



NUCLEAR NEWBUILD PROJECTS

Lessons learned from Finnish 21st century NPP projects

Construction and preparation project cases 1,2 and 3

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CONTRACT TYPES

Turnkey project (so-called EPC - in this presentation, fixed-price EPC). One supplier or consortium takes care of planning, procurement, licensing, commissioning and construction - right up to the start of use. This model is often used when a nuclear power plant is built into a country for the first time or the new plant type differs from previous ones, e.g. FBR or SMR and not PWR/BWR. This type of contract involves large risk, and the supplier usually adds as a large risk provision to the price of the facility. Managing the acquisition of technologically separate parts, e.g. automation, emergency diesels and fuel changers, as well as obtaining the information needed for the equipment's permit process is often challenging. The amount of information required for regulatory review varies significantly depending on the country. There are also variation in the licensing process and design stages and required design maturity in these stages.

A shared EPC-type contract. Technical responsibility and planning is divided among several suppliers, each of which builds a relatively large part of the plant (reactor supplier, turbine supplier, buildings supplier, automation supplier, emergency diesel supplier, fuel changer supplier). Typically, an engineering firm representing the owner (the owner's architect-engineer) takes care of the licensing and the coordination of the suppliers' delivery packages.

The difficulty is finding an engineering firm with the required overall expertise, including correct defining of contract packages and identifying and managing their interfaces. In addition, equipment level requirements are difficult to provide, when design is divided among several suppliers,. One of challenges is to find competent sub-suppliers to achieve comprehensive level of the equipment requirements/design.

Multi-contract approach. The owner or engineering firms representing the owner are responsible for the design of the facility, approval of official documents and construction of the facility. The construction of the plant is divided into technical parts, which are managed in sub-projects coordinated by the owner.

This model is possible only to the owner with very good overall and country specific competence and/or possibility to contract competent engineering firms to take care of general design and define and negotiate contract packages. There are no additional risk provisions, and the price and schedule impact of the regulatory reviews can be minimized.



CONTRACT TYPES

In a **fixed-price EPC**, the supplier's risk reserve can be 40-70% of the plant's price, and the equipment suppliers' risk reserves added to the total price can be 25-40%.

The maximum contract fine resulting from a delay in the plant's completion schedule and a delay in the start of operation is typically no more than 20% of the total price in fixed-price EPC contracts for power plants.

Risk reserves (if they are made in full) produce an EPC contract price that is 150-230% of the starting price. The costs of the owner's delay also include e.g. the interest on the capital during construction and the price of replacement electricity, as well as the management of possible licensing and approvals issues not included in the contract.

Before finally choosing the type of contract, the owner can easily assess the price of the skills and labor to be purchased and its risks compared to the risk reserves of suppliers and costs of project delays.



RESPONSIBILITIES BASED ON CONTRACT TYPE

Activity	Contract types		
	Turnkey	Split package	Multiple package
Pre-project activities	U	U	U
Project management	MC	AE or U	U + AE
Project engineering	MC	AE or U + SS	U or AE
Quality assurance/quality control	MC + U	AE + SS + U	U + AE
Procurement	MC	AE or U + SS	U or AE
Application for license	U	U	U
Licensing	RA	RA	RA
Safeguard, physical protection	U	U	U
Manufacturing	MC	SS + EM	EM
Site preparation	U or MC	U or AE	U or AE
Erection	MC	AE + SS	U or AE
Equipment installation	MC	AE + SS	U or AE
Commissioning	MC	AE + U	U or AE
Plant operation and maintenance	U	U	U
Fuel procurement	U	U	U
Fuel fabrication	FS	FS	FS
Waste management	U	U	U

Symbols:

