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MANAGEMENT OF SAFETY REQUIREMENTS IN SUBCONTRACTING DURING THE OLKILUOTO 3 NUCLEAR POWER PLANT CONSTRUCTION PHASE

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3. 1. BACKGROUND AND OBJECTIVES OF INVESTIGATION

The Radiation and Nuclear Safety Authority (STUK) concluded in connection with the construction of the Olkiluoto 3 nuclear power plant that the performance of the organisations involved in the project and the interaction between the organisations did not in all respects meet the expectations that STUK has on good safety culture during the construction phase of a power plant. The identified problems had already impeded progress of the project and possibly increased schedule-related pressures during the later stages of the project.

STUK considers important that problems during construction and manufacturing will not result in impaired quality of the final products, or even in uncertainty about the achieved quality. For this reason, the performance of the organisations involved in the construction of the Olkiluoto 3 nuclear power plant unit should be improved. In order to identify the needs for improvement, STUK appointed an investigation team and asked the team to present an assessment of the performance of the organisations in the light of certain case studies that were selected as examples. In addition, STUK asked the investigation team to present recommendations for improving the performance of the licensee Teollisuuden Voima Oy (TVO), and the vendor consortium CFS, formed by Framatome ANP (FANP, currently Areva NP) and Siemens AG. Within the project, Framatome is responsible for the reactor island and Siemens for the turbine island. As the construction project proceeds, STUK will assess how these recommendations have been materialized in the operations of the parties.

The investigation team also analysed the needs for development in STUK's own operations and issued recommendations for this purpose.

The task given to the investigation team is shown in Appendix 1, and the composition of the team in Appendix 2. The investigation entailed interviews of persons in different capacities in organizations (TVO, CFS, FANP, subcontractor, research institute) that have taken part in the Olkiluoto 3 project, as well as a visit to the Olkiluoto 3 construction site and the concrete batching plant. The investigation programme is shown in Appendix 3. Appendix 4 contains a description of STUK’s activities as the regulatory organisation for the nuclear power plant construction project.

2. PERFORMANCE DEMONSTRATING GOOD SAFETY CULTURE

2.1 Indicators of good safety culture

In safety-critical fields the organisations are expected to possess an ability also to manage situations that are difficult to predict. The characteristics of organisations operating with high reliability include a serious attitude towards even small errors, an overall assessment of situations, emphasis on professional competence over organisational status, and avoiding over-simplification in the analysis of important issues [1].

Within the field of nuclear power, an assessment of the performance of organisations focuses on attitudes toward safety, and how safety is ensured. Each organisation has its own perception of the importance of striving to ensure safety, and how safety can be achieved. These perceptions are usually unconscious and commonly shared, and they influence practical operations. For this reason they can be referred to as the safety culture.

The conditions in the Construction Licence, the YVL Guide 1.4 [2], as well as the OL3 project plan prepared by TVO require a high-level safety culture in the design, construction and operation of the nuclear power plant. In discussions on safety culture within the nuclear power field, reference is usually made to IAEA's guidance that, since the Chernobyl accident, has emphasised the safety significance of organisational factors. IAEA has defined safety culture in the INSAG-4 report [3] as follows: *"Safety culture is that assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance."*

When assessing whether the safety culture of an organisation is "good" or "bad", attention is in practice paid at least to the following issues (INSAG-15) [4]:
- Visible management commitment to safety.
- Conservative decision-making, i.e. the safer alternative is chosen in uncertain situations.
- Compliance with specifications and regulations.
- Reporting of nonconformancies and the aim to learn from them.
- Questioning of performance that jeopardise safety.

The indicators of good safety culture can be analysed when assessing both the operation of a nuclear power plant and the performance of subcontractors involved in the construction project. The important thing is the attitude towards safety and how it is shown in practice.

IAEA has suggested that there can be different levels of safety culture [5]. In the most advanced safety cultures each member of the organisation is considered able to influence safety. The attitudes and the behaviour of the staff are influenced through e.g. training, communication and leadership. In advanced safety cultures safety is not emphasised merely for reasons of publicity and external pressures.

2.2 Safety culture in the construction of a nuclear power plant

The technical and organisational preconditions for the safe operation of a nuclear power plant are created during the construction phase of the plant.

A basic principle established and proven in the nuclear power industry is “defence in depth principle” meaning in-depth assurance of safety. The first layer of this principle is to ensure undisturbed normal operation of the plant. This presupposes that the reliability and high quality of equipment is ensured for the safety-classified systems as well as for the entire process of power production. Good safety culture is characterised by that work practices at the site are in every respect carefull and consistent, and without distinction between activities on structures or equipment that are important to safety or classified non-nuclear. In addition to this, the quality and reliability of safety-classified equipment is ensured through additional requirements according to the relevant safety class. The special requirements for such equipment are taken into consideration e.g. in the dimensioning of structures, the properties of materials, type tests and the quality control programme.

It should be borne in mind that the culture and the work practices for the future operation of the plant are at least partly created during the construction stage. In other words, the construction of the plant and the manufacture of the components for the plant represent activities that are equally critical to safety as the operation of the plant.

Efficient and reliable operation of individuals and organisations is of crucial importance in the assurance of safety. The professional competence and the vigilance of individuals, as well as the ability of organisations to openly deal with matters may reveal and prevent e.g. deficiencies in design or uncertainty factors involved in manufacturing. On the other hand, incompetence and hiding of errors made in the manufacturing process may impair quality in a way that is not easy to detect in the final product.

The organisation that bears total responsibility for the construction of the nuclear power plant is obliged to ensure that every organisation and individual involved in the construction process recognises the quality expectations that apply to their work. It is unrealistic to expect that all the persons working at the construction site or in the manufacturing of components understand without explanation the significance of their own work as a part in ensuring nuclear safety. For this reason training shall be provided for them on the safety significance of their work and the expectations that apply to quality.

In construction and manufacturing industry, the safety culture is usually considered to be connected with occupational safety. In the construction of a nuclear power plant, it is important that the wider significance of safety and the respective implications for work practices are recognised. Regardless of their tasks, every employee should be aware of the properties of the final product that are particularly important in terms of safety. It is also important that factors relevant to safety in each specific work object are brought out and explained before work is started. An overall understanding of the principles followed to ensure safety of a nuclear power plant, and of the work practices adopted in the nuclear field also help in perceiving the expectations that apply to one's own work.

When building up a safety culture, the basic values familiar to professional workers have to be emphasised in the training and guidance for the employees: responsibility for faultless performance of one's own work and professional pride on the skills required to achieve high quality. In addition, everybody should assume responsibility for necessary interaction with others involved in the project, to ensure everyone can succeed in his own work. It is also important that the principle of openness is made clear to ensure that any non-conformancies detected in construction or manufacturing are brought up, and to emphasise the right and duty of everybody involved in the project to react to non-conformancies. In unclear and unpredicted situations the employees must comprehend the need to discontinue their work and to eliminate the problems before resuming work. The general objectives that apply to the construction of a nuclear power plant are very similar to those during the operation of the plant: the objective is that the performance of work is designed, implemented and documented as well as possible, and that indifferent attitudes towards problems or to the quality of the final product are not tolerated.

3. CASE STUDIES

The investigation team assessed the performance of TVO, the plant vendor and STUK in the light of three case studies selected as examples. The investigation report refers generally to the performance of the consortium (CFS) that supplies the plant, but also to the performance of FANP in cases where the investigation team could distinguish which consortium partner was concerned. The example cases are the concreting of the base slab, the manufacturing of the steel liner for the reactor inner containment, and the selection of manufacturer as well as the start of the design process for the polar crane and the material hatch in the containment. The background and the sequence of events in these three cases are described below.

3.1 Concrete base slab

3.1.1 Background information on base slab

Parties to the contract responsible for concrete fabrication

The parties to the contract were the plant builder (Framatome ANP, FANP), the structural designer of the base slab (Finnprima), the concrete supplier (Forssan Betoni Oy) and the contractor that performed the concreting work (Hartela Oy).

Requirements for and construction of base slab

The reactor building, the safeguard buildings and the fuel building share a common base slab.

The design requirements used in the dimensioning of the base slab have been defined by FANP as part of the containment design. The essential safety requirement is that the slab must withstand not only the expected loads, but also dynamic loads (impacts, vibration) in conjunction to potential accidents, as well as an internal over-pressure in the containment. In other words, the design bases of the slab include loads during the construction stage, loads during plant operation, loads caused by internal accidents or external collisions against the plant, as well as earthquakes. Security against collapsing of the entire construction based on the slab as a result of earthquake or collision loads has also been required. The design requirements have been approved by STUK as part of the pre-inspection documentation of the containment.

IAEA's safety standard 50-C-QA [6] concerning quality assurance presupposes that a graded approach during the different phases of the nuclear power plant's life cycle is used in the definition of requirement levels for functions in the quality management system of the plant. The level of and the need for quality assurance and control during construction is determined on the basis of the object's nuclear safety classification and structural classification based on the building regulations.

The nuclear safety classification of the base slab is SC3 in the parts under the safeguard buildings and the fuel building, and SC2 in the reactor building. However, pursuant to the proposal of TVO, and approved by STUK, the entire concreting and reinforcement work for the base slab have been carried out and inspected applying the same SC2 requirements to the whole base slab, in compliance with YVL Guide 4.1 [7].

According to the Finnish Building Code Part B4, Concrete Structures, the base slab is assigned to structural class 1. Structures and structural parts may be assigned to a certain class, provided the design and work specifications of that class are complied with. The structural designer and the concrete work supervisor shall possess the qualifications for the class in question. Structures and structural parts, whose design is considered to require special qualifications or with which the assurance of structural functionality requires special care, are implemented in structural class 1.

The base slab is 103.1 m wide and 100.8 m long. The thickness of the slab under the reactor building is 3.15 m and under the safeguard buildings 1.5 m. The slab is over its entire area supported on rock (design strength 140 MPa). A ca. 1.5 m thick levelling concrete is first cast on the excavated rock structure (strength class C32/40 according to Eurocode 2, K40 according to the Finnish Building Code Part B4). The levelling concrete and the slab are not anchored to the rock. The strength class of the base slab concrete is K40-1 (compressive strength 40 MPa, structural class 1), the reinforcement consists of ribbed bars A500 HW (yield strength, 500 MPa). The design life is 65 years and the exposure classes are XC2, XS1 and XA1 according to EN 206-1, i.e. resistance to chemical exposure caused by carbonation, chlorides and sulphates.

Structural design of base slab

Finnprima Oy carried out the detailed design of the structures in compliance with the requirements of Part B4 of the Finnish Building Code (RakMK) and the Eurocode 2, prEN 1992-1-1, April 2003, which applies to design of concrete structures. The fulfilment of the design requirements for the base slab has been verified on the basis of structural calculations reported by Finnprima and reviewed by STUK. The structural calculations are based on linear FE structural analyses (compying with the theory of elasticity). STUK also required that the design calculations shall be verified by means of non-linear FE analyses (that take into consideration cracks in the structures and plasticizing of materials).

Special features of base slab in comparison with common concreting projects

The base slab differs from common concrete structures by its massiveness and large size. Moreover, concreting had to be completed without breaks, as casting joints were not allowed in the base slab of the reactor building. Continuous concreting of structures of this size is extremely rare in Finland.

In massive concrete structures, temperatures tend to rise considerably during the curing process due to hydratation heat, and temperature gradients are usually high. The high temperature gradient in the concrete may cause cracks in the curing structure, and a high temperature may result in loss of strength in the concrete. Due to the cracking risk caused by the high temperature gradient and the loss of strength caused by high temperature, measures are usually taken with massive concrete structures to restrict the temperature rise. In order to limit the increase in temperature, the binder used in the base slab concrete contains an abundance of furnace slag instead of Portland cement, since the heat production rate of furnace slag during curing is considerably slower. Abundant use of furnace slag also improves the chemical resistance of concrete.

The concrete composition used in the base slab is not used in conventional construction work, and in that sense it is rare. Similar mixes are mainly used only in massive structures. The type of concrete used in the base slab cannot be considered to pose any special difficulties in fabrication or concreting, provided the concrete mix has been validated with sufficient preliminary tests.

3.1.2 Work practices generally followed in construction

Designing concrete composition

The common practice followed in concrete construction is that the structural designer specifies the requirements for cured concrete. Normal requirements specified by structural designers include strength (here K40-1) and durability (here XC2, XS1 and XA1). The requirements have an effect e.g. to the amount of binder (cement and furnace slag) and to the water-binder ratio of the concrete. The water-binder ratio affects the strength and the durability properties of concrete.

Requirements on fresh concrete are normally not specified by the structural designer but by the concreting contractors - in this case Hartela Oy. In some special projects the structural designer may define additional requirements for concreting. A typical example is that he defines the maximum temperature that the structure may not exceed during the curing of the concrete (e.g. 55ºC). Most Finnish structural designers do not possess enough practical expertise in concrete material technology to make them qualified to design the final composition.

The builder (or the concreting contractor) usually always orders the concrete on the basis of the specified requirements, with the concrete supplied directly into the formwork. The supplier of the concrete is responsible for the compliance of the concrete with the requirements specified by the structural designer and with the requirements that concern the manufacture (concreting) of the structure, specified by the builder. Such requirements apply to the pumpability, compactibility, consistency, setting time, and the rate of strength development, among others.

The final concrete mix is usually designed by the concrete supplier, as they know their own materials (particularly the aggregate) and have the laboratory facilities for performance of tests to support the design process. The final mix is always influenced not only by the requirements specified by the structural designer, but also by requirements that concern placeability. In order to enable casting and compacting of the concrete, it must be easily workable, it may not become segregated, and it must be pumpable as required. Detailed mix design requires knowledge of the aggregate to be used, and the additives (e.g. plasticizers and retarders) that need to be used if required to ensure the desired workability properties.

If the water-cement ratio is relatively low, plasticizers are used to ensure good pumpability and workability of concrete. Plasticizers reduce friction between the ingredients of fresh concrete during casting. Plasticizers do not affect the properties of cured concrete. The amount of plasticizer must be exactly correct to provide the desired effect. The plasticizers of different manufacturers give the desired effect with different mixing ratios and, therefore, preliminary tests must be separately carried out for the plasticizer that will be used.

Plasticizers can, however, be used for affecting pumpability to a limited degree only, and the effect of too low water-binder ratio cannot be compensated by merely adding plasticizer. In addition, aggregate has a significant effect on pumpability. Crushed aggregate is worse from the point of pumpability than natural aggregate.

In demanding construction projects the correctness of the concrete mix has to be validated by preliminary tests. The mix proportion is changed and fine-tuned as required on the basis of the test results. If changes are made, the preliminary tests have to be repeated. The more the composition differs from conventionally used mixes, the more work and preliminary tests are required to determine the mix proportion. The determination of the final concrete composition is always an "iteration" process.

Pumpability test is usually conducted last. By then other tests have already been performed to verify that the properties of the concrete meet the requirements. If pumping problems are encountered, the mix proportion is changed and tests are repeated.

If preliminary tests show that the concrete meeting the requirements cannot be fabricated and poured within the restrictions that concern the concrete mix, the concrete supplier shall contact the structural designer. The structural designer and the concrete supplier then together agree on the changes required in the restrictions that concern the mix proportion.

Quality control for concrete

The quality control tests to be performed during fabrication, as well as their total number and documentation, are defined in the quality control plan. When the quality control plan is drawn up the complexity of the concreting process, the size of the concreted area as well as the conditions need to be taken into consideration. During concreting, tests are made on fresh concrete according to the quality control plan, both at the batching plant and on the concreting site. In addition, test specimens are cast for the tests of the properties of the hardened concrete.

The quality of the concrete in a completed (hardened) structure can always be analysed by means of samples taken of the structure. The required number of core samples is drilled from the structure at desired points. The core samples are used to produce test specimens for tests of desired properties. The specimens are usually tested in compliance with standards. If no applicable standard is available, other commonly used testing methods are employed. The properties that can be determined include e.g. compressive strength and porosity of concrete.

The internal structure of concrete can be studied by making thin sections of the drilled samples, and subjecting them to a microscopic analysis.

3.1.3 Division of work and operation at Olkiluoto

Selection of concrete supplier and base slab concreting contractor, and concrete delivery agreement

The consortium started the process for the selection of concrete supplier in the autumn of 2004. The person responsible for the matter was an employee of the consortium, who at the time worked in Germany and later acted on the site as FANP's supervisor of the batching plant. The call for tenders was sent to four potential concrete suppliers named in the Main Contract. According to the information received in the interviews, the call for tenders contained the technical specifications and the YVL Guide 4.1 [7] was appended. No other requirements were specified in the call for tenders in terms of requirements concerning quality control in a nuclear power plant construction project (e.g. the requirement for a laboratory) or any other special requirements, such as reference to IAEA's safety standard IAEA 50-C-QA.

The consortium FANP-Siemens (CFS) selected Forssan Betoni from the four potential concrete suppliers apparently on price grounds, although the small size of the company was considered a risk. However, Forssan Betoni had taken part in some large-scale construction projects before, such as bridges and power plants, and according to CFS the company fulfilled the criteria defined for the selection.

At the time the agreement was concluded, Forssan Betoni was not required to have a valid certified ISO 9001 quality system, although most of the other candidates were already at the time using an ISO 9000-based quality system. In connection with the signing of the agreement, the requirement for a quality system to be realised later was specified. Forssan Betoni declared that they were working on their ISO 9001:2000 certification, and that the certificate would be applied for during the concrete deliveries. According to the consortium's interpretation the fact that the company was being inspected by an organisation (SFS-Inspecta) approved by the Finnish Ministry of the Environment, as referred to in Annex 1 of YVL Guide 4.1, was a sufficient validation for quality. TVO made no complaints on the selected supplier.

