital Upgrades, EPRI TR-108831 (1997).
[22] ELECTRIC POWER RESEARCH INSTITUTE, Handbook of Verification and Validation for Digital Systems, EPRI TR-103291, Vols. 1–3 (1994).
[23] ELECTRIC POWER RESEARCH INSTITUTE, Guidelines for the Verification and Validation of Expert System Software and Conventional Software, EPRI TR-103331, Vols. 1–8 (1995).
[24] ELECTRIC POWER RESEARCH INSTITUTE, Verification and Validation for High Integrity Systems, EPRI TR-103916, Vols. 1&2 (1995).
[25] ELECTRIC POWER RESEARCH INSTITUTE, Guidelines for Electromagnetic Interference Testing of Power Plant Equipment: Revision 2 to TR-102323, EPRI 1000603 (2000).
[26] ELECTRIC POWER RESEARCH INSTITUTE, Handbook for Electromagnetic Compatibility of Digital Equipment in Power Plants, EPRI TR-102400, Vols. 1&2 (1994).
[27] ELECTRIC POWER RESEARCH INSTITUTE, Abnormal Conditions and Events Analysis for Instrumentation and Control Systems, EPRI TR-104595, Vols. 1&2 (1996).
[28] ELECTRIC POWER RESEARCH INSTITUTE, Guideline on Evaluation and Acceptance of Commercial Grade Digital Equipment for Nuclear Safety Applications, EPRI TR-106439 (1996).
[29] ELECTRIC POWER RESEARCH INSTITUTE, Evaluating Commercial Digital Equipment for High-Integrity Applications: A Supplement to EPRI Report TR-106439, EPRI TR-107339 (1997).
[30] ELECTRIC POWER RESEARCH INSTITUTE, Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety Related Applications, EPRI TR-107330 (1996).
[31] ELECTRIC POWER RESEARCH INSTITUTE, Guideline on the Use of Pre-Qualified Digital Platforms for Safety and Non-Safety Applications in Nuclear Power Plants, EPRI 1001045 (2000).
[32] ELECTRIC POWER RESEARCH INSTITUTE, Plant-Wide Integrated Environment Distributed on Workstations (Plant-Window) System Functional Requirements, EPRI TR-104756 (1996).
[33] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Ageing of I&C Equipment in Nuclear Power Plants, IAEA-TECDOC-1147, Vienna, (2000).
[34] INTERNATIONAL ATOMIC ENERGY AGENCY, Self-assessment of Operational Safety for Nuclear Power Plants, IAEA-TECDOC-1125, Vienna, (1999).
[35] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Safety Performance Indicators for Nuclear Power Plants, IAEA-TECDOC-1141, Vienna, (2000)
[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Harmonization of the licensing process for digital instrumentation and control systems in nuclear power plants, IAEA-TECDOC-1327, Vienna, (2002).
[37] A. Hetzmann, J. Eiler, I&C Modernization Activities in the Paks NPP, IAEA Proc.: Regional Europe Training Course on Modernization of Instrumentation and Control in Nuclear Power Plants, 9–27 Oct. 2000, Karlsruhe, Germany, 2000.

[38] J.Vegh, C.Major, S.Lipcsei et al., Experience with the PLASMA On-line Nuclear Power Plant Safety Status Monitoring System, Proc.: Enlarged HPG meeting on Man–Machine Systems Research and High Burnup Fuel Performance, Safety and Reliability and Degradation of In-core Materials and Water Chemistry Effects, HPR-357, Lillehammer, Norway, 11–16 March, 2001.
[39] ELECTRIC POWER RESEARCH INSTITUTE, Application of a Cost-Benefit Analysis Methodology to Nuclear I&C System Upgrades, EPRI-TR 101984 (1992).
[40] INTERNATIONAL ATOMIC ENERGY AGENCY, Economics Evaluation of Bids of Nuclear Power Plants, 1999 edition, 2000, IAEA-TRS-396, Vienna, (2000).
[41] NUREG – 0700. Rev. 2, Human–System Interface Design Review Guidelines
[42] NUREG – 0711, Rev. 1, Human Factors Engineering Program Review Model
[43] INTERNATIONAL ELECTROTECHNICAL COMMISSION, Design for Control Rooms of Nuclear Power Plants, IEC 964, IEC, Geneva(1989)
[44] INTERNATIONAL ATOMIC ENERGY AGENCY, Configuration management in nuclear power plants, IAEA-TECDOC-1335, Vienna, (2003).

TERMINOLOGY

ACEs	Abnormal conditions and events
ALARA	As low as rasonably achievable
ASSET	Assessment of safety significant event team
BOP	Balance of plant
BWR	Boiling water reactor
CAD	Computer aided design
COTS	Commercial-off-the-shelf
CMF	Common mode failure
DB	Database
ERCATD	Event root cause analysis tool and database
EMC	Electromagnetic compatibility
EQ	Equipment qualification
FAT	Factory acceptance test
FMEA	Failure modes and effects analysis
HMI	Human–machine interface
HVAC	Heating, ventilation and air conditioning
I&C	Instrumentation and control
ITB	Invitation to bid
TWG-NPPCI	Technical Working Group on Nuclear Power Plant Control and Instrumentation
MCR	Main control room
NPP	Nuclear power plant
NSSS	Nuclear steam supply system
O&M	Operations and maintenance
OLC	Operational limits and conditions
PSA	Probabilistic safety assessment
PWR	Pressurized water reactor
QA	Quality assurance
R&D	Research and development
RBMK	Russian made channel-type reactor that is graphite moderated and water cooled
SAT	Site acceptance test
SPDS	Safety parameter display system
TG	Turbine generator
V&V	Verification and validation
WWER	Russian made water cooled and water moderated power reactor analogous to PWRs

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