AE: Architect engineer

RA: Regulatory authority

EM: Equipment manufacture

SS: System supplier FS: Fuel

supplier U: Utility

MC: Main contractor



Table 1: Construction costs of recent FOAK Gen-III/III+I projects

Type	Country	Unit	Construction start	Initial announced construction time	Ex-post construction time	Power (MW _e)	Initial announced budget (USD/kW _e)	Ex-post construction cost (USD/kW _e)
AP 1000	China	Sanmen 1, 2	2009	5	9	2 x 1 000	2 044	3 154
	United States	Vogtle 3, 4	2013	4	8/9*	2 x 1 117	4 300	8 600
APR 1400	Korea	Shin Kori 3, 4	2012	5	8/10	2 x 1 340	1 828	2 410
EPR	Finland	Olkiluoto 3	2005	5	16*	1 x 1 630	2 020	>5 723
	France	Flamanville 3	2007	5	15*	1 x 1 600	1 886	8 620
	China	Taishan 1, 2	2009	4.5	9	2 x 1 660	1 960	3 222
VVER 1200	Russia	Novovoronezh II-1 & 2	2008	4	8/10	2 x 1 114	2 244	**

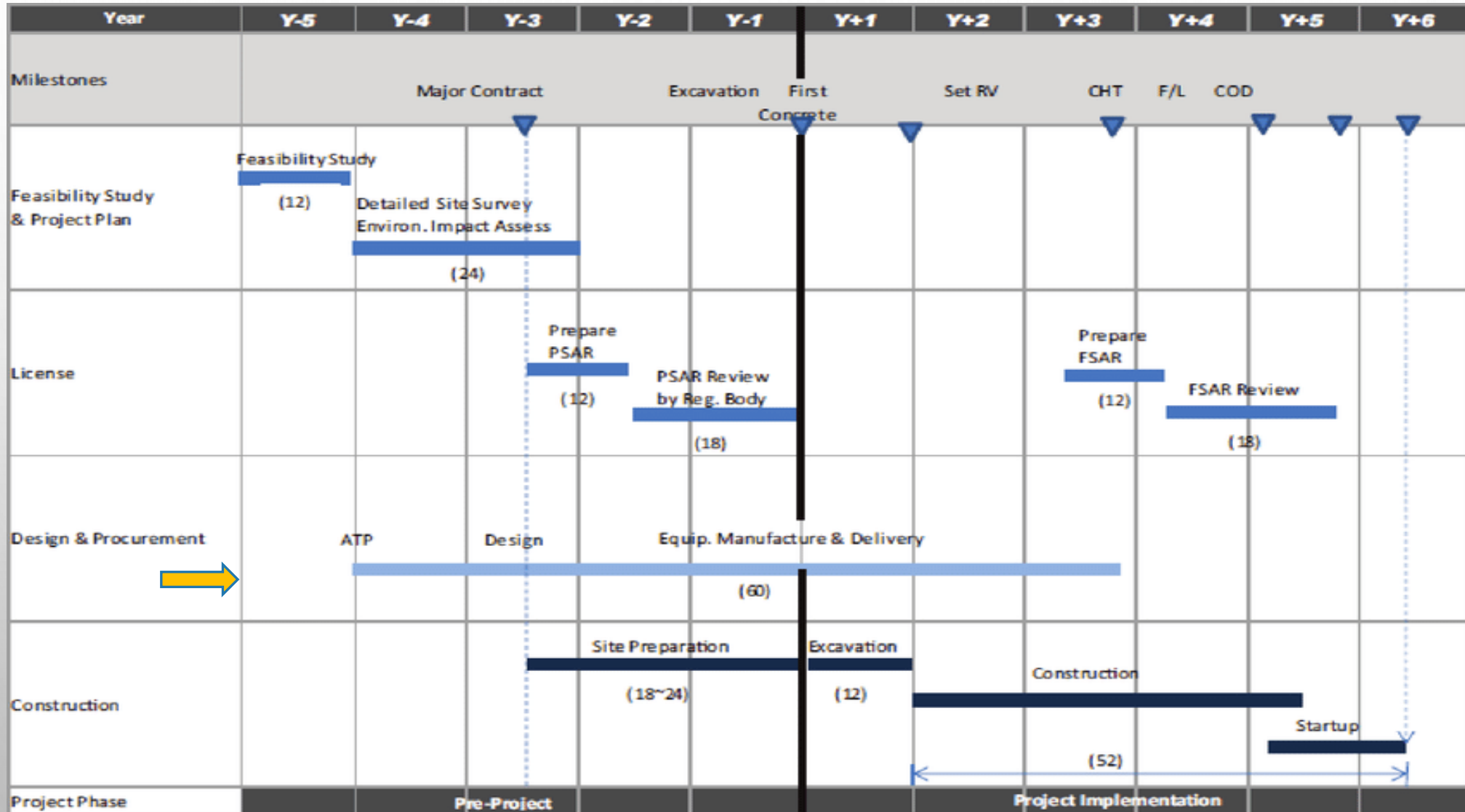
* Estimate. ** No data available.