No training related to safety culture was provided to the personnel of Forssan Betoni before the concreting of the base slab. All the parties (FANP, TVO, Forssan Betoni) considered the site introduction training and the occupational safety training included in it, which is required for the granting of an access permit, to be sufficient.

According to information received from a representative of Forssan Betoni, the concrete delivery agreement contained the requirement that the order for concrete would in each situation be sent to the batching plant two weeks before the concreting was to be started, regardless of the size of the concreting area. For large concreting jobs, the placing of an order two weeks in advance can be justified, but for smaller concreting jobs the requirement that FANP specified for itself is unusual. Another unusual aspect of the agreement was that no responsibility for the pumpability or castability of the concrete was defined for the concrete supplier. The responsibility for the pumping and casting into the formwork rested completely with the builder (FANP) and the contractor it had assigned to carry out the concreting work. These factors suggest that the persons who concluded the agreement are not very familiar with the practical aspects of construction projects.

Hartela was chosen by FANP as the concreting contractor from among several candidates. The selection was strongly influenced by TVO's request to employ Finnish contractors on the site.

According to TVO's representatives the Main Contract specifies that the responsibility for the batching plant, the composition of concrete and the concreting work rests solely with FANP, and TVO merely supervises work in its capacity as the orderer and licensee.

Batching plants

Forssan Betoni set up three batching plants for concrete deliveries. Batching plants Olkiluoto 1 and 2 are located in immediate vicinity of the power plant construction site, and batching plant no. 3 in the area of Interrock. The Olkiluoto 1 and 2 are new plants, and plant no. 3 was built in 1999. Concrete for the water tunnels and the harbour, where TVO acted as the builder and Lemcon as the contractor before the construction site was handed over of the consortium, was delivered from batching plant no. 3.

On 17.92004 SFS-Inspecta Sertifiointi Oy conducted an intial inspection at the batching plant in the Interrock area and approved it into their inspection programme on 30.9.2004. SFS-Inspecta Sertifiointi Oy conducted on 15.3.2005 an initial inspection at the new batching plants no. 1 and 2 and approved them into their inspection programme on 16.3 2005. After the initial approval, SFS Inspecta controls the quality of the plants by making inspections at the plants a few times every year.

TVO conducted several inspections at batching plants no. 1 and 2 before the concreting of the base slab. At that time, production at the plants had not yet been started. TVO was represented in the inspections by the supervisor of concrete fabrication and a representative of quality control. The inspections were based on check lists that listed the issues covered in the inspection. Some minor deficiencies and remarks were recorded in the inspection reports.

When TVO inspected batching plant no. 1 (29.-30.3.2005) and batching plant no. 2 (11.4.2005), the plant facilities had not yet been finalised, but the deficiencies were not considered to be so significant that fabrication of concrete could not be started. The laboratory and the storage facilities for materials and test specimens were still in the Interrock area. It was noted that there was no camera controlling of the fabrication process. Water supply had not been connected and the foundation on the buffer water tank had not been built. As far as quality control was concerned, the quality manual and the graphic presentation of quality control measurementswere noted to be missing. TVO sent the inspection reports to FANP by a cover letter on 19.4.2005 for further actions.

TVO had already before made inspections at batching plant no. 3, which is located in the Interrock area. In a follow-up inspection conducted in December 2004, the acceptance of cement was found to deviate from the requirements of Finnish Building Code of Concrete Structures B4 (RakMK B4, By50). The batching plant operating records were still under development at the time of the inspection. It was noted in the inspection that the graphic presentation of the quality control measurements as well as vibration limit measurement equipment earlier required by TVO were missing from the plant (the code RakMK B4 does not separately require the measurement of vibration limit). In a repeated inspection on 20.1.2005, TVO concluded that these deficiencies had been eliminated and there were no obstacles with respect to the concrete batching plant to the manufacturing of safety class 3 concrete structures for the inlet and outlet of the seawater tunnels.

TVO and FANP audited the main office of Forssan Betoni on 4.5.2005. Three critical non-conformancies were found in the performance of Forssan Betoni, which together with four minor non-conformancies prove that at the time of the audit the quality system of the company and compliance of operation with the quality system were partly still at design stage. A quality management system compliant with ISO 9001 was under construction, and according to plans was to be certified within a few months. Deficiencies detected in the recording of documents as well as deficiencies in the definition of interfaces between Forssan Betoni, the client and the design organisation, were also defined as critical non-conformancies. The recording of documents received by Forssan Betoni or submitted by Forssan Betoni to the client or to the subcontractors, was not included in the document processing routine. Due to deficiencies in the definition of the interfaces Forssan Betoni was using a concrete specification that had not been officially approved by FANP.

The minor non-conformancies detected in the audit included the lack of an official reporting practice related to quality issues between the OL3 batching plant and the head office of Forssan Betoni in Forssa. Deficiencies were also found in the documentation of the examination and approval of the results of tests performed by Forssan Betoni. The quality system of Forssan Betoni did not describe in detail the procedures regarding the traceability of concrete. The availability of quality records was not verified and the requirements of IAEA's quality standards were not taken into consideration in the quality management system.

Forssan Betoni did not obtain the ISO9001 certificates until after the concreting of the base slab on 14.2.2006. The Olkiluoto 1 and 2 batching plants have valid NQA certificate no. 20620/7 and batching plant 3 (in Interrock area) NQA certificate no. 20620/6.

Design of concrete composition, and preliminary tests

The mix of the base slab concrete was designed by a concrete specialist (expert A) employed by Finnprima and with experience on massive concrete structures. In addition to the normal strength and durablity requirements he, thus, also specified the maximum amounts of binders in order to restrict the generation of heat. The design of the base plate concrete composition was based on the technical and quality requirements specified for the concrete, including e.g. compressive strength and exposure class (durability) requirements. The designer specified the binder amounts that fulfilled the exposure class requirements (cement 80 kg/m^3, furnace slag 240 kg/m^3) and the water-binder ratio (0.45). The designer also specified the maximum amount of binder (320 kg/m^3). This was specified due to the massiveness of the structure, where temperatures during curing need to be restricted to restrict thermal stresses that result in a cracking risk. Forssan Betoni also ensured through their examinations that heat generation would not be too great. The water-binder ratio of the concrete was determined taking into account the influence of the ratio on the strength and the durability properties of concrete. If the designed water-binder ratio is exceeded, in other words more water is used than specified, the strength and the durability properties of concrete are impaired.

Expert A did not determine the detailed final composition of the concrete, nor had FANP ordered it from Finnprima. For instance, expert A could not take pumpability into consideration, as he did not know the aggregates or the pumping lengths. Expert A stated in the interviews that his design was not intended as the final composition of the concrete, he merely gave on the basis of the technical and quality requirements the conditions (specifications) that the final composition should fulfill. The responsibility for the detailed design of the concrete composition was left to the concrete supplier.

According to the Project Manager responsible for the operation of the batching plant of Forssan Betoni (hereinafter the batching plant manager), expert A determined the mix composition of the concrete in terms of the binders "to the kilogram". In his opinion Forssan Betoni had in practice no possibility at all to influence the composition of the concrete. In the interview the batching plant manager, however, questioned the requirements (primarily those concerning durability) set by expert A on the base slab and, based on this, he also questioned the whole design. In his opinion the specified mix proportions made it impossible to reach good pumpability due to the very strictly set limits.

Expert A admitted in the interview that the water-binder ratio defined by him at 0.45 results with the restricted amount of binder to such a small amount of water in the concrete that without a good plasticizer it would be impossible to achieve good workability for the concrete. According to him the workability and pumpability of the concrete could have been improved by increasing the amount of both binder and water. According to Forssan Betoni, however, both expert A and FANP specifically denied this procedure in several instances. The batching plant manager told in the interview that he had noticed problems in the workability of the concrete, and had for this reason contacted expert A, who had said that the plasticizer should be changed.

Forssan Betoni drew up the preliminary test programme and performed the preliminary tests. The preliminary test programme and the test results were approved by FANP on 25.05.2005 and by TVO on 17.06.2005. In the conclusions of the test result report, Forssan Betoni has drawn attention to the fact that if the amount of binder is reduced and the water-binder ratio kept unchanged (0.45), this may result in extremely dry composition, which will make the concrete very difficult to place and impossible to pump. The representative of Forssan Betoni told the investigating group that they also proposed pumpability tests to be arranged but here was no reply to their proposal.

According to Forssan Betoni, they did not have the permission to be in direct contact with the designer but to deliver all information via FANP.

The test programme and the test results were submitted to STUK for information. STUK does not issue a separate approval for concrete. STUK approves the start of concreting in connection with the inspection of readiness for concreting and, according to the YVL Guide 4.1, the approved composition of concrete may not be changed during concreting.

As concerns the mix composition of the base slab concrete, TVO asked FANP for preliminary results of the tests performed on the concrete, for the results of fresh concrete and for the test results obtained with the new plasticizer. Between June and September TVO reminded the consortium in writing several times of the YVL Guides and of STUK's involvement in the approval of concrete. The comments made by TVO concerned e.g. workability and castability. TVO reminded also the fact that if the composition of the approved concrete is changed, the preliminary tests have to be performed again and the results submitted to STUK for information before the inspection of readiness for concreting is performed.

According to the information that has been received, no external parties were present in the preliminary tests. External supervision is not a common practice in general. According to expert B, who was hired by FANP and represented the Polytechnic of Kymenlaakso (KyAMK), the amount of water in the preliminary tests performed due to the change of the plasticizer was larger than the amount of water in the designed composition of the concrete. This opinion is based on the comparison of compressive strength results from tests performed by KyAMK and Forssan Betoni. In the compressive strength analyses performed by KyAMK the obtained strengths have corresponded to the results obtained from the test specimens produced by Forssan Betoni. The test specimens of KyAMK were produced at the batching plant during the concreting of the base slab using premixed fresh concrete, and their water content was higher than in the designed and approved composition. Expert B determined the amounts of water in these test specimens on the basis of batch reports and measurements of the water content of the aggregate.

According to expert B the designed mix composition of concrete has been defined "too tight". Variation in the quality of the different components has not been taken in consideration in the preliminary test plans.

According to both FANP's Deputy Site Manager and Finnprima's expert A, Forssan Betoni did not clearly enough bring up the fact that the designed composition is defined too "tight" and the required workability and pumpability cannot be achieved without changes in the mix proportions. The concern expressed by Forssan Betoni is, however, clearly indicated also in the result report dated 24.5.2005 and delivered to STUK for information and in the copy of the same report received from Forssan Betoni, where it is seen crossed out (according to Forssan Betoni FANP had crossed it out).

Observations and course of events prior to concreting of reactor building base slab

Construction works were implemented at several points in the plant area with TVO as the developer before the consortium started the actual construction of the plant. These included e.g. construction of water tunnels and the port. Forssan Betoni's batching plant no. 3 in the Interrock area delivered the concrete for these works. The requirements for the composition of the concrete were defined by the same expert A employed by Finnprima, who also took part in the design of the mix composition of the base slab concrete.

According to TVO's Site Manager initial problems were also encountered with the pumpability of the concrete in the construction works carried out with TVO as the developer, and the composition of concrete had to be fine-tuned by regulating the amount of filler (the finest part of aggregate). The batching plant manager confirmed this. After the mix composition was fine-tuned, the concreting was completed as planned.

Levelling concrete of the base was cast before the concreting of the base slab started. According to FANP's representative the concrete mix composition defined for the base slab was used for the levelling concrete in March, and at that point a pumpability test was performed on the base slab concrete. A representative of Forssan Betoni had been invited to the pumping test. In connection with the placing of the levelling concrete, variations were detected in the quality (consistency) of the concrete and also segregation. Hartela's employees who implemented the concreting also brought up on several occasions the variations in the quality of concrete. FANP believed that after Forssan Betoni had been contacted and criticism given, the variations in quality would be eliminated and the quality of the concrete would be as planned. According to Forssan Betoni, the problems were not, however, specified in a way that would have made it possible to correct them, and their written request to FANP for detailing the presented criticism was not replied.

Due to the variation in the consistency of the concrete, detected in the concreting of the base slab for fuel building UFA (concreted on 12.-14.8.2005) and safeguard buildings 2-3 UJH/UJK (concreted on 1.-2.9.2005), a new plasticizer was taken in use for the concreting of the reactor building base slab. The new plasticizer had been proven less sensitive to the accuracy of batching. In addition, a retarder was introduced to the composition, in order to prevent the previous concrete layer from setting before the next layer is concreted. New preliminary tests were performed on 15.9.2005 using the new plasticizer and the retarder, as required by YVL Guide 4.1. The purpose of the preliminary tests was to determine compressive strength, consistency and setting time. No pumpability test was performed.

In the first inspection of readiness for concreting of the reactor plant on 23.09.2005 only 7-day compressive strengths of the concrete were available. At that point TVO stated that on the basis of the available compressive strength results it was not possible to assess with certainty that the required strength would be achieved after 91 days, and thereby readiness for concreting was not sufficient. FANP and TVO decided to conduct a new inspection on 26.9.2005.

In the inspection on 26.9.2005 FANP assessed on the basis of the additional results the development of the strength of the concrete and the achievement of the required strength (91 days). TVO still did not consider the assessment sufficiently reliable. FANP and TVO agreed to conduct a new inspection on 30.9.2005, when the 15-day compressive strength values would be available.

STUK granted a concreting permission for the reactor building base slab on 30.9.2005. The approval of concrete strength was at that point based on 15-day compressive strength results and on the assessment made on the basis of these results by FANP's experts of the 28 and 91-day strengths and of the strength variation range.

Concreting of reactor building base slab

The base slab was concreted in three stages as follows:

- In August, base slab of fuel building UFA, 12.-14.8.2005. Amount of concrete ca. 1500 m^3
- In September, base slab of safeguard buildings 2-3UJH/UJK, 1.-2.9.2006. Amount of concrete ca. 2000 m^3.
- Base slab of reactor building UJA as well as safeguard buildings 1 and 4UJH/UJK 3.-8.10.2005. Amount of concrete ca. 12 000m^3.

Variation in the consistency of the concrete between different truck loads was detected in connection with the concreting of the base slab for fuel building UFA and for safeguard buildings 2-3UJH/UJK. This variation had also been observed during the concreting of the levelling concrete (STUK's memorandum 6.3.2006). The variation was interpreted to be caused by the plasticizer and the accurate dosing it requires. As a result, a new plasticizer was taken in use, as described above.

For the concreting of fuel building UFA in August, FANP issued the order to start concreting with a very short notice time. The two-week notice time specified in the agreement was not complied with in this case. Considerable difficulties were encountered in the concreting process, as the contractor (Hartela) did not have enough time to properly prepare for concreting. The levelling and the steel trowelling of the slab surface, in particular, were not done properly because the workers were too tired. This does not, however, have any influence on the strength or durability of the concrete. In subsequent concreting operations Hartela was prepared for this and had hired extra workers.

The Polytechnic of Kymenlaakso (KyAMK) controlled the quality of concrete during the concreting of the base slab of reactor building UJA and safeguard buildings 1 and 4UJH/UJK. The party in charge of the management of construction work of the reactor building (FANP) had ordered expert C, employed by a German company, to act as FANP's expert at the batching plant.

According to information received from TVO, the large base slab concreting operation on 3 October was started using the designed and approved composition of concrete. TVO's supervisors detected problems in the concreting work on the afternoon of the first concreting day (3.10.2005 at ca. 16.00). Problems were encountered with the pumpability of the concrete, resulting in e.g. concrete pumps breaking down. TVO’s supervisors inquired at the site for possible reasons why the pumps had failed or become clogged. The next morning, TVO contacted FANP's representatives by e-mail on 4.10. enquiring whether changes had been made in the composition during the concreting operation. FANP informed that no changes had been made in the composition of concrete.

However, Forssan Betoni and expert B have told that expert C, who acted at the batching plant as FANP's expert, reduced the amount of filler in the aggregate. Problems persisted, and according to the batching plant manager the composition was changed again 24 hours later back to almost the original composition. The amount of filler was still a bit smaller than in the designed composition.

The Site Quality Manager who supervised the concreting operation on behalf of the consortium also told that expert C had ordered changes to be made at the batching plant in the composition of the concrete on the basis of the consistency measurements performed by KyAMK.

According to TVO's Site Manager, the rest of the concreting operation went as planned. In the Site Manager's opinion the representative of STUK had not been informed about the change in the composition of concrete.

After the concreting operation, TVO contacted FANP several times (by e-mail), trying to find out if the composition of concrete had been changed during the concreting operation. On 5.10.2005, for example, TVO asked FANP to submit the batch reports for the concrete fabrication batches. Despite several requests, these reports were not submitted to TVO.

After the concreting operation, the concreting contractor Hartela drew up two nonconformity reports. The non-conformance report dated 15.11.2005 (Hartela NCR 0030) reported the disappearance of the compressive strength test specimens for 32UJH and 33UJH equipment pit. The non-conformance report dated 19.01.2006 (Hartela NCR 0029) stated that the reference strength of the concrete according to the site test specimens did not meet the requirement in area 2-3UJH.

Course of events after concreting of the reactor building base slab

Claims for submittal of batch reports of fabrication batches

Since FANP did not, despite several requests, submit the batch reports, TVO conducted on 14.10.2005 an inspection at the batching plant. Present in the inspection were the supervisor of concrete fabrication and the quality control expert from TVO, the Site Quality Manager from the consortium as well as the person responsible for the supervision of the batching plant for FANP. In this inspection, the representative of TVO concluded that considerable changes had been made in the composition of concrete during the concreting of the UJA building. In the inspection, TVO's representatives asked for copies of the batch reports, but FANP refused to produce them. It was agreed in the inspection that TVO would send an official request for the copies to FANP.

FANP informed TVO by an official letter on 20.10.2005 that the batch reports would not be submitted until in connection with the completion of the plant.

This resulted in active correspondence between TVO and FANP, and on 14.11.2005 FANP agreed to submit the requested batch reports. The reports were delivered to TVO on 21.11.2005. On the basis of the batch reports TVO concluded that the composition of concrete had been changed during the concreting operation. TVO prepared a draft non-conformance report on 23.11.2005. The actual non-conformance report (no. 0593) was drawn up by TVO on 14.12.2005 and the next day TVO informed STUK by e-mail of the non-conformance report that had been entered in the Kronodoc folder. Kronodoc is a system where STUK can in advance read material that will be later provided on paper.

In a letter dated 20.12.2005, FANP still denied that any changes had been made in the mix composition of concrete. In addition, FANP refused to accept receipt of the non-conformance reports and asked TVO to withdraw them.

In a letter dated 5.1.2006 TVO refused to withdraw the non-conformance reports and asked FANP to make a proposal for action to be taken by 10.1.2006.

At the end of January (26.1.06) and at the beginning of February (3.2.06 and 8.2.06) FANP submitted non-conformance reports to TVO for examination, concerning concrete structures in the base slab of the reactor building. TVO forwarded the non-conformance reports immediately to STUK for information.

Report by Polytechnic of Kymenlaakso (KyAMK)

The preliminary report by KyAMK (drawn up by expert B) on the tests performed during the concreting operation was submitted to FANP (to the site) in November (dated 13.11.2005, received at site on 14.11.2005). The report was preliminary because the 91-day results for the concrete were missing (the quality assessment age for concrete is 91 days). The report did, however, show considerable variation in the water-binder ratio in some batches. Towards the end of the concreting operation, the water-binder ratio exceeded the designed value, and varied between 0.53 and 0.56. The highest single value was 0.64.

The site did not forward KyAMK’s preliminary report either to TVO or to STUK. According to the information that was received the report was not sent to FANP's head office, either. The report was studied by FANP's Site Manager and his deputy. FANP also asked the batching plant to provide the batch reports for making more detailed analyses as, according to them, no conclusions could be drawn without binding results. According to FANP's Deputy Site Manager the report was not forwarded to the other parties due to its preliminary nature. FANP had decided to distribute the report only after the final results were available.

According to the Deputy Site Manager, FANP's perception was that the changes made in the composition of concrete during the concreting of the reactor building base slab were not relevant.

The preliminary report by KyAMK (copy) was sent to Forssan Betoni on 20.11.2005. Forssan Betoni did not comment the report at this point.

The Civil Work Contract Manager of FANP's parent company Areva arrived at the site in mid-January to settle a contractual problem between FANP and Boygues, the contractor of the containment. Boygues had informed that they would terminate the contract because they did not trust the batching plant’s capability to deliver appropriate concrete. After Hartela had sent a letter (non-conformance report) informing about the disappearance of the test specimens, the Contract Manager responsible for civil work had an investigation made by a party independent of the batching plants, the Technical University of Darmstadt.

Report by the Technical University of Darmstadt

Representatives of the Technical University of Darmstadt visited the batching plant and recorded several deficiencies (10 findings), but some of them were clearly based on misunderstanding. According to their inspection aggregates were not stored in silos, which resulted in a number of findings: there was no layer at the bottom of the storage pile to prevent mixing with soil, the particle size fractions had not been properly marked and the aggregate piles were not covered which, according to the inspectors, caused a risk of mixing and exposed the piles to rain and snow. In fact, the aggregate used for the concrete of the base slab was delivered by the supplier directly into silos without any intermediate storage. The aggregate piles detected in the inspection served as 2-hour stockpiles, in case transports had been delayed. According to the inspection, laboratory equipment had not been maintained in regulatory condition. This referred to the set of sieves, but the bowl that had been inspected was not part of the set. Deficiencies were also found in the storage of test specimens. According to the batching plant manager the test specimens were being transferred from one storage pool to another at the time of the inspection, which is why some of the test specimens were on a work table, in "dry" condition. The training level and qualifications of the staff could not be established in the inspection, as no documents concerning this were available. Nor was the Quality Control Plan for concrete production available. According to Forssan Betoni, the documents could not be presented because the inspection was made at a time when the English-speaking project manager of Forssan Betoni was absent.

Areva's Contract Manager responsible for civil work contacted the batching plant manager and emphasised in this discussion the critical status of concrete in terms of safety. He also warned the manager that the operation of the batching plant might have to be discontinued. A list of corrective action concerning the batching plant was drawn up (on 17.1.2006). The Contract Manager responsible for civil work also contacted the Managing Director of Forssan Betoni. Forssan Betoni was not able to implement the corrective action in the tight schedule demanded by FANP. After this, the Stop Work Order for the manufacturing of concrete at the batching plant was issued by FANP’s Site Manager for the first time on 24.01.2006. According to the Civil Work Contract Manager the discontinuation of operation was specifically based on the Darmstadt report. The batching plant manager said that in his opinion the report was goal-directed. FANP informed TVO about the discontinuation of operation at the batching plant by a letter dated 26.1.2006.

To TVO, the discontinuation of operation at the batching plant came as a surprise and TVO enquired about the reasons for the discontinuation.

FANP informed TVO on 30.1.2006 that the batching plant had been given a permission to resume operation.

At the beginning of February, Areva's Civil Work Contract Manager heard for the first time about the report by KyAMK. He did not know why the report had not been distributed widely enough for information within the FANP organisation. Having read the report, he found the problem to be serious. The subject matter content of the report was examined in Darmstadt. After discussions with several persons concerning KyAMK's report, the Contract Manager responsible for civil work decided to discontinue the operation of the batching plant the second time. Operation was discontinued again on 6.2.2006.

In a meeting between FANP and TVO on 3.2.2006, FANP informed that the water-binder ratio had exceeded the design requirements. STUK was informed of the matter in a meeting held on 9.2.2006.

The report of the Technical University of Darmstadt draws an unfair picture of Forssan Betoni's operation in terms of the storage of aggregates. The manager of Forssan Betoni's batching plant did not find the competence of the inspectors very high, either, as observations were made of matters that had no part in the production process. The inspection had been carried out in the absence of the batching plant manager.

According to Areva's Civil Work Contract Manager most designed compositions of concrete are such that they cannot be properly fabricated or poured. New preliminary tests were performed on the mix compositions in Darmstadt. The Contract Manager expressed his concern on the attitude of Forssan Betoni and its owner company.

Inspections for the re-start of batching plant

FANP/TVO presented on 28.2.2006 to STUK the investigations that had been conducted by that time, as well as their opinion of the conditions on which concrete fabrication could be continued. FANP's representative presented in the meeting the plans that they had drawn up, and which had been approved by TVO, for short-term and long-term corrective action.

TVO submitted the following clarifications concerning the batching plant and quality control at the plant to STUK on 8.3. and 9.3.2006:

- Clarifications for the development of quality control at the batching plant
- OL3-specific QA manual of Forssan Betoni, including procedures and documentation
- Forssan Betoni, QA manual ISO 9001:2000
- Clarifications concerning FANP's and TVO's intensified efforts for the control of the quality of concrete and the batching plant
- Work specification concerning the batching plant and transports.
- Quality plan concerning the batching plant and transports.
- Inspection plan for the batching plant before re-start of operation.
- Complementing of FANP and TVO organisations for quality control of concrete and the batching plant.
- Report of the Technical University of Darmstadt on corrective action implemented at the batching plant.

In addition, TVO submitted to STUK for approval the corrective actions required by critical non-conformance reports and the other non-conformance reports for information.

An inspection of the readiness for resuming operation was conducted at the batching plant on Friday 10.3.2006. The inspection was performed in compliance with the sequence outlined in the specifically prepared plan, CW Inspection & Test Plan, Fabrication of ready-mix concrete, Re-start of Batching Plant, 6.3.2006.

In the inspection, it was noted that the control and traceability of the water-binder ratio had still not been arranged in the required manner, despite the fact that the non-conformancies in the quality of the base slab concrete were primarily due to variation in the water-binder ratio. It was also concluded that the safety culture training referred to in the OL3 quality plan of Forssan Betoni had not been provided.

Due to these deficiencies, TVO refused to issue permission for re-starting of the batching plant. STUK agreed. It was decided that the next re-start inspection would be performed after the deficiencies had been corrected.

The new re-start inspection of the OL3 mixing plant was conducted at the Olkiluoto batching plant of Forssan Betoni on Wednesday 15.3.2006. FANP and TVO signed a report which stated that the required short-term corrective actions had been taken and the operation of the batching plants of Forssan Betoni could be resumed. STUK's inspector stated that STUK had no comments to make on the report.

On 28.3.2006 TVO audited Forssan Betoni's Olkiluoto batching plants no. 1 and 2. In the audit, 10 findings were still made, 4 of them non-conformancies. For example, the inaccuracy of measurements of furnace slag exceeded the tolerance allowed by the concrete norms (10 % > permitted 3 %). A positive finding was that the traceability of the water-binder ratio in the batch report and the delivery note had been sorted out swiftly and well. One of the three recommendations issued was that special attention should be paid on motivating the personnel.

3.1.4 Summary of problems that disturbed the concreting of base slab

Selection of concrete supplier, and purchase agreement

The procedure followed in the selection of the concrete supplier for the OL-3 project did not in all respects meet the requirements of FANP's quality system. At least the following deviations were found in the selection process:

- The call for tenders did not specifically state that special requirements are placed on quality management in the construction of a nuclear power plant. The requirements for quality management should have been stated so clearly that the tenderers would have been able to assess the amount of extra work required to meet them, and later operate without unpredicted cost pressures due to quality control.
- The key criterion applied to the comparison of the tenders was the price of concrete production.

- The quality system of Forssan Betoni did not at the selection stage meet the requirements of ISO 9001.
- The quality system of the consortium requires that each subcontractor prepares a quality plan before work is started. However, Forssan Betoni did not receive the specifications for the preparation of the plan until February 2006, and prepared their quality plan after that.

The delivery of concrete to the pump is not acommonly used limit. Usually the concrete supplier is responsible for the concrete properties up to the concreting site (formwork). Due to the specified delivery limit, the concrete supplier had no interest based on an agreement to pay sufficient attention to the pumpability of concrete.

For large-scale concreting operations, the required two-week notice time for concrete orders is justified. FANP did not respect this requirement in the concreting of the base slab for fuel building (UFA) 12.-14.8.2005, but submitted the notice of the start of concreting on the day that concreting was started. For this reason, the concreting contractor Hartela did not have enough time to properly prepare for the operation (did not manage to acquire a sufficient number of workers) and this influenced the progress of concreting operation particularly at the finishing stages. On the other hand, the required two-week notice time that FANP specified for itself is unusual in smaller concreting operations, and indicates that the persons who concluded the agreement are not very familiar with the practices followed in construction projects.

The acquisition followed the agreed procedures in main parts. However, the special features of nuclear power plant construction were not clearly emphasised and no OL3-specific quality plan, nor inclusion of IAEA's requirements for quality management in the plan was required of the tenderers at the tendering stage. These were not required until the audit that TVO carried out in the head office of Forssan Betoni in the spring in 2005.

Batching plants and their staff

The Olkiluoto batching plants no. 1 and 2 were new plants. The start-up of operation and the commissioning of new machinery and equipment always takes time, but the technical conditions for the production of good quality did exist at the time the base slab was concreted.

Forssan Betoni had no experience in a nuclear power plant construction prior to the OL3 project and all the quality requirements applied to nuclear power construction were not brought up at the tendering stage. Also, the special safety requirements in the nuclear field were not emphasised by FANP in the training of the batching plant staff before concrete fabrication was started. After the site was handed over, the consortium and Forssan Betoni discussed the quality requirements and the work practices repeatedly, and Forssan Betoni felt that requirements outside the agreement were placed on them.

The staff at the batching plants possessed the required qualifications. However, several features in the performance of Forssan Betoni came up during the investigation that are not in accordance with a high-level quality and safety culture. Practices followed in the nuclear field, but deviating from practices normally followed in construction work, were not fully observed. For instance, concrete fabrication was not implemented according to the specifications and requirements, non-conformancies were not reported without delay, and there were delays in corrective actions for the reported non-conformancies.

The responsibility of the batching plant manager for the quality of concrete was not clear, as experts hired by the consortium assumed a significant role in the determination of the composition of concrete, and the changes in the composition were also during the concreting operation made in collaboration with the consortium's expert. In the interview, the batching plant manager stated that in his opinion the changing of the composition was not a relevant issue. He mainly considered it to be an inconvenience, as it resulted in pumps breaking down.

Several of the interviewed persons commented on the difficulties they had in cooperation with the staff at the batching plants. According to their experience, the staff at the batching plants did not take variations in the quality of concrete seriously enough and did not actively try to sort out the problems together with the other parties.

However, it is not right to blame an individual supplier for the poor safety culture, as the consortium's practices in the selection and guidance of the concrete supplier were deficient. The consortium should acknowledge the fact that jobs in the nuclear field are rare and it is therefore to be expected that nuclear safety is not the number one priority in the subcontracting companies operating in different fields.

Some of the interviewees questioned the professional competence of the staff at the batching plants with respect to concrete fabrication, and language skills were suspected of having caused problems, as well. Yet, there are no grounds for these perceptions concerning the competence and the language skills of the staff, and the negative views may have been presented to serve a purpose. From the point of the agreement, it is not justified to make the language skills an issue, as the contract between CFS and Forssan Betoni defines Finnish as the language to be used at the site.

Forssan Betoni and its parent company Lemminkäinen voiced their outrage on how the quality of the base slab and the operation of the batching plant were presented in public after the concreting of the base slab. They emphasised that the concreting was completed and the quality of the concrete is good. Attitudes of this kind in the management do not promote the development of a quality and safety oriented atmosphere in an organisation.

Preparations for base slab concreting

Variations were detected in the quality of concrete (consistency, segregation, pumpability) in several contexts before the concreting of reactor building base slab. Observations were made at least in preliminary tests, the concreting of levelling concrete, the concreting of base slab for fuel building UFA and the concreting of base slab for safeguard buildings 2-3UJH/UJK.

In other words, the experts of all the parties were aware of the problems connected with concreting, but active measures to correct the situation in good time before the concreting of the reactor base slab were not taken. Attempts to correct the situation were not started until in the autumn just before the planned start of concreting, when e.g. the plasticizer was changed and a retarder was added in order to increase the workability time.

In practice, cooperation between the structural designer and the concrete supplier has been virtually non-existent. FANP has actually required that all communication be handled through them. FANP trusted that Forssan Betoni would implement the corrective action once problems had been occured in previous concreting operations and the matter had been reminded. FANP did not check whether the corrective actions had actually been taken.

FANP's Deputy Site Manager hired expert B from the Polytechnic of Kymenlaakso (KyAMK) as an independent quality controller for the concreting of the reactor building base slab. The Deputy Site Manager assumed that the factors detected in the mix composition before the concreting operation had been corrected. Several experts, including expert A who designed the mix composition, expert B and the German expert C had seen the composition of concrete, but did not warn about any problems.

Concreting of base slab

According to the information received and the results obtained in the investigation, the quality control personnel of FANP did not identify serious quality problems during the work.

The composition of concrete had been changed during the concreting operation, which is in violation of YVL Guide 4.1. According to FANP the change was not relevant, but this claim can be questioned as the change exceeded the limits specified in the Finnish Building Code Part B4, Concrete Structures for weighing accuracy (±3 %). Only changes within these limits can be interpreted as non-relevant. In all other cases the influence of the change should be analysed.

During the concreting operation it was not clear to the parties involved, Forssan Betoni or FANP, who was responsible for the composition of mixes. In this case the quality of concrete was changed on an order given by FANP.

Course of events after the concreting of reactor building base slab

Information about the results of the KyAMK report was not distributed widely enough even within FANP. The relevant results were presented already in the preliminary report. Leaving the report without forwarding to and the concealing of the results from TVO and STUK do not reflect an open attitude toward problems which would be in line with good quality culture.

The disappearance of the compressive strength test specimens made by Hartela indicates deficiencies in quality control.

Conclusions

The construction of the base slab was impeded by the following factors:

- No appointed responsible manager at the site unambiguously in charge of the base slab fabrication, with authority to issue orders that are binding to all parties.
- The base slab delivery chain did not share a common perception of the safety significance of the quality of concrete.
- In the selection of the concrete supplier, the special quality requirements applied in a nuclear power plant construction were not brought up in the tender invitations, whereas cost factors were strongly emphasised in the selection.
- No training was provided to the staff involved in the fabrication of concrete concerning practices in the nuclear field and the safety significance of their own work.
- The division of the concrete supply contract resulted in interfaces, the management of which failed.
- In quality control, too much trust was placed on the responsible attitude of the parties in the elimination of the detected problems.
- Responsibilities were unclear and problems existed in communication with respect to the design of the mix composition, fabrication of concrete and quality assurance.
- The problems observed in previous concreting operations did not result in effective corrective actions implemented in time.
- The approved composition of concrete and the concreting specifications were not adhered to in concrete fabrication.
- Quality non-conformancies connected with the composition of concrete and concreting were not handled without delay and in an open manner.
- The handling of quality problems in the base slab concrete has been characterised by a search for guilty parties instead of focusing on developing the practices.

3.1.5 Investigation team's assessment of the acceptability of the concrete slab

The water-cement ratio of concrete influences the strength and the durability of concrete. A higher-than-designed water-cement ratio reduces the compression strength and impairs the resistance of concrete against environmental impacts.