Notes: MW_e = megawatt electrical capacity. kW_e = kilowatt electrical capacity.

Source: NEA analysis based on publicly available information.



PROJECT SCHEDULE - IAEA



IAEA, NP-T-2.7, 2012



CONTRACT EXPERIENCES – CASES 1,2,3

The evaluation of the owner's EPC contracts should include an assessment of the supplier's desire and ability (see cases 1 and 2) to build the power plant within the already presented schedule.

Case 1 (2003-2022) – The supplier did not have resources for functional design of automation of unit and this design problem was not early enough included in the schedules with corrective actions.

This caused several years of delay in the project. In addition, the owner stopped the use of an engineering consultant with national expertise and project expertise immediately after granting the Construction License.

Case 2 (2015-2022) – The supplier/owner's plan for the interfaces of the licensing documents and their planned schedules contained several problems. However, part of the problems were solved just during project termination.

Case 3 (2008-2010) – The owner compared possible risk provisions of Vendor to the price of increasing own design and procurement resources. Also risk evaluations with error margins was done for selection of the contract type. According to the evaluations, the multi-contract approach with the increased resources of owner was seen favorable and the EPC contract seems not to be acceptable to the owner.

Based on the price of the risk reserves, it is difficult to understand the reason to negotiate and conclude a fixed-price EPC contract for the renewal of the nuclear power plant or its automation. Especially, when the national regulations and an independent safety authority already exists in a country. This conclusion has been confirmed by various experiences of Finnish and Swedish nuclear power plant projects in the 21st century.



SCHEDULE EFFECTS OF THE LICENSING PROCESS

IAEA (NG-T-1.6, 2020) proposes one year for the creation of the PSAR and two years for its official review. WANO (WANO roadmap to Operational Readiness) proposes a 24-month authority review period for the entire Construction License application. The official process approval process of a NPP in Finland is emphasized in two stages: Construction license and Operating License.

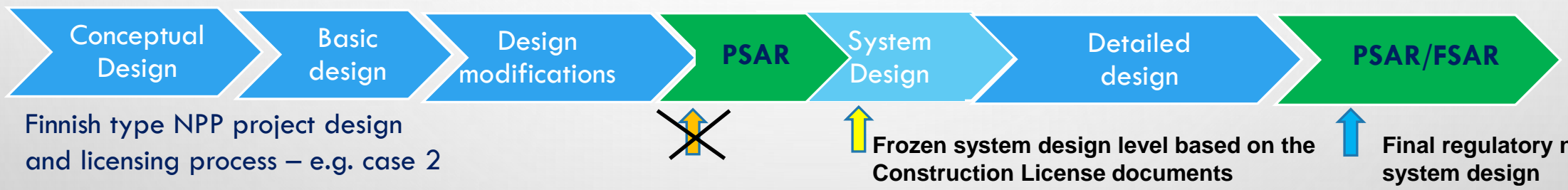
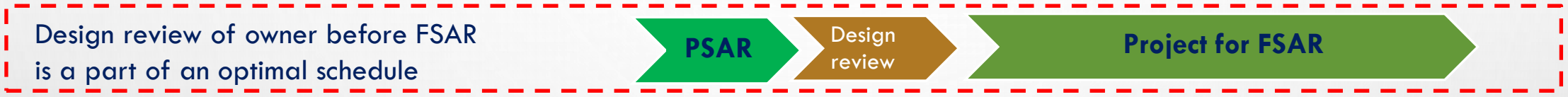
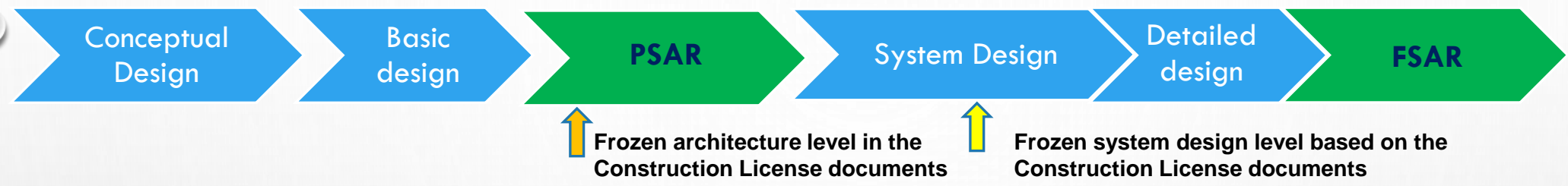
The content of the Preliminary SAR (with its numerous appendices and references) required in Finland today, corresponds in quality and detail to the level of requirements of the Final SAR content in international level. The required details of system and equipment information are available only with the binding procurement contracts with the manufacturers. When the regulator review is leading to modifications the price effect is considerable, or in worst cases the manufacturer is necessary to be changed.