Despite the higher water-cement ratio, almost all the 91-day reference strengths determined for the concrete samples taken of the base slab fulfil the requirement specified for K40 (C32/49) strength class concrete. The 91-day strength has been below the value required of strength class K40 only in area 2-3UJH, and even there the value is only slightly below the required value. None of the additional samples that were taken were below the required strength class value. STUK has approved the test results.

When assessing the compressive strength of concrete, it should be borne in mind that the development of strength does not stop at the age 91 days when the quality is determined, but continues as the age of concrete increases. In addition to age, the composition of mix and the conditions also influence the development of strength. For concrete that contains furnace slag, the development of strength continues for a long time. On the basis of experience gained from previously built structures, the increase in strength is usually considerable in comparison with the 91-day results.

As a result of what has been presented above, the concrete of the base slab can be considered to meet the specified requirements for compressive strength.

Concerning durability requirements, the concrete meets the specified requirements in terms of exposure classes XC2 (carbonation) and XS1 (chlorides).

Due to the higher-than-designed water-cement ratio, the concrete does not meet the requirement of exposure class XA1 (chemically aggressive substances). Owing to the high amount of furnace slag, however, the chemical resistance of the concrete is in practice very good. As the concrete is ageing and its strength is increasing, its density will also increase, which further improves its chemical resistance.

With respect to durability requirements, it should be noted that they apply to the side surfaces of the base slab. Damages to the surface parts take place very slowly. The binder composition that has been used (more than 70% furnace slag) is normally used in extremely demanding environmental conditions in which chlorides are present, and where the corrosion risk of the concrete due to other chemical substances is considerable. Nevertheless, to ensure base slab chemical resitance TVO has announced that it will in any case require the protection of the base slab against external moisture and the impurities it will bring along.

3.2 Containment steel liner

3.2.1 Background information on containment

Contractual parties responsible for the manufacture of steel liner

The parties to the contract were the builder (Framatome ANP, FANP), the structural designer and supplier of the steel liner (Babcock Noell Nuclear GmbH) and their subcontractor (= as the manufacturer), a Polish Engineering Works (Energomontaz-Polnoc Gdynia (EPG)).

Purpose and structure of containment

The nuclear safety related purpose of the containment is to prevent release of radioactive materials into the environment and to protect the reactor coolant circuit and the safety systems against external events. The containment is a cylindrical double containment that is about 60 m high and has a diameter of about 45 m. The walls and the dome of the inner containment are made of pre-stressed concrete. A steel liner is installed on the inside of the concrete structure. The inner containment can resist the over-pressures and the temperatures caused by accident situations, without loosing its tightness. The outer containment is an extremely massive reinforced concrete structure that can withstand e.g. airplane crashes.

The reactor and the entire rector coolant circuit (the primary circuit), parts of the steam and feedwater systems as well as equipment of the safety systems are installed inside the containment. The containment is normally accessed through a personnel airlock. A backup airlock is also provided for emergencies. The material hatch of the containment can be temporarily opened during outages, if required for maintenance purposes. These airlocks are integral parts of the steel liner and the surrounding concrete.

In an accident situation the inner containment is isolated by closing the exit routes from the building. This prevents the release of radioactive materials into the environment. The steel liner including all its penetrations and hatches is assigned to safety class 2.

3.2.2 Manufacturing of steel liner

Method of manufacturing

The steel liner is made of 6 mm thick structural steel. The steel plates are joined together at the engineering works by welding them into 30-degree segments, the surface of which is then finished (sandblasting + coating). The segments are transported to the port and welded into 180-degree sections. At the site, the sections are first joined together into rings and the rings are then assembled to make up the complete liner as the construction of the containment progresses.

According to the welding specification applied to the manufacturing of the steel liner, the root gap between the plates, which is to be filled with the welding material, is 2-5 mm. The welding procedure have been carried out using this gap size. The use of ceramic weld support in the welding process has been approved later.

Selection of steel liner supplier

Several potential steel liner suppliers were indicated in the Main Contract. FANP called tenders for detailed design and manufacturing from four Finnish and five Central European companies, but only two of them submitted a tender. As the steel liner is a SC2 steel structure, the manufacturer needs to be approved by STUK. In addition, STUK performs several construction inspections during the manufacturing of the structure [8].

Babcock Noell Nuclear GmbH (BNN) was selected as the supplier. The selection process followed Framatome ANP's standard procedure and was based on both technical and commercial selection criteria. The division of work between FANP and the supplier is that FANP performs the required basic design work and lays out the requirements in the project specification. The supplier is responsible for detailed design, taking the requirements of the project specification into consideration, and prepares the detailed construction plan on the basis of these. The steel liner is manufactured according to the approved construction plan.

Selection of steel liner manufacturer

Babcock Noell Nuclear GmbH selected as their subcontractor (=the manufacturer) the Polish Engineering Works Energomontaz-Polnoc Gdynia (EPG). The representatives of FANP told in the interviews that the selection of the manufacturer came as a surprise to them. The contracts concluded between FANP and various suppliers refer to the use of subcontractors, but FANP has no real say in their selection. The interviewed representatives of TVO had also been surprised by the selection of the manufacturer. The feedback on the selected manufacturer obtained from a Finnish company given as reference was reasonably good, but emphasised the importance of constant supervision to ensure that the desired final product would be achieved.

FANP, TVO and STUK audited the Polish manufacturing company on 29-30.3. 2005. The audit focused on e.g. materials handling, welding, dimensional control, sandblasting, coating, transport logistics as well as inspection, testing and quality management procedures. During the audit, 8 non-conformancies were recorded which required corrective actions. Two of the non-conformancies concerned filler metals used in welding, for which no handling or storage specifications had been drawn up, and for which humidity and temperature reports for the storage facility were missing. Weld inspection procedures were incomplete, and no systematic procedure existed for the daily control of welding reports. In addition, the usability of the liquids for the development of X-ray films could not be verified. Deficiencies were also found in the calibration of micrometers in the DT laboratory.

TVO had earlier performed a pre-audit in March 2005, in which 11 non-conformancies had been recorded. Corrective actions had, however, been completed on them by the time of the actual audit.

An application was submitted to STUK in compliance with YVL Guide 3.4 [9] for the approval of Energomontaz-Polnoc Gdynia as a manufacturer of nuclear pressure equipment. The NDT testing organisation of the company was approved according to YVL Guide 1.3 [10] for the test methods used during manufacturing (radiographic, ultrasonic, liquid penetrant, magnetic powder, and leakage testing). In terms of welding technology, the construction is demanding and NDT inspections are really important in manual welding due to the large number of run-on and run-off points in the welds.

STUK has approved the construction plan of the steel liner and numerous subsequent additions to it. The steel liner is considered as a nuclear power plant steel structure according to YVL Guide 4.2 (the bearing steel structures of a reactor containment made of concrete) [11].

The manufacturing process in Poland is supervised by the quality controllers of FANP and BNN as specified in the quality control programme of the construction plan. The quality controllers of TVO also visit the engineering works weekly to supervise manufacturing. STUK performs construction inspections on prefabricated components before coating in compliance with YVL Guide 1.15 [8] as the manufacturing progresses. TVO's representative will also be present in these inspections.

Requirements specified for quality assurance of steel liner manufacturing

In order to ensure the quality of the steel liner, FANP defined the following activities:

1. Qualitative assessment of the BNN the EPG and the testing organisation based on documentation, and their comparison with valid (ISO) standards and YVL Guides.
2. Verification of fulfilment of requirements by audits performed by TVO and STUK.
3. Inspection performed by TVO of construction plan documentation drawn up by FANP/BNN/EPG and submittal of the construction plan to STUK for approval.
4. Starting permission for manufacturing.
5. Maintenance of the quality level of the manufacturer through training (repeated training events) of the entire personnel, from the top executives to the workers, based on important/current issues related to manufacturing, and on FANP's requirements (taking into consideration also the comments made by TVO and STUK in connection with their control efforts).
6. Inspection of the manufacturing documentation of FANP/BNN/EPG with respect to each plate part, segment and the dome.
7. Starting permissions granted separately for each separate segment and part.

For the bottom part AS10 of the steel liner (the base plate and the bottom part of the wall welded to it), FANP defined the control phases as follows:

1. Prefabrication of segments, conical parts and base parts at the engineering works under continuous control of FANP, BNN and EPG. Random test type inspections by TVO and STUK.
2. Inspection of all welds by FANP, BNN and EPG, as well as by TVO and STUK, after which coating permission is granted.
3. Sandblasting of parts to class SA 2½ and 80 µm coating with zinc-silicate paint under control of the parties referred to above.
4. Inspection of coating by TVO (and STUK), after which transport permission to the port of Gdynia for sub-assembly.
5. Assembly of the base part halves by means of a steel frame under continuous control of FANP, BNN and EPG. Random test type inspections by TVO and STUK.
6. Sandblasting of the halves to class SA 2½ and 80 µm coating with zinc-silicate paint under control of the parties referred to above.
7. Inspection of coating by TVO (and STUK), after which shipment permission to Olkiluoto.

The manufacturing and control phases of the cylinder rings and the dome are analogous.

3.2.3 Observations made in the manufacturing of steel liner

Deficiencies and problems in manufacturing

Some schedule-related problems were encountered in the submittal of the construction plan before the start-up of production, due to the obviously incomplete state of the design. The construction plan submitted to STUK was incomplete and has been later supplemented on several occasions. This has required extra work from the various parties and made the approval process difficult (schedules, perception of the whole). In addition, due to this process the manufacturer has not always known what the most recent updated version of the design drawings is. For this reason, holes for pipe penetrations were cut in wrong places as instructed in the old design drawings, and the holes had to be patched up later.

From controlling point of view, the relatively long "control / supply / production chain" (STUK->TVO->FANP->BNN->EPG) has proven problematic. It causes delays e.g. in communication, the handling of critical non-conformance reports, and the implementation of corrective actions related to production. In addition to the long "chain", there are also considerable differences in cultural attitudes as well as in problem handling and solving skills (e.g. "instability" of the arch detected in the stud welding of anchoring plates) and in the implementation of corrective actions. Unclear responsibilities are also emphasised in the different parts of the "chain" (e.g. quality assurance).

As production has progressed in Poland, TVO and STUK have implemented oversight activities on a regular basis. For STUK, regulatory control has consisted of construction inspections of subsections and components, such as penetrations and anchoring plates, as specified in YVL Guide 1.15. Perhaps the worst deficiency in the performance of construction inspections has been the fact that the inspection documentation has fallen way behind production. This makes it very difficult to perform construction inspections which are required in order to enable the manufacturer to proceed to the next work stage (=sandblasting + coating) in an optimum production schedule. STUK has made several admonitions about this to TVO (most recently in February 2006) and TVO has correspondingly informed FANP on the matter by letter, at least on two occasions. As a result, the situation has slightly improved lately, although it has not been corrected to the desired level, yet.

The production conditions at the engineering works of EPG are at a modest level, considering that safety class 2 components are welded and finished there. Deficiencies can be found in e.g. lighting, cleanness and temperatures. Manual welding can in a case like this also be considered quite a primitive choice.

The EPG has experience in the manufacturing of large-scale steel structures for conventional applications, but no earlier experience in deliveries to nuclear power plants. For this reason, FANP's requirement for repeated training events to maintain the quality level of the manufacturer was justified. However, in practice no training was provided although the requirement is recorded in EPG's Quality Manual. No training on the promotion of safety culture has been provided, either.

It has also been observed that FANP has left the control of actual production too much to BNN (at times FANP’s control has appeared to be completely based on random tests). FANP's performance combined with the limited experience of BNN's supervisor in this type of manufacturing has resulted in obvious delays in e.g. the handling of documents, the solving of problems and the implementation of corrective actions. For these reasons TVO and STUK have in practice had to assume the responsibility of the plant supplier in carrying out inspections (control). This has been justified to ensure that corrective actions are initiated without delay, but FANP has failed to react to this by sufficiently improving its own performance.

The problem is that the manufacturing schedule of EPG is constantly "alive". The EPG does not manufacture the steel liner according to a steady schedule, but accepts other orders in-between depending on the market situation and their own production capacity. This results in production breaks from time to time in the manufacturing of the steel liner, while at other times the schedule is excessively tight. On the other hand, it has not always been possible to continue the manufacturing of the steel liner as scheduled, due to deficient construction plans.

During the manufacturing of the steel liner at EPG, in a regular construction inspection the inspector of STUK and the quality controller of TVO noticed excessive root gaps in the welds between plates. In terms of welding technology, the use of weld support makes it possible to use larger root gaps, and the manufacturer has started to take advantage of this in the welding process. The use of a larger root gap in the welding process does not comply with the original welding specification, qualified by procedure tests. The problem of an excessive root gap in the welding of the components was detected twice in the autumn of 2005, and STUK sent a remark of this to TVO. The inspectors of TVO and STUK stopped production to take corrective action. A non-conformance report was drawn up and it was assured that the problem would not occur again.

In connection with a construction inspection performed by STUK in the port of Gdynia in Poland (on 10.5.), it was noticed that the problem re-appeared in the assembly of the segment sections. The measured root gap in the horizontal weld was ca. 7.5 mm at its maximum, instead of specified 2-5 mm. STUK's inspector discussed the problem in Poland with the representatives of TVO, BNN and the consortium, and later in Finland with TVO's quality controllers. In TVO's opinion this operation is not acceptable and TVO is investigating a resolution to the problem.

Errors in the manufacturing of steel liner

The following errors, for example, have occurred in the production, and required repairs and extra tests:

1. Root gap exceeded the maximum specified gap of 5 mm in manufacturing at the Engineering Works (and prior to that the introduction of weld support to the welding process).
2. Root gap increased to 7.5 mm in the assembly process carried out in the port (observed on 10.5.2006).
3. Use of non-approved welding method for repairs (repairs using electrode welding, although the only approved welding method is flux cored arc welding).
4. Holes for pipe penetrations cut in wrong locations (old design drawings)
5. Defective anchoring plates (deficiencies in stud welding, observed on 15.3.06) in the steel liner jacket.

Repeated use of an excessive root gap is a clear quality non-conformance to the officially approved procedure and absolutely unacceptable to this extent. A situation like this should not be possible in a well functioning quality system. Quality control based on the welding specification shall be continuous, and every worker must be responsible for the quality of his own work. In this project the next control step is defined so that FANP's quality controller controls the compliance of the performance with specifications and the fulfilment of quality requirements. The inspection following that is performed by TVO's quality control inspector. STUK is not responsible for quality control during production, but only for the conduct of of the prescibed construction inspections. In addition, the quality system requires traceability in a situation where it is possible that a defective product has passed through quality control during production. In this case it is not clear how widely excessive root gaps have been used in the welding processes.

The acceptability of the welds that do not conform to the welding specification has been subsequently verified by additional qualification tests. STUK has approved the programme of the welding procedure test and seen the preliminary results. The result report has not yet been submitted to STUK for review. According to TVO, the primary objective will, however, be to improve the accuracy of manufacturing and the construction practices.

The use of a non-approved welding method (the 3rd non-conformancy above) was detected in a construction inspection performed by STUK. The manufacturer had decided to modify their earlier work practices and chose an unqualified method instead of having recorded and reported a non-conformancy, proposed corrective actions, and waited for approval before continuing the work. The welds produced using a wrong method were removed by grinding and re-welded using a qualified method.

The cutting of pipe penetration holes in wrong places was due to the use of non-approved design documents. Information about changed location of the holes did not reach the manufacturer before the work was started. The manufacturing of the respective parts of the steel liner was started with FANP's permission before the design documents had been approved. The holes were detected in TVO's control inspections. They were patched up using appropriate methods and the result of the repair was verified by X-raying.

In connection with the construction inspection of the installation welding of the jacket (AS 20 ring), defects were detected in the anchoring plates welded to the steel liner. The stud welding of the anchoring plates had failed in some of the studs welded on the edges of the plates. This was shown as an inconsistent "collar" at the root of the stud. The plates had to be removed and new plates with correctly welded studs were joined to the steel liner.

A clear deviation from specifications is the waviness of the bottom part AS10 of the steel liner. In its final place, the bottom shold be as flat as possible to minimize the ai pockets between the liner and the concrete, in order to avoid corrosion of the liner in the long term. The bottom structure without stiffeners was a choice made by the designer. The defined waviness tolerance may not have been realistic, taking into consideration the problems connected with manufacturing (=welding). In order to evaluate the possible problems caused by waviness, the steel liner was subjected to a water filling test. In its final location in the containment, concrete will be placed into the steel liner, and the purpose of the water filling test was to simulate the weight of the concrete. On the basis of the results of the test, it was concluded that the load straightens the steel liner, and the waviness exceeding the tolerance is not significant. Nevertheless, in order to eliminate the possibility of air pockets, concrete will be injected between the steel liner and the base plate after concreting work inside the steel liner have proceeded to a suitable point. For the injection work grooves have been milled to the surface of the base plate and through them the grout will penetrate the whole area of the plate.

Conclusions

The following factors have impeded the manufacturing of the steel liner:

- Responsibility for the selection and control of the manufacturer was left to the subcontractor.
- Requirements on quality and the supervision of manufacturing were not emphasized at the design and tendering stage, and came as a surprise to the manufacturer.
- The working practices and equipment used by the manufacturer are outdated for this type of manufacturing.
- Permissions have been granted by FANP for the continuation of manufacturing in situations where the design of the phases and the approval of the design documents have not been completed.
- The safety significance of the welds of the steel liner has not been emphasised to the workers involved in manufacturing, and no training has been provided to themconcerning quality management practices in the nuclear field.
- The inspection documentation of the steel liner has not been available in full in construction inspections.
- The long supplier chain has slowed down the non-conformance handling process.
- The quality control implemented by the subcontractor and the plant supplier has been deficient, and required extra activities from TVO and STUK.