In the Finnish projects of the 70s, the approval process was the same than today, but the design process during construction was multi-phased and the processing of system data included multiple freezing phases was accepted by all parties, including regulator. The data required by regulator in stages was not limiting the selection of manufactures and the licensing process was kept in predictable level.



ROLE OF PSAR AND FSAR IN LICENSING

International process with Construction License and Operating License



In Finland, the level of design required for the Construction License stage is the system design with information of essential equipment. It should be provided in detail without the possibility to use the frozen plant architecture approved by the authority as a basis on system design. Hence, the financial risk of owner/supplier and the equipment suppliers in case of required major modifications to the architecture are considerable. In addition, the definition of the design requirements and design for an EPC contract is very challenging.

The lessons learned of recent NPP projects in Finland has shown that the regulatory approval of architecture is paramount starting point for the system design.



SIZE OF PROJECT ORGANISATION

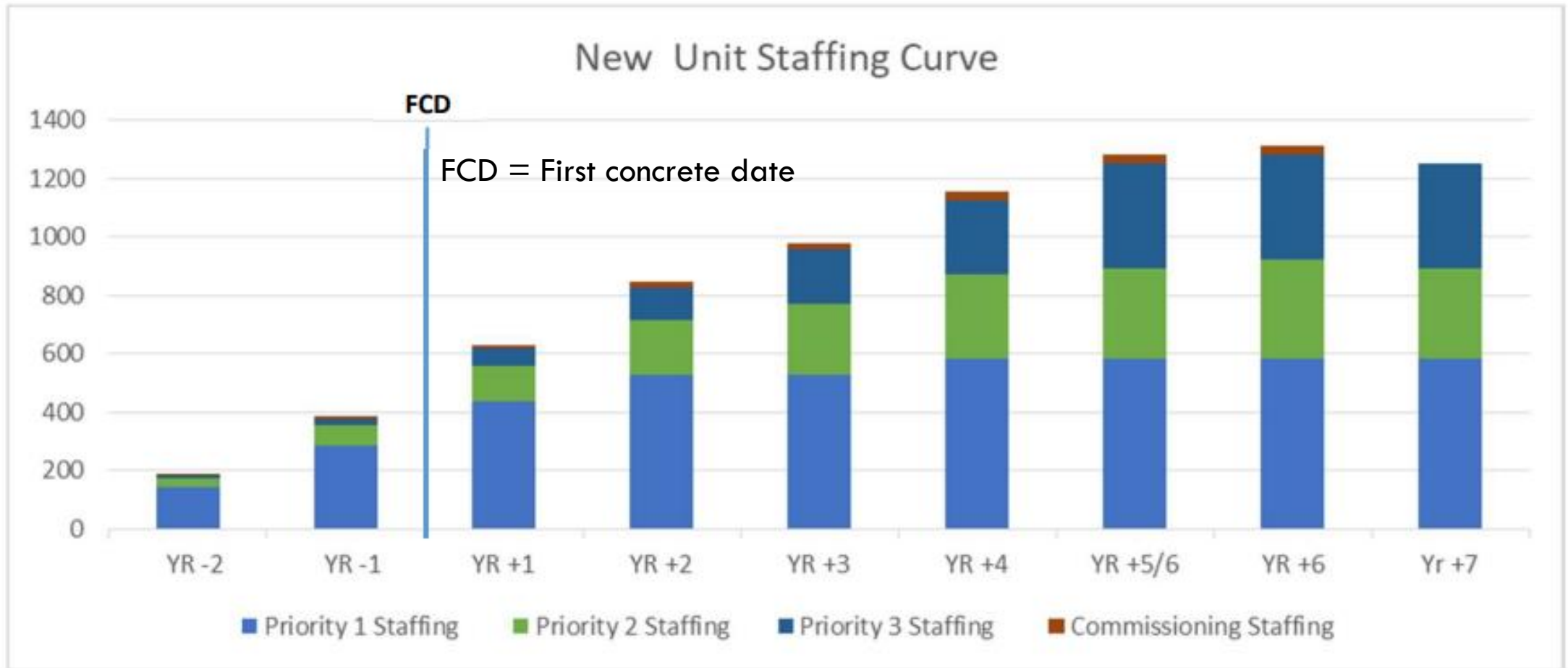


Figure D.13 New Unit Staffing Curve

Source: New Unit Assistance Working Group



PROJECT EXPERIENCES- CASES 1,2 AND 3

Common sources of problems

1. The requirement framework created by the authority guidelines is not feasible

- a) Some of the regulatory requirements have never been applied to a nuclear power plant project
- b) The regulatory guidelines contain contradictory requirements technically and in terms of project phasing
- c) The owner or supplier does not have sufficient competence to correct and apply conflicting requirements
- d) Configuration management and identification of configuration units to be monitored were required to be started before the first available freeze point, i.e. too early.

2. The joint organization of the owner, main supplier and equipment suppliers was not correctly built

Case 1- A joint organization did the licensing documents and the application of the guidelines until the Construction License was granted. E.g. the owner's comments on the document were given within a week (the owner also wrote several documents). -- After the CL was granted, the owner decided that more official and legally binding process is followed - all comments on the documents were given in an official letter in eight weeks (8 weeks answering model)

Case 2