3.3 Polar crane and material hatch

The deliveries of the polar crane for the reactor hall and the material hatch for the containment are at the design stage, and their manufacturing has not yet been started. The common denominator for these deliveries is the same designer and manufacturer. The background information of both deliveries and the progress of the deliveries so far are described briefly below.

3.3.1 Background information on polar crane and material hatch

Contractual parties responsible for the manufacturing of polar crane and material hatch

The parties to the contract were the plant vendor (Framatome ANP, FANP) and the structural designer and manufacturer of the polar crane and the material hatch (Eiffel).

General information on the company

Eiffel is part of the Eiffage Group and employs 1060 people. The company specialises in the manufacturing of large-scale steel structures, such as bridges, locks, towers and pressure vessels. Polar cranes represent only a small part of the product range. The polar crane and the material hatch will be manufactured in Lauterbourg near Strasbourg and designed in Colombes, Paris.

Requirements specified for polar crane and its construction

A so-called polar crane will be installed in the top part of the reactor hall at the Olkiluoto 3 nuclear power plant unit. There are tens of cranes in use at the nuclear power plant, but only the cranes used in the transfer of nuclear fuel or in other safety significant lifting operations are under special control of STUK. The polar crane is one of these, and it is assigned to safety class 3.

Due to the circular shape of the reactor hall, the crane construction must also be designed with a special rotating crane bridge. A rail is mounted in the top part of the wall construction in the reactor hall, and the crane bridge will rotate on this rail. Because of the movement that differs from that of a normal gantry crane, cranes of this type are referred to as polar cranes.

The span of the polar crane bridge is 44.3 m and the maximum capacity of the main lifting gear is 320 tons. There are two smaller lifting gears in the crane, as well (35 t and 5 t).

Selection of polar crane designer and manufacturer

Four potential polar crane suppliers were indicated in the Main Contract. FANP invited tenders for detailed design and manufacturing from three Central European companies and one Finnish company. The French company Eiffel was selected as the supplier. Eiffel is on FANP’s list of approved suppliers.

Eiffel's engineering works in Lauterbourg produces great numbers of large-scale steel structures, and the manufacturing of a unit the size of polar crane does not differ much from their production in general. This company has experience in the manufacturing of polar cranes for nuclear power plants. The most recent delivery was in 1998 to a Chinese nuclear power plant.

In the call for tender, Eiffel was required to include IAEA's safety requirement 50-C-QA [6] or the requirements of some other nuclear standard in their quality system or in the project-specific quality plan, since the polar crane and the material hatch are safety classified equipments. According to FANP, Eiffel has been qualified pursuant to FRA/N/100E/OL3. The quality system of the manufacturer carries the ISO 9001:2000 certificate. In addition, nuclear standards are included in project specifications as requirements.

Progress of the polar crane delivery

The project specification of the polar crane was approved (20.12.2005) by a decision of STUK, which contained eight admonitions. The admonitions mainly concerned consideration of standards and regulations, and their updating in the project specification and in its requirements.

The construction plan of the polar crane was in mid-March 2006 in approval review between TVO and Framatome, but had not yet been submitted to STUK for approval.

Requirements specified for the material hatch and its construction

The diameter of the material hatch located in the reactor hall is 8.3 m. The lock is opened by lifting it up along rails. The material hatch is used during annual outages and repair shutdowns to transport large equipment into or out of the reactor hall. The material hatch, together with the steel liner as a whole, is assigned to safety class 2.

Selection of material hatch designer and manufacturer

Five potential material hatch suppliers were indicated in the Main Contract. FANP invited tenders for detailed design and manufacturing from four Central European companies and one Finnish company. The French company Eiffel was selected as the supplier.

Progress of the material hatch delivery

TVO audited Eiffel in mid-March 2006, and the questions connected with the material hatch were dealt with in this context. At the time, the design of the material hatch had proceeded to almost half way.

3.3.2 Observations in connection to acquisition of polar crane and material hatch

Quality management implemented by FANP

FANP audited Eiffel's design activities in December 2005 and the factory in March 2006. In other words, in this case FANP audited both the design and the manufacturing organisation. However, the audits were late, as they were conducted about a year after the project had started. No significant remarks were made in FANP's audit of the design activities.

Audits performed by TVO on Eiffel

TVO performed an audit on Eiffel on 14.-15.2.2006. The purpose was to assess Eiffel's design, manufacturing and quality management activities, and other preconditions for operation. Activities related to design were assessed in Paris and issues connected with manufacturing in Lauterbourg.

The audit produced 12 recorded findings and 8 recommendations. The findings and recommendations were focused primarily on the safety culture, manufacturing methods and meeting practices.

At the time of the audit, the design organisation had worked on the OL3 project for about a year. The construction plan for the polar crane was being examined by TVO and FANP, but has not yet been submitted to STUK for approval. It was also established during the audit that about half of the design work for the material hatch had already been completed, but the engineering works did not have reports of design review meetings available for inspection. Eiffel had understood that independent reviews of the design activities could be realised by organising weekly meetings of the technical design team.

IAEA's safety standard 50-C-QA or some corresponding requirement had not been taken into consideration in the quality system. According to the information received in the audit, Eiffel had not been informed of the requirement. Two non-conformancies related to this observation were recorded in the audit; one of them concerned safety culture training to personnel involved in the OL3 project.

The other non-conformancy that concerned forwarding of safety requirements was that Eiffel did not have STUK's decision on the project specification (29.12.2005). Also, the supplier had old versions of YVL Guides 1.4 [2] and 5.8.[12]. In the project specification, compliance with renewed versions had been required. A recommendation connected with this was that all the applicable YVL Guides shall be made available to all the employees in electronic form, e.g. in the company's intranet system.

As factory facilities are not particularly clean, it was recommended that the facility in which I&C and electrical components are installed should be separated from the other production facilities due to dirt and dust. The other recommendations concerned harmonising the acquisition of outsourced components, clarifying the procedures for acceptance of incoming material, and including change management procedures in the quality plan. It was also recommended that Eiffel conduct an internal audit focusing on the OL3 project.

The audit also revealed several deficiencies in the practices of the engineering works, such as incorrect use of a hoisting hook for lifting plates. The calibration dates of some equipment and welding machines had expired. Deficiencies were also found in the quality control of welding materials and filler metals. Heat treatment specifications were not available in the heat treatment room.

Eiffel's design and manufacturing organisations have initiated measures to implement corrective action on the basis of these non-conformancies, and the safety of the nuclear power plant under construction has not been considered to be endangered in this case.

Conclusions

The result of the audit conducted by TVO on Eiffel confirmed the impression that TVO's audits are more detailed and produce more findings than FANP's audits. Along with the other examples, this case also showed that the special requirements that are applied in the nuclear field are not properly forwarded from the plant supplier to the subcontractor.

4. MANAGEMENT OF THE OL3 CONSTRUCTION PROJECT AND QUALITY MANAGEMENT

4.1 Management systems

The main parties to the OL3 project are the licensee TVO who has ordered the OL3 nuclear power plant unit and the power plant vendor CFS that is a consortium formed by Framatome ANP (FANP) and Siemens GmbH. The reactor island will be supplied by FANP. The main focus of this investigation has been on the performance of FANP with the exception of activities and findings that clearly relate to the whole consortium. In these cases the whole consortium is referred to in the text.

4.1.1 TVO’s management system and cooperation with FANP

TVO’s role

In the OL3 project plan, TVO defines its own role as follows: *“The OL3 project is responsible for project management and for coordinating and supervising all the works and services related to it. Particular effort is directed to safety culture and quality management”*. TVO as the Construction License holder is responsible for assuring safety and quality at the power plant under construction.

The OL3 safety and quality culture management process described in the TVO’s quality system is applied only to TVO’s own organisation. For example, it describes the assessment of the operations of TVO's own personnel. The creation of safety and quality culture in the supply chain and in the construction organisation takes place indirectly, since the plant vendor is responsible for construction and for the selection and management of the subcontractors that participate in construction.

In the Main Contract, TVO has transferred the responsibility for licensability to CFS, as well as the implementation of the works, the selection and management of subcontractors and the site management. In practice this means that after the handover of the site in February 2005, TVO does not communicate directly with the subcontractors, except for TVO's audits and control activities. In all other respects TVO receives information about the progress and the quality of the subcontractors' work through the consortium, and STUK, in turn, receives this information from TVO.

Quality management

The quality policy of the OL3 project clearly emphasises the key significance of quality management to the successful implementation of the project.

Quality management in the OL3 project is organised to be a part of the management activities and it is divided into quality control (QC), on one hand, and quality assurance (QA), on the other hand.

There are 12 permanent employees in the quality management unit of the OL3 project; eight of them are quality assurance engineers. In addition there are external part-time QA engineers and auditors. Further, the OL3 project QC team for plant technology engineering consists of altogether nine people, part of them working as inspectors in the manufacturing locations. The OL3 project QC team for construction technology engineering comprises 13 people. TVO ensures the quality of construction and the equipment by means of audits of organisations' activities performed by the QA staff, as well as by inspections and quality control of structures and equipment carried out by the QC officers.

Training

Introduction training organised by TVO is only provided to TVO's own personnel and consultants employed by TVO on a regular basis. Introduction training and other guidance provided by TVO is the key channel in providing basic knowledge and safety culture of the nuclear field to the personnel involved in the OL3 project. Training has been designed presuming that the personnel employed by TVO for the OL3 project primarily comes from outside the nuclear field. It takes time before a clear understanding is reached in the OL3 project of the safety principles to be complied with in the construction and operation of a nuclear power plant, and of the roles of the various organisations. Opinions were expressed in the interviews that STUK was at this stage considered as part of safety assurance mechanisms.

According to the interviews, an important objective in the training provided to TVO's own OL3 personnel is that CFS and its subcontractors can be supervised in a consistent manner. On the other hand, safety training directed to the subcontractor's employees was not emphasised by the OL3 management. On the contrary, some interviewees expressed opinions that it is impossible to define a training material that all the parties involved in the project should understand. Furthermore, some interviewees were also of the opinion that the special characteristics and the rules of the nuclear field are obvious to all involved and need not to be separately communicated.

Supervising CFS and its subcontractors

Any non-conformancies found as a result of TVO's quality control or quality assurance or in connection with some other activities are each recorded in a specific non-conformance report, and reported to CFS. In other words, non-conformance reporting is the most important tool of the quality system that can be used to deal with any problems detected in transferring safety requirements or in technical quality.

In the interviews, the OL3 project management was asked what the key mechanisms are for transferring safety and quality culture to the supply chain and to the construction organisation. According to the interviewees, the key mechanisms for creating or transferring safety and quality culture to the plant supplier and its subcontractors include supervision and reaction to non-conformancies. In other words, TVO's operating model appears to be based on a belief that CFS and its subcontractors will during the project learn to fulfil the strict requirements of TVO and the authorities, which are specified in various meetings and audits, in the review of design documentation and in construction inspections.

TVO's participation in selection of subcontractors

The procedures for the selection of suppliers and subcontractors in the OL3 project are for TVO's part described in Chapter 7.4 of the OL3 quality manual, "Purchasing". The quality manual is part of TVO's management system. The Main Contract for supplying the plant concluded between TVO and CFS also discusses issues connected with the selection of suppliers.

At the subcontractor selection stage, TVO has the opportunity to draw attention to the requirement that preconditions for fulfilment of quality and safety requirements are verified in the selection process.

CFS guidelines describe how information is provided to TVO and how TVO can influence the selection of subcontractors. For minor purchases, CFS informs TVO about the sending calls for tenders case by case or on TVO’s request. For minor purchases, TVO may recommend some subcontractors to CFS. CFS takes the recommended subcontractors into consideration in the tender competition, provided this does not significantly delay the process. TVO is informed about the selected minor suppliers in the monthly reports.

For major purchases, CFS informs TVO before the tender invitations are sent to potential suppliers as well as after the selection of the supplier. TVO is provided the opportunity to influence the content of the tender invitation and the selection of the supplier but in certain cases TVO has to pay for the requested change of supplier.

4.1.2 CFS management system

CFS’s role

CFS is responsible for the licensability of the OL3 plant, implementation of the project, selection and management of subcontractors and site management. Each of the consortium partners deals with its own area of the scope of the delivery. FANP is responsible for the reactor island structures and equipment on which this investigation focuses, and Siemens for the turbine island. CFS is responsible for transferring the technical safety requirements to its subcontractors. The responsibility for the selection and management of subcontractors entails that CFS is also responsible for explaining the safety relevance of their work for all the companies and every individual involved in the construction of OL3.

Quality management

The quality management model of the OL3 project comprises several steps, starting with the quality assurance programme of CFS and the quality policy of FANP, and ending with the quality management procedures that the subcontractors are required to follow.

FANP's general quality management system (Plants QEM Manual Rev. F, Jan 2005) emphasises the particular importance of quality management to the successful implementation of the project. Quality policy emphasises the independence of the Quality and Environmental Management Unit of other project units, its authority to verify compliance with the agreed procedures and its authority in all situations that might endanger quality.

The quality procedures of CFS that concern purchasing also describe practices for the monitoring of agreements and deliveries. These procedures specify that the ability of the supplier to deliver the agreed products is controlled continuously and that any deficiencies detected are immediately reported to the supplier. All significant observations are also communicated to TVO. The monitoring of fulfilment of contractual obligations includes control of e.g. quality, compliance with technical specifications, compliance with agreed quality assurance procedures, keeping to the schedule as well as commercial and contractual questions.

Non-conformancies are in terms of their handling divided into technical, contractual and process non-conformancies. Process non-conformancies are handled following the procedures presented in the quality assurance programme of the CFS partners.

Quality management at the plant site and its performance are described in the site procedures.

FANP's quality assurance organization (SE-G) includes about 50 employees, 13 of whom are involved (perform audits) in the Olkiluoto 3 project. Their practical tools are the same as those of TVO's corresponding staff; non-conformance reports that call for corrective actions and that are used to monitor the implementation of such actions.

According to the views expressed by FANP's representatives, safety is created as a result of good quality, and safety culture refers to compliance with the quality system. However, a "safety culture programme" has been under development at FANP since 2004. It is a training program targeted at FANP's top managers. Employees involved in the OL3 project and the site management have not yet been covered by this training programme.

Training

After the handover of the site, the plant vendor has been responsible for the site introduction training. The content of this training focuses on occupational safety. The introduction training has not specifically emphasised the significance of work to the safety of the nuclear power plant under construction, or the quality and quality control requirements arising from safety significance, or how it influences the practices. The general principles to be followed in order to ensure the safety of a nuclear power plant have not been presented in the introduction training, either. However, in April 2006 the content of the introduction training was supplemented with knowledge content designed to promote safety culture.

Selection of subcontractors

The purchasing procedures followed by CFS in the OL3 project and the practices for the selection of subcontractors are clearly described in the quality systems of both CFS consortium partners and in the OL3-specific quality plan.

The criteria defined by CFS for the selection of subcontractors include references from similar deliveries, experience of the CFS partners of the supplier from previous projects and contracts (including TVO's experience if available), the CFS partners' own assessments (based on audits, if necessary), quality certifications, technical expertise and ability to implement the project, capability for fulfilling safety requirements, and technical properties of the equipment compared with the technical requirements. CFS also ensures that the subcontractors apply similar criteria in the selection of their own subcontractors.

The documents to be included in the tender invitations are defined in the consortium's guidelines. OL3-specific procurement and delivery terms must be included in the tender documents. They also describe how subcontractors shall be required to take nuclear field specific and OL3-specific requirements into consideration, including relevant YVL Guides.

4.2 Assessment of management and quality management

4.2.1 General observations

Reasons for and consequences of schedule delays

Controlled implementation of the OL3 project and keeping to the schedule have been hindered by the slow completion of detailed design in relation to how fast the constructors and the equipment manufacturers could act if the plans were available in time.

When the Main Contract for the plant supply was signed and the Construction License was applied for, the basic design of the plant had been completed and the technical requirements for the systems had been specified. This means that the lay-out of the buildings, the main features of the systems (e.g. the pressures, temperatures, flows for process systems, main pipelines and valves, pressure vessel dimensions, and technical requirements for pumps) and the locations of the systems in the buildings had been defined almost to the final extent. In other words, design had proceeded so far that it had been possible to make the required safety analyses and practical preparations for the construction project could be started, including equipment purchases and site preparation.

Detailed design (e.g. dimensioning calculations for determination of required concrete strengths and reinforcement as well as final site drawings) had not been carried out, and the time and the amount of work added for accomlishing the design had clearly been under-estimated. An additional problem was caused by the fact that the plant vendor was not familiar with the Finnish practices. According to the Finnish requirements, the detailed design of the safety cassified systems, structures and equipment is inspected both by TVO and STUK. Designs and plans must be approved by all involved parties before the manufacturing of equipment and components or structures at site can be started. The attempts to keep to the schedule, which had been unrealistic from the beginning, has required extra work and thereby further delayed and impeded the progress of the project.

According to STUK's experience, the documentation submitted by TVO’s OL3 project to STUK is sometimes of poor quality and inspectors are invited to perform construction inspections on systems or structures for which the approval of design documentation or the quality control documentation has not yet been completed. Even if the situation has improved as the project has progressed, it still appears that due to deficient resources and tight schedules TVO is not able to review all the design documents with a sufficiently questioning attitude.

The incompleteness of detailed design even at the time of the investigation, and the delaying of the construction schedule primarily for this reason, make the overall management of the project extremely demanding.

Impact on safety

TVO's representatives emphasised in the interviews that problems in manufacturing of the equipment and in construction only concern the project schedule, and nuclear safety has not been endangered because of them. According to TVO’s project management, the large number of non-conformancies first of all reflects the accuracy of TVO's control activities. Finnish preciseness and attention to details are of a level, which the plant vendor did not expect. In other words, this is a cultural difference, a difference in expectations.