- a) The communication between the owner and the plant supplier was partly based on the plant contract and partly on the "lessons" of some personnel in the case 1, i.e. the slow 8 weeks answering model were followed in whole project.
- b) The owner's organization was built based on the future operating organization; therefore, a large part of the owner's organization was not focusing on obtaining a Construction License. (*The joint organization shall always direct its activities according to the ongoing phase: applying for a permit, purchasing equipment or construction.*)
- c) The owner had a strange idea that the owner shall be independent on the design and safety solutions of the plant supplier and his own plant.



PROJECT EXPERIENCES – CASES 1, 2 AND 3

- 3. The fixed price EPC contract contained ambiguities, or its requirements or their interpretation are inconsistent with national requirements**
 - a) Case 1 and 2 - the authority changed its instructions and their interpretation throughout the construction. The plant contract could not be valid in all respects. Large legal problems and scheduling problems arose all the time.
 - b) Case 1 – some of the authority instructions mentioned in the plant contract were in the draft stage when the plant contract was signed.
 - c) Case 2 – All plant design deviations from the national regulations were required to be justified, even though some of the written requirements cannot be applied in any nuclear power plant project. The Finnish authorities' guidelines contain contradictory requirements in terms of safety design and a newbuild project schedule.
 - d) Case 2 - The plant contract contained non-prioritized, conflicting additional requirements. The requirement level was too detailed, and the importance and grading of the requirements could not be identified.

- 4. Supplier's project management were not able or willing to understand approved CL design**
 - a) Case 1 - The design documents drawn up after the Construction License was granted were no longer following the design frozen in the Construction License documents and approved by the authority.
 - b) Case 1 – the freeze points for all design areas could not be set in the system and equipment design phase; apparently due to the inconsistency of the project and deficiencies in the plant supplier's project management



PROJECT EXPERIENCES - CASE 1

It took 13 months to prepare, approve and obtain the Construction License (CL) application materials in Case 1 project. The architecture was based on direct discussions between the owner, supplier and regulator (STUK). For CL application the owner interpreted the regulatory requirements directly to the supplier and guided the supplier with preparation of design modifications.