The impression obtained during the investigation about the safety impact of the non-conformancies is in main parts similar to the view presented by TVO's representatives. No compromises have been accepted in the required quality level and the tests and inspections that have been performed have proven that this level has been achieved, although in some cases only after several corrections.

Safety culture

The case studies seem to indicate that TVO's supervision activities have not reached their goal to institute a high-level safety and quality culture in the supply chain and the construction organisation. Although an abundance of technical non-conformancies have been identified in the manufacturing of different equipment, components, and in construction as well, and these have been recorded in non-conformance reports, the observations made during the investigation show that the plant vendor and its subcontractors have not essentially improved their working practices or attitudes toward safety. The striving for performance that is careful and faultless to the extent possible, as required in the nuclear field, and an open disclosure and prompt elimination of non-conformancies have not been emphasised in a clear manner in the supply chain.

The investigation showed that in the OL3 project so far there is no clear and commonly shared view of what is important at the construction stage for the achievement of the safety objectives, and how widely and intensively safety awareness should be promoted. According to the opinions expressed in the interviews by TVO's and FANP's OL3 project personnel nuclear safety can be ensured by verifying the correct technical quality of safety class 1 and 2 equipment, components and structures. Activities on the site are generally considered to be non-safety relevant. The role of TVO's safety committee has remained quite remote in addressing the non-conformancies found in the performance of the parties involved in construction and in discussing safety culture issues.

During the investigation it was noticed that the responsible performance required in the nuclear field is not self-evident to all employees working on the construction site and in the manufacturing organisations. Even strive for flawlessness of one's own work can not always be seen, let alone care for the best possible preconditions for others to succeed in their work.

Quality management

In general, the supervision of construction work and equipment manufacture seems to have been implemented in the project as planned, and both TVO and the plant vendor employ competent persons for this in their organisations. Non-conformancies are recorded carefully and their correction is being monitored. The independent role of quality management comes true in this respect. On the other hand, the quality control organisation's authority, excutive power and courage to immediately intervene in any detected non-conformancies demanding their timely repair do not appear to be sufficient.

According to the observations made in the investigation, there is no clear practice for the handling of products that do not conform to quality requirements. The ISO 9001 standard requires that there is a clear procedure for the dealing with non-conformancies, and the responsibilities and authorities for that have been defined. In the OL3 project it is unclear which organisation and person is in different cases responsible for the approval of a product not conforming to the specification, and how the approval is issued in practice. According to the quality system the designer defines the quality requirements for the product, and the production these requirements. In some cases the designs are submitted to TVO and also to STUK for approval, and if they are changed, the approval procedure has to be repeated. No evidence was found in the investigation of this procedure being followed in the case of the bottom part of the steel liner. Instead, some interviewees mentioned that "the tolerances specified by the designer were too tight". According to information received from the consortium's Quality Manager, in many cases the specified quality cannot be realised in practice and the specification is changed instead. This may be a realistic procedure and acceptable as such, but the acceptability of the specification change should still always be proven and the related documents examined at the same level that granted the original approval.

An examination of audit reports indicated that TVO's auditors had recorded several findings concerning safety culture and the lack of related training. No corresponding findings had been recorded in audits performed by FANP. All in all, there is a consistent difference in the number of findings made in the audits performed by FANP and TVO in the same location, with TVO's audits always producing more findings.

Training

The so-called safety culture training to all those participating in the plant delivery, as stipulated in IAEA regulations and in discussions between STUK and TVO, has in practice not been provided in most cases. One expert of TVO's quality organisation stated in the interview that, as far as he knew, this training had not been provided in any organisation. It has not been defined what the content of the training should be and who should be responsible for its provision. It has not been defined either what level of knowledge of the specific requirements of the nuclear field the employees of the plant vendor and its subcontractors should possess.

Language problems

In practice the project language is as a rule English although in some subcontracting agreements the language is defined as the language of the subcontracting company. Not all parties (e.g. subcontractors) are proficient enough in English to make it certain that everything is fully understood.

4.2.2 Observations concerning TVO

Relationship with plant supplier

The OL3 management emphasised in the interviews that in the assessment of their role, it should be borne in mind that this is a turn-key delivery whereby they have to trust the plant supplier and allow it to do things in its own way without too much disturbance. In the investigation team's opinion this is not the correct attitude. TVO must control that the plant vendor's obligations are fulfilled and the plant vendor also assures the quality of the subcontractors' work.

At this stage of construction there has already been many harmful changes in the vendor’s site personnel and even the Site Manager has retired and replaced. This has made overall management, as well as detection and handling of problems difficult. The transfer of responsibilities in such situations has been unclear to all the actors. It is not clearly stated neither in the joint documents of the parties nor in the project manuals of the parties what kind of possibilities TVO has to make certain that appropriate measures are employed to ensure stability in FANP's site organisation and that the staff is capable of fulfilling their responsibilities and obligations.

Management and promotion of safety culture

As the holder of the Construction License, TVO is responsible for all issues related to safety and quality, and cannot assign this responsibility to the plant supplier or any other party by any kind of contract or agreement. A perception of STUK's key role in ensuring safety came up in the interviews, but this interpretation must not reduce TVO's own responsibility for safety.

The principle of continuous improvement of operation and safety has been adopted at TVO's operating nuclear power plant units, but the OL3 project is somewhat separate from the operational plants and TVO's traditional culture. TVO's own organization also includes a large number of personnel in the OL3 project that has come from outside the nuclear field, and appreciation of the safety culture is not yet complete in the project organization.

In the OL3 project, TVO's management does not seem to pursue determined communication to the actors outside their own organisation with the aim of developing a high-level safety culture in the entire construction project. TVO considers the responsibility for construction to rest with the plant vendor, with TVO's own focus being on commissioning and the operating stages after that.

The interviews gave an impression that inside TVO the schedule-related questions connected with organising construction work are the most important issues in handling of OL3 project matters. The pressure to keep to the schedule is probably hard for TVO's technical experts, as the plant vendor's plans are submitted late and the schedules do not allow enough time for their evaluation. It seems that evaluation of the design documentation submitted by the plant vendor cannot in all cases be carried out with the required accuracy and a questioning attitude. As a result, documentation of poor quality is forwarded to STUK. The investigation showed that problems are easily multiplied when the plans have been deficient and STUK requires them to be corrected. This also involves the risk that problems are not detected, or tackling them at a later stage will cause considerable problems if TVO has approved deficient documentation. TVO should in situations like this possess enough its own expertise and resources so that essential unclarities in the designs can be tackled effectively.

Good safety management entails identification of also weak signals and prevention of problems. In the management of the OL3 project main focus has been on solving detected problems, however, and no evidence was found of a proactive approach. It was not clear even to the responsible management what the potential signals could be that would require initiation of preventive action.

The prevailing perception in the OL3 project about safety and the actions needed to ensure safety focuses strongly on the technical quality of safety classified systems, stuctures and equipment. TVO audits the plant vendor and its subcontractors in a systematic manner, but the way in which TVO intervenes in problems or forecasts problems with various parties is not well defined. Within TVO the responsibility for the handling of deficiencies in the performance of the subcontractors has been distributed in a complex quality organisation, and the individuals and the committee that are responsible for safety evaluation do not handle the deficiencies observed in performance. In the light of the investigated sample cases, issues connected with the quality and reliability of the performance of the plant vendor and its subcontractors are handled slowly.

An important factor of safety culture is open disclosure and handling of non-conformancies and other problems. TVO has not emphasised the principle of openness outside its own organisation, and therefore information about events has not in every case been openly communicated to TVO and further to STUK. Only TVO employees can record non-conformancies in TVO's KELPO system. According to the interviewees, this anonymous mail box system is mainly designed for situations endangering occupational safety. The problem with concrete showed that there are no tools to bring non-conformancies out, unless enough evidence exists for a non-conformance report.

Dealing of non-conformancies and supervision of subcontractors

TVO has a limited insight of what is happening in the subcontractor network and what kind of problems are encountered. The audits are TVO's only direct contact with the subcontractors, otherwise interaction with them takes place through the plant vendor. Audits are performed both by TVO's own QA and QC engineers and by QC consultants employed by TVO. Their responsibility is restricted to the recording of non-conformancies and to the monitoring of the closing of non-conformancies. TVO's representative reacts to every non-conformancy – whether a major or a minor non-conformancy – by drawing up a non-conformance report, an NCR report, which is submitted to the consortium. It is up to the consortium to decide whether the report is presented to the subcontractors. Not all reports are presented to the subcontractors, so the procedures for the handling of non-conformancies are deficient in this respect.

On the basis of the interviews, it appears that the quality personnel of TVO has not understood that in unclear situations they have the right to suspend work and receive the quality data that they need.

Even in cases where the procedure defined in the quality system for the handling of non-conformance reports is precisely complied with, it is questionable whether corrective actions are taken at the stage that from the point of view of the final result would be the best for their implementation. The reason for this is the large number of NCR reports and the long time that their distribution and handling takes. During the investigation there were some 700 open non-conformancies. When a subcontractor is found to have a quality problem, the non-conformance report drawn up during the audit is sent from the TVO's auditor to the plant supplier, who forwards it to the subcontractor and in many cases it is forwarded still further in the subcontractor chain. If the observation is made by STUK, yet an additional step is inserted to this path. In other words, just writing non-conformance reports is not enough, but TVO must in a determined manner ensure that they lead to corrective actions in time.

A concrete demand made by TVO has been that the quality personnel of the consortium should be expanded so that the numerous open non-conformancies could be handled faster. At the time of the investigation the consortium was trying to increase the number of personnel in quality control by making persons working in other projects available to the OL3 project.

During the investigation, it turned up that in some cases TVO's quality controllers had assumed a guiding role in supervising the work of a subcontractor that had displayed poor quality. This is not the correct procedure, either, as the consortium is responsible for the guidance and supervision of subcontractors, while TVO is responsible for ensuring that this obligation is fulfilled.

TVO has not conducted any systematic analyses of non-conformancies, their types and possible common denominators. However, the management of the OL3 project has paid attention to the fact that many non-conformancies are repeated from one subcontractor to the other. For example, the forwarding of the nuclear field specific and technical safety requirements from the consortium to the consortium's subcontractors has been deficient in some parts. The consortium seems not to have learned their lesson from TVO's previous remarks when they start cooperation with a new subcontractor.

All in all, it is unclear what TVO's means are for verifying that the plant vendor systematically verifies the achievement of the required quality level and that the performance of subcontractors is of high quality.

Selection of subcontractors

In the case of a fixed-price contract it is to be expected that money becomes the most important criterion in the selection of a subcontractor. TVO has limited possibilities at the selection stage of subcontractors to control that quality and safety criteria are given a sufficient priority. In practice, if the subcontractors that submitted a tender meet the agreed criteria but TVO refuses to approve the lowest price subcontractor with as proposed by FANP, TVO has to pay a separate compensation for changing the subcontractor. On the basis of the investigated sample cases it was obvious that quality and reliability criteria were not always the first priority in decision-making when selecting subcontractors.

4.2.3 Observations concerning FANP

FANP's organisation and its performance in OL3 project

In the organisation of FANP which is an alliance of a French and a German company the different organisational cultures can still be distinguished. The OL3 project is the first large joint project for the former competitors. As the project also involves consortium cooperation between FANP and Siemens the situation is challenging for these big international companies. It is also a new thing that the plant vendor has assumed overall responsibility for the project.

Although FANP is an experienced vendor of nuclear power plants, in previous projects it has assigned the responsibility for construction to other organisations and is therefore rather inexperienced as a constructor. The logistic layout of the construction site, the contract boundaries and the control of suppliers differ from equipment and component supplies. In addition, delays in the construction schedules and the postponement of works to another season have created significant additional challenges to total management. The incompetence in the constructor role becomes obvious in the preparations for concreting of the base slab.

The impression obtained in the interviews was that the structure of the site organisation, responsibilities and practices are still unestablished. The structure of the organisation has changed several times and some of its management level employees have been replaced. Some of the consortium's managers are leased employees. These factors reflect in the total management of the project in a negative way. There is confusion both among the consortium's own site personnel and among the subcontractors about responsibilities.

The weakness of internal communication in the consortium as well as unclear responsibilities and authorities in tackling non-conformancies have become apparent particularly during the concreting of the base slab for the reactor building. Even inside the consortium only a small group was aware of the problems. Despite requests, the management of the site organisation has been reluctant to submit e.g. the results of concrete mix analyses to TVO. Neither have they submitted the preliminary quality control results that indicated non-conformancies to the quality management of the consortium, nor to the management in Germany that is responsible for the control of subcontractors.

The consortium has a habit of employing new people for problem solving, which seems to have resulted in even more confusion about responsibilities. This was the case, for example, with the regulation of the workability of concrete when the consortium hired an outside concrete expert to the batching plant to carry out the fine adjustment of the composition. A new person was also recruited to handle contractual problems, and he was obviously given the authority to override the decisions of the site management.

FANP’s safety culture

With FANP's long experience in nuclear engineering, it could be assumed that the company has a clear safety policy and safety management philosophy. Instead, only the consortium management is so far being trained in safety culture issues.

FANP tries to meet the safety requirements specified by TVO and STUK, but seems not to emphasise the fact that nuclear safety should be prioritised already in activities during construction and manufacturing. In the interviews, representatives of FANP were of the opinion that safety culture is a new name for an old thing. According to them, safety and safety culture mean compliance with the quality system.

FANP has not actively and systematically focused efforts on ensuring that the subcontractors understand the special features of the nuclear field and the resulting requirements concerning work practices, such as e.g. the striving for the best possible result, open disclosure of non-conformancies and discontinuation of work if unclarities that might influence safety are detected. According to the interviewed representatives of the consortium, responsibility for the training of these matters does not rest with them. The personnel of the consortium have not proven in their own performance either that they understand their responsibility for and authority to intervene in problems, nor have they followed the principle of informing about non-conformancies. The most serious problem in the handling of non-conformancies revealed in the investigation was the quality control report that concerned the concreting of the reactor base slab the results of which were available already in November 2005. Effective actions on the basis of the report, however, were not taken until in 2006.

There is no clear evidence of TVO's attempts to educate the consortium about the principles applied to the nuclear field in Finland or about the safety culture that TVO strives to create. According to the interviews, the perception of the representatives of FANP concerning management of safety requirements is that they act in this project in the same way as in all their other projects, and this is their principle. The public debate on safety culture training, raised up in connection with the re-start inspection of Forssan Betoni exercised the minds of the FANP representatives. According to the persons responsible for FANP's quality management, the requirement for a high safety culture that STUK and TVO had put forward had been surprising. The interviewees stated, among others, that as safety culture is a concept usually associated with plants that are in operation, it has been difficult for them to understand what it could mean at the construction stage.

Due to the problems encountered in the sample cases FANP has made communication in the non-conformance handling process as a development priority, but sees no reason to develop in any other way the procedures employed in the selection and supervision of subcontractors.

Selection, training and supervision of subcontractors

At times, there have been deficiencies in the forwarding of the nuclear field specific requirements and technical safety requirements for the OL3 project from FANP to the subcontractors. Essential requirements that affect quality and the possible additional costs caused by these requirements have not been clearly communicated to the potential subcontractors at the call for tender stage. FANP management says that for them the problem has been that if strict requirements or special requirements are specified for a delivery, companies are not willing to submit tenders in the present market situation considering the minor volume of nuclear power construction.

The investigation showed that the procedures described in FANP's quality specifications for the selection of subcontractors are not always followed in practice. For example, the consortium has not systematically paid attention to whether the subcontractors are capable of meeting the requirements of IAEA's safety standard 50-C-QA. The investigation seems to indicate that the subcontractors' safety and quality culture has been noted mostly in TVO's audits.

In the case of a fixed-price contract, it is to be expected that the most important criterion in the selection of a subcontractor is the price. In the case of the steel liner supplier, for example, price has been a more significant criterion than technical competence. It appears that the consortium can select a more risky but lower cost subcontractor, believing that the strict control exercised over the subcontractors during the project will make them develop their performance. This kind of strategy is in contradiction with the quality policy described in FANP's guidelines. The subcontractors' operating cultures change very slowly (just as in all organisations). However, suppliers that could provide sufficient quality already at the start of cooperation have not been favoured in the selection of subcontractors.

The interviewed representatives of the consortium made it clear that in their opinion there was no need to develop the selection procedure of subcontractors because of the problems encountered, for example, with concrete or with the manufacturing of the containment steel liner. However, they could not give a clear view of why these cases involved such a large number of non-conformancies in terms of quality and performance.

The consortium mainly intervenes in the performance of the subcontractors only if technical quality problems are detected or if non-conformancies are found in TVO's audits. It seems that proactive prevention of problems is not working.

The interviews gave an impression that responsibilities in the investigated example cases were most unclear. It was a repeated feature that the interviewees had presumed that some other party had noted, dealt with or informed about the problems. Still, the interviewees did not see any strong need for developing the practices employed for the management of subcontractors.

TVO's subcontractor audits have revealed non-conformancies that clearly predict problems in manufacturing. FANP's ability to eliminate such non-conformancies prior to the start of manufacturing has been poor. The interviews brought up many reasons for this:

- The number of subcontractors is large and FANP is not in practice capable of exercising true control of the competence and quality of work of all its subcontractors.
- Economic objectives are emphasised at the contract stage and quality issues are usually brought up only after manufacturing has started.
- FANP relies on TVO and STUK to handle any deficiencies.
- FANP is not familiar with the characteristic features of construction business.
- The site organisation of the consortium is confused and authorities to deal with problems are not clear.
- Because FANP is experiencing schedule-related pressures the subcontractor's preconditions to meet the quality requirements are not always subjected to a critical assessment.

The investigation team got the impression that FANP does not prioritise nuclear safety over financial and schedule-related objectives. Safety is not the number one guiding factor in e.g. the selection of suppliers, content of agreements, selection of tools and materials. When minimum criteria are met, FANP seems to select cheaper suppliers despite bigger quality risks. FANP does not always enter safety-related requirements in the supplier's agreements, but tries to deal with them without incurring any costs. Due to the tight cost limits and delays in schedules subcontractors are not willing to meet afterwards additional requirements that exceed those specified in their agreements. On the other hand, delays in schedules result in more financial pressure.

5. STUK'S OPERATION AS REGULATOR OF NUCLEAR POWER PLANT CONSTRUCTION

5.1 Oversight system and implementation

Both the use of nuclear power and the construction of nuclear power plants are subject to licence. The licence applicant or holder can apply from the Government the Decision in Principle to launch a nuclear power plant project, the related Construction License required for its implementation and the Operating Licence required for its operation.

Oversight of safety during the construction and operation of nuclear power plants is responsibility of the Radiation and Nuclear Safety Authority (STUK). Furthermore, STUK’s duty in each licensing stage is to draw up safety assessment and statement before the Government grants the respective license.

General safety requirements are given in the Government Degrees, and more detailed technical requirements are specified in YVL Guides issued by STUK. The YVL Guides also provide guidelines concerning STUK’s regulatory control, and specify the obligations of the licence applicant/licensee. YVL Guide 1.1 [13] presents a summary of STUK's oversight in connection with the review of applications for nuclear facility’s licences, as well as during the construction and operation of a nuclear facility.

STUK oversees the construction of the plant and the manufacturing of equipment for the plant. The purpose of this oversight is to ensure that the conditions of the construction licence, regulations governing pressure equipment, and the plans submitted to STUK with the application for the construction licence, which STUK has approved, are complied with, and that the nuclear facility is also in other respects built in conformity with the regulations of the Nuclear Energy Act.

Appendix 4 presents the stages of the OL3 nuclear plant project, referred to as the FIN5 project at STUK, the licences and license processes required for the implementation and the organisation of STUK’s project, different stages and inspections. STUK’s activities in each sample case are not described in more detail, because they were already discussed in connection with these cases. Besides observations on STUK’s performance in the sample cases there are also other corresponding examples and situations that have emerged in the oversight of the OL3 project and have been used as basis for the observations discussed below.

5.2 Observations on STUK's activities

As the sample cases of the investigation indicate, the regulatory oversight by STUK control is primarily focused on ensuring the quality and safety of the end products. As part of its construction oversight, STUK has developed an inspection programme for assessing TVO’s management and quality management procedures, but corresponding systematic monitoring is not applied to the activities of other organisations involved in the OL3 project. Thus, not enough attention has been paid to the common organisational background factors of technical problems and their connection to the recurring problems has not been analysed.

STUK has no systematic procedure for recording, collecting and analysing signals received from different sources about the performance of organisations. Scattered signals about weaknesses in the performance of the organisations involved in the construction project have not always reached the management of the FIN5 project or the department of Nuclear Reactor Regulation to enable STUK to react to them effectively.

STUK has required TVO and FANP to define safety culture, and both organisations have done it in their quality management guidelines. STUK has examined the dissemination of the requirement on good safety culture to other organisations involved in the project when participating in audits conducted by TVO. In such instances STUK's inspectors have often recorded in their travel reports that the development of the safety culture has not received enough attention in the audited organisations and that TVO has given notice of it. However, STUK's inspectors have not usually identified the individual deficiencies observed in the safety culture, and STUK has not required TVO specify them in the notices given as part of the audits to provide the audited organisation a clearer idea of what is expected from the safety culture.

STUK has repeatedly emphasised the significance of the quality of design documents and construction inspection documents to TVO and the plant supplier as a prerequisite for smooth progress of the project and for ensuring adequate quality of the end products. As the project has advanced, the materials submitted by FANP and some experienced subcontractors have improved but extending the learning process to the performance of new subcontractors has generally not succeeded.

STUK's aim to keep things running on schedule as far as possible has in some casess made it necessary for STUK to assume responsibility for prompt handling of problems it has detected, and even to act as part of the quality assurance chain, when other parties have failed to fulfil their obligations. STUK's strong intervention in the detected problems in the investigated example cases can be justified in these cases. Although STUK has on several occasions told the plant supplier and TVO that safety and quality requirements must be met also without direct intervention from authorities, essential improvement in this respect has not taken place in the studied cases.

On the other hand, the investigation also revealed that in some cases STUK's representatives failed to require correction of problems detected by them when they should have been corrected without delay to make for easy correction and to avoid new problems. As the problems observed by STUK's inspector were recorded in documents presented to TVO or sometimes only communicated orally and without stressing the urgency of the measures to be taken, the information was slow to reach the parties who should have taken the corrective action.

The FIN5/OL3 project includes a lot of meetings between STUK's own personnel, with representatives of TVO, and often also with representatives of the plant supplier. The status of different meetings and possible decisions taken in them seems to be unclear to some parties outside STUK, although STUK has emphasised that it does not make formal decisions on the acceptability of technical solutions in the meetings. In the light of the observations of the investigation team, a systematic method for distribution of the minutes of the meetings to ensure smooth flow of information has not been defined, and responsibilities for monitoring the fulfilment of the recorded obligations have generally not been specified.

6. RECOMMENDATIONS TO FANP, TVO AND STUK

The following recommendations based on the main observations of the investigation team are made to the plant vendor, the licensee, and the regulatory body.

The recommendations are numbered to facilitate their further processing. The numbers do not indicate the priority or order of implementing of the actions to be taken.

FANP

1. FANP should see to it that all design documents it submits to TVO, including those prepared by the subcontractors are, of the scope and quality that no considerable amendments or changes are required afterwards.

2. The site organisation of FANP should be made aware of its definite responsibility for ensuring the quality of all subcontractors operating on the site. It is particularly important that a responsible manager is appointed for each work entity at the construction site, with undisputable authority to give work-related orders.

3. FANP should intensify the guidance to its subcontractors to ensure that they fulfil their tasks in the manner expected by FANP and produce acceptable quality. FANP's management should make it clear to its personnel that they have to inform the management without delay of the detected quality problems.

4. An improved practise should be developed for the distribution and dealing of non-conformance reports, to ensure timely initiation of corrective action.

5. The principles defined in FANP's own quality procedures should be adhered to in the selection of subcontractors. In particular, it should be verified that the subcontractor already at the time of signing the contract is capable of producing the expected quality and performing in compliance with the requirements of the nuclear field. Tender invitations and purchase agreements should clearly provide all information on quality control requirements typical for nuclear power plant construction and exceeding the conventional standards applied in the branch.

6. Site introduction training should include general information about the special requirements to be met in the construction of a nuclear power plant as well as guidance on practices for ensuring nuclear safety. Corresponding training should also be provided for the personnel of manufacturers that fabricate equipment specifically designed for the nuclear power plant.

7. The significance of open disclosure of any detected problems and errors made as well as the obligation to discontinue the conduct of work in unclear situations should be emphasised at all levels of FANP's own organisation as well as to the subcontractors.

8. Remarks made during audits and inspections should be analysed systematically in order to identify recurring observations. Particular attention should be paid to observations concerning deficiencies and problems in the performance of the subcontractors' organisations.

9. FANP should assess together with TVO why most of the non-conformancies recorded in TVO's audits have not been noted in FANP's own audits of respective organizations.

10. Before starting demanding jobs at site, a thorough pre-job briefing should be organised for all persons involved. Examples of issues to be covered include the significance of the job to safety, the responsibilities and authorities of different actors, the schedule, work stages and critical points, overall coordination of work and actions to be taken in potential problem situations. In this context the potential problems foreseen by the persons implementing the work should be discussed. Pre-job briefing is particularly important for work implemented jointly by several organisations.

11. FANP should make it clear which requirements stipulated in IAEA's safety standards concerning quality systems and safety culture are to be taken into account when assessing the performance of the organisations involved in the construction of the plant and the manufacture of components. Special attention should be paid to these issues in the selection and guidance of subcontractors.

TVO

1. TVO’s management should communicate clearly to the entire personnel of the OL3 project that, in spite of the turn-key delivery, TVO is ultimately responsible for the safety of the power plant and that this responsibility cannot be assigned to the vendor by the terms of supply contract.

2. The management of TVO should regularly inform the site managers and supervisors of the consortium CFS and its subcontractors about the safety and quality objectives of the OL3 project and the related practical operating methods. It should also be ensured that both TVO's own and the consortium’s site personnel have understood these objectives and implement them in their work.

3. TVO should ensure that its own project personnel strictly follow the general principles for nuclear power plant safety in their operations. It is of particular importance that the safety first approach is consistently applied in all decisions and acts of the project management.

4. TVO should ensure that the site introduction training provided by CFS gives everyone coming to the site sufficient basic knowledge of the special requirements related to the work methods in the construction of a nuclear power plant.

5. TVO should ensure that the tender invitations sent out by CFS as well as purchase agreements with subcontractors include information about the quality assurance requirements for the delivery in question that are normally applied in nuclear plant construction and exceed the conventional standards applied in the branch.

6. TVO should emphasise to its own quality control staff the importance of effectively dealing with detected non-conformancies, and should develop its own practices to ensure that this staff has sufficient authority and can bring the observations recorded in non-conformance reports to corrective process without any detrimental delay.

7. TVO should together with CFS create practices that ensure open, consistent and prompt reporting of non-conformancies to both TVO and all other parties expected to deal with those non-conformancies. TVO should also remind CFS of TVO's right to discontinue work and receive the desired quality data.

8. TVO should ensure that the OL3 project has sufficient resources to examine the design documents submitted by the vendor and to effectively deal with any concerns raised in the design documentation before it approves start of manufacturing or submits the documents to STUK for approval.

9. TVO should systematically analyse the remarks made in audits and inspections in order to identify any recurring observations.

10. TVO should together with FANP clearly specify which requirements stipulated in IAEA's safety standards concerning quality systems and safety culture are to be taken into account when assessing the performance of the organisations involved in the construction of the plant and manufacturing of components. The specified requirements should be clearly communicated to all TVO's experts who take part in audits and inspections.

STUK

1. The findings of STUK inspectors should be systematically collected and analysed with the intent to identify recurring deficiencies. Particular attention should be paid to observations concerning weaknesses and problems in the management of organisations. STUK's management should regularly discuss the results of analysis

with TVO's management to eliminate the identified problems and to improve the quality of operations.

2. In case STUK's inspectors notice during audits that the quality systems and safety culture of the audited organisation are not on the level required by IAEA safety standards, they should ensure that TVO's representatives present the detected non-conformancies and requirements on corrective actions in the most concrete and unambiguous manner. For this, STUK's management should clarify to their inspectors which requirements concerning quality systems and safety culture, provided by the IAEA safety standards, should be examined with particular care in evaluating the performance of organisations that participate in the construction of the power plant and manufacturing of equipment, and indicate STUK's expectations with regard to meeting the requirements.

3. STUK's inspectors should actively demand TVOs representatives to take immediate corrective actions for elimination of any detected problems, where prompt actions are well founded to facilitate correction or to avoid new problems, and other parties have not taken the necessary action.

4. If quality deficiencies are detected in structures and equipment during STUK inspections, the performance of quality control organisations should also be assessed, in addition to production processes and products. STUK's management should ensure that it receives without delay a report and description of any occasions where the manufacturer or the builder is not producing sufficiently high quality and the quality control personnel of neither the consortium nor TVO has not demanded effective corrective action. Significant deficiencies detected in the performance of organisations should be discussed with TVO's project management.

5. STUK should develop a practice that supplements the inspection records and other reports and allows direct communication of the most important quality problems and other deficiencies to the project managements of both STUK and TVO so that corrective actions can be initiated on an optimal schedule.

6. STUK should together with TVO find a way for improving the quality of all design and construction inspection documents submitted to STUK to a level that would eliminate the need of revisions, and repeated handling.

7. In order to improve communication within STUK one should define the standard distribution of minutes of various meetings related to the OL3 project, as well as the obligation to get acquainted with these minutes. Also, a procedure should be defined for monitoring the implementation of the obligations recorded in the minutes.

7. REFERENCES

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[11] YVL 4.2 Steel structures for nuclear facilities, 19.12.2001.

[12] YVL 5.8 Hoisting appliances and fuel handling equipment at nuclear facilities, 5.1.1987.

[13] YVL 1.1 Regulatory control of safety at nuclear facilities, 10.2.2006.

8. APPENDICES

1. Assignment and objectives of investigation
2. Investigation team and performance of investigation
3. Investigation programme and schedule
4. STUK's operation in control of nuclear power plant construction

10.7.2006

APPENDIX 1.

ASSIGNMENT AND OBJECTIVES OF INVESTIGATION

INVESTIGATION OF OPERATIONAL EVENTS 1/2006

OLKILUOTO 3 – MANAGEMENT OF SAFETY REQUIREMENTS IN CONSTRUCTION STAGE PURCHASES FOR A NUCLEAR POWER PLANT

The quality non-conformancies detected in the concrete used for the base slab of the plant unit under construction in Olkiluoto brought out the need at the Finnish Radiation and Nuclear Safety Authority (STUK) to investigate the procedures used in selecting subcontractors, their prerequisites for meeting set requirements and the supervision of their operation. The subcontracting for Olkiluoto 3 is done by the vendor, FANP. Teollisuuden Voima Oy (TVO) is informed about the selected suppliers.

The investigation set up by STUK is looking into the management of safety requirements in subcontracting and in purchases of structures, equipment and components during the nuclear power plant construction phase. The selection and control of the suppliers of the concrete base slab and the containment inner steel liner, as well as the the polar crane and the material hatch, are used as sample cases in the investigation. The tasks of the investigation team are:

- to determine and assess any negligence in complying with requirements in selecting and supervising suppliers of safety significant structures, equipment and components
- to determine and assess any quality management deficiencies in the performance of TVO or the plant vendor in selecting and controlling suppliers
- to determine and assess TVO’s and the vendor’s management views and the attitudes on requirements for the selection and control of suppliers, non-conformancies, inspections and implementation of corrective actions
- to establish TVO’s and the vendor’s procedures for tender invitations, selection of approved suppliers, training of the subcontractors' personnel, supervision of subcontractors as well as the various parties’ quality management, and practices for approval of test results
- to establish the passege of information in the selected sample cases
- STUK's regulatory oversight.

Investigation manager Mrs. Seija Suksi (STUK) acts as the leader of the investigation team. Experts in quality management, safety culture and various technical fields from STUK and outside STUK will be assigned to the team. The investigation team will make its recommendations by the end of March, and the investigation report will be completed by the end of April 2006.

Director Lasse Reiman

APPENDIX 2. 1 (2)

INVESTIGATION TEAM AND PERFORMANCE OF INVESTIGATION

Mrs. Seija Suksi, investigation manager (STUK), acted as the coordinator and leader of the investigation team. The investigation team consisted of the following experts in quality management, management, safety culture and various technical fields, both from within and outside STUK:

Expert	Organisation, task	Focal area in investigation
Suksi, Seija	STUK, investigation manager	Root cause analysis, regulatory control
Koskinen, Kaisa	STUK, development manager	Quality management
Valkila, Aila	Aila Valkila Oy, managing director	Quality management
Koivula, Nina	STUK, inspector	Human and organisational factors
Oedewald, Pia	VTT, researcher	Safety culture
Pitkänen, Pertti	VTT, senior researcher	Concrete structures, characteristics of concrete

The investigation team availed of the services of the following STUK's experts for the sample cases:

Expert	Organisation, task	Focal area in investigation
Myllymäki, Jukka	STUK, senior inspector	Concrete structures, construction plans
Lehto, Rauno	STUK, inspector	Mechanical components, lifting equipment
Cederberg, Mark	STUK, senior inspector	Materials and welding technology, construction inspection

Conduct of investigation

The input documentation reviewed by the investigation team consists of possible non-conformance reports or description prepared by the licensee of the event or non-conformance under investigation, inspection reports by STUK in the area, memoranda and minutes of meetings as well as other associated documents and records. The details of the event are looked into on the plant site on the basis of interviews and by studying the event and its handling, decisions made, correspondence, contracts, work orders, test reports, procedures, etc.

Comprehensive background material was collected in support of this study consisting of the following documents:

- description of the consortium's organisation as well as descriptions of management and responsibilities
- the consortium's procedures related to approval and control of suppliers
- TVO's project quality manual and, particularly, procedures and descriptions related to approval and control of suppliers
- TVO's project plan (including a description of the project organisation and tasks)
- STUK's FIN5 project plan
- Inspection reports on quality management and quality assurance belongin to STUK's Construction Inspection Programme (RTO), decisions and minutes of meetings
- key technical (general) documentation and inspection memoranda for the sample cases.

The first week of the investigation was spent studying the subject areas through presentations requested from STUK's experts, the FIN5 project and sub-project managers, as well as the responsible coordinators of the Olkiluoto 3 project and the quality and purchasing managers of CFS. People performing various tasks in the Olkiluoto 3 project (TVO, CFS, FANP, subcontractor, research institute) were interviewed during the second week, and the investigation team visited the Olkiluoto 3 construction site and the concrete batching plant. Detailed notes were made of all presentations and interviews. Daily observations were collected onto a form designed for the purpose and/or during discussions conducted at the end of the day. The writing of the report and the formulating of recommendations started in the third week. The investigation programme is shown in Appendix 3.