1. The facility supplier was not able or willing to follow the principles and instructions approved in CL documents. Also, interpretations of the instructions were changed by regulator or by supplier during construction. – *Cause: After granting of the CL, the owner's direct guidance was stopped, because the licensing and regulatory approval process responsibilities were assigned to the supplier with the EPC contract.*
2. The deficiency of the supplier's expert resources was already identified at the Construction License stage without corrective actions. The owner reserved only 25% of the required resources for his own work and stopped using an engineering consultant with national expertise and project expertise after The CL was granted. *Cause: The owner severely underestimated the project's own resources and the necessary know-how, because they received incorrect advice and the owner's project management have a lot of experience on power operations but lacked nuclear new-build project know-how.*
3. Several suppliers and subcontractors had lost their expertise without new nuclear power projects, and the plant supplier guided selected experienced suppliers and experts incorrectly. The equipment procurement specifications, coordination of standards and the authority's authentication steps in the equipment manufacturing process (hold point; witness point) were not described or were described inconsistently in the project materials. The number of changes during construction was several thousand and the changes led to delayed construction. – *Cause: The owner guidance is lacking, and supplier and sub-suppliers didn't have knowledge how to produce detailed sub-plans for licensing and how to select the correct nuclear standards based on the approved CL materials.*

The operating license was granted for 11 years after CL was granted and the plant's regular electricity production began 18 years after CL was granted.



PROJECT EXPERIENCES - CASE 1

- a) The supplier did not have an established supply chain and suppliers had not been selected and the equipment suppliers' ability to deliver had not been verified before scheduled delivery contracts. Many plant changes made it difficult to trace products and materials during the regulatory approval and procurement process, and the quality requirements of regulator was changing during the procurement process.
- b) Design methods according to well-known nuclear technology standards were required to be applied in a new way in this nuclear power plant project. This caused confusion among experienced equipment suppliers and subcontractors. *(This emphasizes the need to get experienced (and competent) people into new nuclear power projects - to restore the credibility of the implementation process for nuclear power plant construction projects).*
- c) Unrecognized differences in the approved applications of the authority's requirements at the operating nuclear plants in Finland led to misunderstandings and confusion in recognizing the exact approval level. The confusion was expanded to the equipment qualification and to the preparation of the final licensing documents for operation.
- d) The plant supplier did not recognize the problems caused by the multicultural organization and differences in work methods at the beginning of the project: *"There are no nationalities-related differences in the work and safety culture at the construction site!"*



PROJECT EXPERIENCES - CASE 2

In case 2, the processing time for the Construction License materials was estimated to be 12-15 months in the initial schedule. The preparation, approval and submission of the Construction License application materials to the authority was suspended in 2022, when the documents had been prepared for 70 months. At that time, the owner's ability to interpret and implement the continuously changing regulatory requirements was still very limited but developing.

Difficulties:

1. The continuous increase in the amount and detail of the material required to obtain a Construction License and the material for equipment approval by regulator caused a significant delay. The amount of CL materials to be sent to the authority increased continuously and well beyond a normal project.
2. Several families of standards were in use, the owner and the supplier lacked expertise in applying the additional requirements of the national guidelines to the design and approval processes of the selected nuclear specific standards in system and equipment level approvals.
3. Numerous multinational experts and groups on the owner's and supplier's side have difficulties in understanding the interconnections and main parts of the standard families, and to decide an unambiguous approval level of systems and equipment to be justified for the regulator in a simplified and logical manner.
4. Caused by lacking competence, the providing of the specifications for equipment purchases, coordinating standards and timing the authority's authentication steps in the equipment manufacturing processes (hold point; witness point) were attempted to be transferred to the equipment suppliers by contracts.



PROJECT EXPERIENCES – CASE 3

Licensing Plan

1. A separate Licensing Plan were decided to be drawn up for the project. The national safety requirements and the owner's interpretation of them and instructions for applying the detailed requirements and nuclear standards were provided into the sub-plans. Basic idea was to get the approval of licensing authority to the licensing plan, which content could be presented in the request for tenders, so that the right quality of documents is known. The correct interpretation and application of the requirements was planned to be ensured in contract negotiations.
2. The approved Licensing Plan was planned to be supplemented with area-specific sub-plans, which could describe in detail the paramount documents provided to the authority, as well as their relationships with each other.
3. The possible additional requirements for each facility type, the type and technical content of the required documents, and the adequacy and timely availability of the supplier's, owner's and the authority's expert resources for the preparation and inspection of the materials was planned to be ensured.


Case 3 – in the project under preparation, efforts were made to integrate the documents required by licensing into the bid documents required from the supplier and further into the design documents. The licensing requirements were to be integrated as part of the plant supplier's planning and procurement process.

Many deviations from the authority's requirements would have been approved in one go in the licensing plan submitted to the authority, and the approval of a processes and systems deviating from the authority's instructions was planned to be the beginning point of the project. In this process the contradictions in regulations has been solved and solutions are approved by all parties before the signed plant contract.



GENERAL LESSONS LEARNED

1. Understanding and applying national requirements is very important. Even the translation of the requirements into English and the difference in the terminologies of the different requirement frameworks (IAEA, EUR, etc) is a large source of mistakes.
2. Digital automation has changed the design stages and interfaces, and the shortened life cycle of electronics has brought new project challenges, which have proven difficult to answer in the nuclear power projects.
3. The number of verification and customized tests threatens to multiply and expand to all equipment of unit. Poorly defined functional safety classification and scope of equipment qualification can lead to quality and qualification requirements being too strict and broad. *(Scope of type tests and tests covering the entire service life should be limited to the essential equipment. The accessibility and the inspection possibilities of equipment during operation as well as the multiplicity of the systems are important i.e. one of the four parallel subsystems of a safety system can be unavailable during maintenance.)*
4. The management of the project shall be competent to evaluate, identify and manage critical technical issues in a short time or to transfer them to an effective scientific investigation. *(This prevents unsolved technical problems from spilling over into the decision of the authority - the authority has smaller resources and therefore a narrower technical competence in use.)*



**QUALIFICATION
PROCESS OF
EQUIPMENT FOR
THE PROCUREMENT
IS NECESSARY TO
BE BUILT
CAREFULLY.**



SAFETY CLASSIFICATION - BASIS

"The general safety classification principle: "All safety-important objects must be identified and classified based on their function and safety significance.", is typically fulfilled by the safety classification of systems, structures and equipment based on functional and structural safety principles. The purpose of the rating is to emphasize/direct the quality and safety assurance resources to the most important targets for the whole.

- 1. Quality management systems use safety classes of items to guide and define requirements and applied standards as well as the content and quality of documents to be produced. The safety classification guides the resources and procedures used for planning, procurement and manufacturing through the standards and operational models that are chosen.*
- 2. Different safety classes require different authority approval stages and sets of documents. Based on the safety class, a supplier of equipment/services is selected to be able to use, review and guarantee all quality management requirements connected to the safety class for the equipment or service.*

There are differences in the application of the safety classification principles depending on the country and quality management system requirements. - In Finnish projects, functional safety classification has been challenging and regulator has changed safety classification during project. The changes in classification have affected the applied design standards, quality requirements and official requirements - **delays in official approval have caused major delays in projects.**



SAFETY CLASSIFICATION - PROCESS

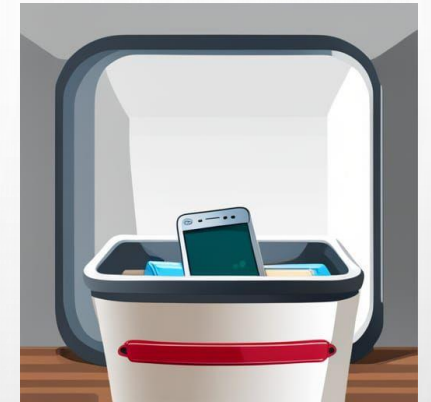
IAEA guideline SSG-30; Vienna, 2014, section 2.3 states: "Safety classification is an iterative process that should be performed periodically throughout the design process and maintained throughout the lifetime of the facility."

The original Finnish approval process of the 80s states that a proposal of functional safety classifications of unit are provided in a classification document and its is sent for regulatory approval in the CL application stage. The idea was that the authority defines/or at least approves the classification principles of systems and equipment, when the CL is granted. These classes and principles are then used in a separate system-specific design approval phase and procurement processes of classified equipment. The safety classification is a paramount for defined level of quality management and control methods to be followed by many different parties in the project. Classified items are then designed and manufactured based on the selected quality level. In a normal construction project for a nuclear power plant, the plant database contains approximately one million safety-classified components, which are procured based on their safety classes.

The classification document to be submitted in the Operating License phase is normally a compilation of the database showing the equipment classification approved in connection with the approval of the systems.

The idea of the IAEA SSG-30 above to have an iterative classification process, is very strange. A change in safety classification practically starts the procurement and manufacturing process again and earlier manufactured items is necessary to be rejected. New safety class may be too demanding to the contracted manufacturer and to the quality control processes of item. Also new manufacturer is necessary to be selected. Normally, the safety classification is changed only at the initiative of the authority.

In an iterative process above, the safety authority reserves the right to reject the QC level and any equipment in any stage of a NPP project.



Could this be done to a NPP after change of the safety class?



SEISMIC CATEGORIZATION OF EQUIPMENT

ROUGH COMPARISON BETWEEN INTERNATIONAL AND FINNISH PROCESSES

Selection of three seismic classes S1, S2 and S2A for equipment

1. S1 for equipment that are needed after an earthquake, list of equipment in class S1 and authentication procedures corresponding to the class and category are determined.
2. Equipment that could fail during an earthquake and prevent S1 equipment from performing their safety function are assigned to seismic class S2A.
3. Other equipment are assigned to class S2B

Finnish regulatory model - cases 1 and 2

1. S1 equipment are defined based on functions and failure criteria, and justification procedures are required.
2. All equipment that could, in theory, cause an S1 equipment to fail, if they fail, are classified as S2A. The risk of loss of function is not proportional and graded, e.g. in process systems the seismic classification boundaries are defined into systems and pipelines. Conservative hazard analyzes are used to define S2A equipment, and the requirements of S2A equipment approach endurance level and margins required on S1 equipment. Failure possibilities of S1/S2A equipment in case of a failure of S2B equipment are required to be analyzed and justified during all hazards.
3. Due to the scope of the assumed fault spectrum of the equipment, all equipment in a building and room including S1 equipment are assigned to category S2A.

Recommended screening of equipment based on seismic events

1. Equipment are defined based on functions and failure criteria, and authentication procedures are defined.
2. The location of equipment that could cause loss of S1 function due to a probable leak, drop or missile is mapped. Faults producing loss of function are prevented by layout design and physical separation; most of the equipment receive class S2B. Only in exceptional cases, the equipment receives class S2A.
3. Other equipment are assigned to class S2B.

Unsuitable verification requirements (S2B location information!), convergence of seismic class S2A equipment requirements to S1 class and the overconservative nature of the earthquake-induced failure mechanism (post-Fukushima applications) have led to a multiplication of the number of seismically qualified equipment in Finnish NPP projects (case 1 and 2).



DESIGN MATURITY OF NUCLEAR NEWBUILDS

According to the public sources at the Flamanville project in France in 2007, only 40% of the detailed design was reportedly complete when construction began. In Korean construction projects, 70–80% of the detailed design is usually aimed at completion during first concrete. Equipment purchases by Koreans are based on previously implemented projects and the quality standards observed in them.

All required national changes in design solutions and quality standards significantly lower the design maturity level and require longer design phase before construction. Additional requirements regarding manufacturing that deviate from the standards during the construction phase practically prevent a high "ready" design degree.

-- **The system design phase shall include regulatory requirements and approvals for most important safety equipment is to be done, but the number of national requirements affecting standardized equipment shall be limited. The standardized equipment with numerous operating experiences in NPP environment shall be preferred.**

In order to avoid the multiplication of detailed planning and its costs, the official approval must be divided into three frozen approval levels:

- 1) the architectural level of the design,
- 2) system design level and requirements for demanding safety important equipment locations,
- 3) equipment specification and procurement specifications for equipment.

Even in FOAK projects the Construction License should be granted at about 50% of the design maturity and freezing level of the final detailed equipment and system design level.