INVESTIGATION PROGRAMME AND SCHEDULE

Week 1 (weeks 12 - 13)

	Wed 15/3 STUK	Thu 16/3 STUK	Fri 17/3 STUK	Sat 18/3	Sun 19/3	Mon 20/3 STUK	Tue 21/3 STUK
Investigation areas Management, QC/QA Safety culture, HOF Root cause analysis Sample cases • concrete • liner • polar crane	Organising Start-up Introduction Planning Presentations: -FIN5 project (KiA) -KOLA (JMo)	Presentations: RAKE -concrete (HSk, JMy) OL3 project organisation (TV) Preparing questions to TVO and CFS	OL3 project presentations: at 9 - 15 Herkko Plit Markku Pitko Timo Kallio Jukka Kangas Dieter Kreckel Herbert Scramm T. Kammerzell			Presentations, interviews and discussions - FIN5 (PT) - liner (MC)	Interviews and discussions - Polar crane (RLe) Summary of observations Preparing for TVO's interviews -list of questions
Safety and risk analyses Regulatory control	Daily observations (1)	Daily observations (2)	Discussion on presentations			Daily observations (3)	

Week 2 (weeks 13 - 14)

	Wed 22/3 STUK	Thu 23/3 TVO	Fri 24/3 TVO	Sat 25/3	Sun 26/3	Mon 27/3 STUK	Tue 28/3 STUK
Investigation areas Management, QC/QA	Interviews At 8 - 16:30 TVO personnel: H. Plit / NS M. Pitko NQ/QM M. Landman N J. Ala-aho NQ/QA R. Hiekkanen NC/QC	Interviews at 8 – 17:30 TVO personnel - Onnela NQ/QA - Manninen NC/Site - Visit to site - Jääskeläinen NC/QC Forssan Betoni: - Bergman - Batching plant	Interviews at 8 - 14:30 TVO personnel Kervinen NC/QC Ala-aho (mat.) Van Graan FANP Mannola TVO/ns Levonen NL Jääskeläinen(mat.)			Area-specific observations / drafting report	Teamwork at 11 - 14:30 Interview of D. Kreckel - Analysing the interview - Making appoints for next day interviews
Safety culture, HOF Root cause analysis						from 12 on: Analysing TVO interviews	
Sample cases concrete liner polar crane	Discussion on interviews		at 15:30 - 20 Travelling to Helsinki			Review of area-specific summaries / observations	
Safety and risk analyses Regulatory control	Travelling to Rauma	at 18 - 19:30 Discussion					

Week 3 (weeks 14 - 15)

	Wed 29/3 TVO	Thu 30/3 STUK	Fri 31/3 STUK	Sat 1/4	Sun 2/4	Mon 3/4 STUK	Tue 4/4 STUK
Investigation areas	Interviews FANP personnel: - H. Beaumont - W. Örtel - Heudes - H. Sinisalo - L. Sikiö KymAmkk - S. Matala	Draft report - writing -verifying facts and observations	Draft report - writing - compiling at 14 -15:30 Interview of Aki Meuronen Key observations Drafts of focal areas to team members for reading			Review of draft report Summary - Key observations (Recommendations)	Writing report
Management, QC/QA							
Safety culture, HOF							
Root cause analysis							
Sample cases • concrete • liner • polar crane							
Safety and risk analyses							Agreeing on reporting of preliminary results
Regulatory control							

Week 4 (weeks 15 - 16)

	Wed 5/4 STUK	Thu 6/4 STUK	Fri 7/4 STUK	Sat 8/4	Sun 9/4	Tue 25/4 STUK	Mon 5/6 STUK
Investigation areas	TVO's clarification: (for information) Additional material for investigation team - description - causes - corrective action - further analyses	Review of TVO's clarification SSu, KaK, NiK, PP, PO Impact on conclusions drawn in investigation	Preliminary results reported: JL, LR, MlJ, PT			Review of draft report AVa, PO, KaK, NiK, MC, SSu, JL writing report: during 26.4. to 22.5. 22.5. –draft version to OL3 project and STUK management	Going through draft report AVa, PP, PO, KaK, NiK, MC, JMy JL Finalising draft report
Management, QC/QA			Draft report				
Safety culture, HOF							
Root cause analysis							
Sample cases • concrete • liner • polar crane							
Safety and risk analyses						22.5.2006 preliminary draft for comments: TVO, STUK	8.6.2006 draft for comments: TVO, STUK
Regulatory control							

STUK AS REGULATOR OF NUCLEAR POWER PLANT CONSTRUCTION

Licenses and safety regulation stibulated in the Nuclear Energy Act

Starting a project for constructing a major nuclear facility necessitates a Decision in Principle made by the Government and ratified by Parliament. As the next step, a Construction Licence is required for the implementation of the project, and the operation of a nuclear power plant requires an Operating Licence granted for a specified period of time. The Operating Licence can be renewed by application. The licensing process and the responsibilities and obligations of the involved parties are stipulated in the Nuclear Energy Act and the Nuclear Energy Decree. The licenses are granted by the Government. The licensing process is administered by the Ministry of Trade and Industry. For each license,, the Ministry has to request a statement from STUK which includes a safety assessment.

General safety requirements are given in Government Decrees, and more detailed technical requirements are specified in YVL Guides published by STUK. The YVL Guides also provide instructions concerning nuclear safety oversight by STUK and specify the obligations to the licence applicant/licensee. YVL Guide 1.1 [13] presents a summary of STUK's oversight activities in connection with the review of applications for nuclear plant licences, as well as during the construction and operation of a nuclear facility.

After the Construction Licence has been granted, STUK conducts regulatory oversight of the construction of the plant and the manufacture of equipment for the plant. The purpose of this oversight is to ensure that the conditions of the Construction Licence, the regulations in force for the pressure equipment, and the plans reviewed and approved by STUK are complied with, and that the nuclear facility also in other respects is built in conformity with regulations based on the Nuclear Energy Act. A particular objective of oversight is to ensure that the work methods applied during construction produce high quality.

Control stages of plant project

In November 2000, Teollisuuden Voima Oy submitted an application for a Decision in Principle (DiP) on the construction of a new nuclear power plant. Even before this, an Environmental Impact Assessment had been completed as stipulated by the environmental legislation. Concurrently with the Environmental Impact Assessment process, started early 1998, STUK had at TVO's request assessed the key safety features of the proposed plant alternatives. On the basis of this extensive preliminary work, STUK was able to produce the required safety assessment and a statement on the application for the Ministry of Trade and Industry after a short period of preparation already in February 2001. The safety assessment was supplemented in January 2002 with respect to external threats such as airplane crashes, due to the terrorist attacks that had taken place in the United States in September 2001.

The Government made a Decision in Principle on the construction of a new nuclear power plant on 17.1.2002. The decision included a statement where the Government indicated that it expects the new nuclear power plant to be built in compliance with stringent safety requirements. Subsequently, the DiP was submitted to Parliament for ratification. STUK's experts were heard by several parliamentary committees, along with many other invited experts, during the deliberation process. The Parliament ratified the Government resolution in May 2002.

The DiP made it possible for TVO to call for tenders for the delivery of the plant. Tenders were called in September 2002 and submitted in March 2003. In December 2003 TVO concluded an agreement with the consortium formed by Framatome ANP and Siemens on turn-key delivery of an 1600 MW nuclear power plant. TVO submitted an application for a Construction License to the Government on January 8. 2004.

TVO started submitting the documents specified in the Nuclear Energy Decree to STUK on the same day the Construction License application was submitted to the Ministry. STUK started examining the documents immediately. Supplementary documentation was submitted throughout the year as requested by STUK, and matters were discussed in numerous meetings between TVO, the plant vendor and STUK's experts. As a result of the review, STUK prepared a statement and an attached safety assessment, and submitted these to the Ministry of Trade and Industry in January 2005. The Government granted a Construction License for the plant on February 17. 2005.

Since the launching of the construction project, STUK has reviewed detailed design documents and conducted regulatory oversight of the manufacture of equipment as well as construction activities.

STUK's preparation for the project

STUK had maintained its preparedness for the control of a new plant project continuously since the existing Finnish nuclear power plants went online at the beginning of the 1980s. This preparedness included studying the development of light water reactors, updating the safety requirements specified in the YVL Guides according to most recent developments, and interaction with power utilities in order to consistently improve the safety of existing nuclear power plants. When the Finnish utilities applied jointly for a Decision in Principle on a new nuclear facility at the beginning of the 1990s, STUK assessed in the course of about three years plant alternatives, which were the predecessors of certain plant types considered for the current project.

Once the current project took shape, STUK studied the proposed plant alternatives and took part in the environmental impact assessment process.

An essential task before launching the project was to update the regulations of the YVL Guides concerning safety and regulatory control. Updating of the Guides continued until the main contract on the new plant was ready to be signed. TVO was provided information about the status of the Guides and about planned new requirements on a regular basis.

The preparations intensified after the Parliament ratified the Decision in Principle made by the Government. In the summer of 2002, the Nuclear Reactor Regulation (YTO) of STUK set up a special project group referred to as FIN5. The team consists of the Project Manager and sub-project managers for various sub-projects. The total number of sub-projects is 11, and each represents a specific field of technology. The project team is responsible for the planning and implementation of regulatory control of the plant project, and for the monitoring of the progress of oversight activities. The project team also assesses and inspects the quality of the licence applicant's and the plant vendor's project management. The project team is responsible for ensuring that the work of the YTO personnel proceeds as planned at different stages of the project. Team members also parcipated assessment and inspections in their respective technical fields.

The project plan that covers STUK's duties from the preparation stage to the granting of the operating licence was completed in January 2003. It describes the different parties involved in the project and their duties, the steering of the project, the division of the project into stages, and the key tasks in implementing oversight at different stages, as well as the interaction with various stakeholders.

Before the application for the Construction License was submitted, STUK's activities focused on the preparation of plans for oversight activities, as well as on contacts with the license applicant to ensure a smooth process. Sub-project plans identified and prioritised the most important tasks in terms of the Construction License process and the resources required for the work. The plans also paid attention to the interfaces between the sub-projects to ensure comprehensive oversight. In addition, the sub-projects specified the needs for external support in control activities. Discussions were conducted and experiences exchanged with authorities in other countries concerning nuclear power plant licensing procedures, requirements for different plant alternatives and experience in the construction of plants. The availability of international consultants was also investigated for areas where Finnish expertise is limited or a third party assessment is possibly required. The discussions were related to such topics as automation, accident analyses and control room design.

One of the project group's key tasks was to develop requirement management for systematic control of the implementation of safety requirements during the entire project. In addition to development work, this involved the conversion of the most significant YVL Guides influencing the design of the plant into a requirement management system. The system is used to monitor fulfilment of the requirements and control of fulfilment at the plant construction and commissioning stage.

Discussions were conducted with TVO about the detailed requirements of the content of the licence documents and about their submittal schedule, as well as about the time STUK needed for their review. STUK and TVO also organised an extensive seminar where discussions were held separately with each plant supplier about the interpretation of safety requirements for the plant alternative in question. At TVO's request, several separate meetings were also organised between STUK and the experts of the plant suppliers that had submitted a tender.

The plant supplier that was finally selected had already before the conclusion of the supply contract ordered the reactor pressure vessel at their own risk. At TVO's request, STUK started inspecting the design, manufacture and quality control of the pressure vessel. The manufacturing process of the reactor pressure vessel continues for several years, and inspections of the manufacturing process have continued uninterrupted since the granting of the Construction License.

Review of the application for a Construction License

During 2004 STUK reviewed the application for the Construction License and prepared its safety assessment. TVO submitted the documents related to the Construction License to STUK at the beginning of January 2004. Technical documentation was supplemented during 2004 as design progressed, and the designs were modified to some extent on the basis of issues raised by STUK. STUK also reviewed the quality management system of the project as part of the safety assessment.

The review of documentation, which was mainly implemented by STUK’s own experts, formed the basis for the assessment of the plant’s safety. Independent reference analyses were ordered from external experts, concerning e.g. plant behaviour in transients and accidents, and the radiation effects of potential transients and accidents. STUK also supplemented its own review by an external expert statement on the design of the reactor coolant circuit, as well as by an external investigation on how to consider airplane crashes in design. Expert statements were also requested on e.g. automation systems, emergency core cooling systems, the water chemistry of reactor coolant, the design of plant buildings, fire safety and protection against weather and electromagnetic phenomena. Moreover, STUK had analyses and tests performed concerning the management of severe accidents and the assessment of the impact of airplane crashes. Plans connected with emergency and security arrangements as well as fire safety were examined in collaboration with other authorities.

As a result of the review, STUK prepared a statement supported by an attached safety assessment, and submitted these to the Ministry of Trade and Industry in January 2005. The submittal also included a separate statement of the Advisory Committee on Nuclear Safety. STUK's conclusion was that the new nuclear power plant can be built as a safe plant. However, in order to meet Finnish safety requirements, STUK's statement called for some changes in the design of the plant. The changes concerned improvement of the reliability of safety functions. STUK's statement also required that as the detailed design of the plant continues during the construction project, the continuation of STUK's inspections and control has to be ensured and sufficient time shall be reserved for them. STUK also pointed out that TVO must ensure sufficient expertise of its personnel. The concern was expressed as follows: *”TVO shall ensure that sufficient expertise is maintained also during future operation of the plant. Due to the characteristic features of the new plant and the technologies utilised in it, TVO should ensure that its organisation reinforced during the construction period retains sufficient expertise also when entering the commissioning stage, particularly in the fields of nuclear safety, mechanical technology and automation technology.”*

STUK’s statement, safety assessment and the statement of the Advisory Committee on Nuclear Safety can be read in their entirety on STUK’s Web pages (www.stuk.fi).

Oversight of plant project during construction

Regulatory control of plant technology

As the first thing, STUK reviews the design of systems, which specify the requirements and the boundary conditions for the design of structures and components. The subsequent review of the design of structures and components used in a safety classified system cannot be started until STUK has found that the information provided on the system in question is sufficient and acceptable. The extent of regulatory control and the specified requirements are determined considering the safety class of structures and components.

The regulatory control of safety-critical buildings as well as concrete and steel structures entails e.g. review of the design documents of structures, inspections of readiness for starting of work on site, manufacturing inspections, construction inspections of steel structures, and commissioning inspections. In lower safety classes, inspections of concrete and steel structures can also be performed by certified experts employed with organisations authorized by STUK.

Regulatory control of pressure equipment and other mechanical equipment used in nuclear power plants entails review of design documentation for the equipment, approval of manufacturers, manufacturing inspections, construction inspections and commissioning inspections. STUK may authorise separate inspection and testing companies to perform certain inspections in lower safety classes.

Furthermore, STUK oversees the design, manufacturing and installation of electrical and automation equipment used in nuclear power plants, as well as the design, manufacturing, transport, storage, handling and use of nuclear fuel.

Conduct of OL3 design review

The acceptability of the main features of the plant's basic design and the systems was assessed in connection with the review of the application for the Construction License. STUK started the review of detailed design of process systems at the beginning of 2005 which also continues in 2006.

So far, the review of detailed equipment design has focused on the reactor and its coolant circuit. STUK has reviewed the design documents and manufacturing and quality control plans of the reactor pressure vessel, the steam generators, the pressurizer, the reactor coolant pumps and the control rod mechanisms before the manufacturing of the equipment was started. respective documents of the internals of the reactor pressure vessel and the steam generators have also been reviewed.

As far as the design of concrete and steel structures is concerned, STUK has reviewed the design documentation of safety class 2 classified parts of the containment and the safeguard buildings. STUK also reviewed the detailed design documents for the base slab under the containment and the safeguard buildings before the concreting was started. In the case of steel structures, review has focused on the design documents and manufacturing plans of the inner containment steel liner.

Regulatory control of manufacturing and construction

The purpose of a construction inspection is to verify that the component or structure has been manufactured and its quality has been controlled in compliance with the approved construction plan. The construction inspection is usually performed on an individual component after manufacturing, before the component is installed. However, for parts that cannot be inspected easily after manufacturing, inspections are performed as manufacturing and assembly proceeds. The construction inspection covers the records of manufacturing and quality control, as well as witnessing the pressure, load, tightness, or performance tests, depending on the component type.

As far as the main components of the reactor coolant circuit are concerned, STUK controlled the manufacturing of forgings for the reactor pressure vessel and the steam generators at Japan Steel Works (JSW). The completed forgings were subjected to construction inspections, after which STUK gave permission for the shipment of the reactor pressure vessel parts to Mitsubishi Heavy Industries (MHI) in Japan and of the steam generator parts to the Chalon plant in France. The last forgings were completed and shipped from the JSW plant in the spring of 2005. The welding of the first steam generator parts started at the Chalon plant in September 2004 under a conditional permission granted by STUK, as the inspection of the plant's design bases had not yet been completed at the time. MHI commenced the manufacturing of the reactor pressure in January 2005 after STUK granted permission for it. STUK's inspectors have observed the manufacturing of the reactor pressure vessel and the steam generators as well as the internals of these components by means of regular inspection visits to the manufacturing sites. STUK has also observed the manufacturing of other primary components (pressurizer, reactor coolant pumps, reactor coolant piping and control rod mechanisms) by visits to the manufacturing sites. The total number of inspections performed by STUK for the Olkiluoto 3 project in 2005 was almost 300.

Before manufacturing started, STUK audited the manufacturers of the main components of the reactor coolant circuit and the connecting parts in order to verify fulfilment of the requirements of YVL Guides. Based on the Nuclear Energy Act, STUK has upon TVO's application approved two manufacturers of main nuclear components and almost 40 other manufacturers of nuclear pressure equipment. In relation to the manufacturing of the primary components, STUK has on TVO's application approved 130 testing organisations to perform destructive and non-destructive tests on mechanical components and structures. STUK has further on TVO's application approved three inspection organisations to perform tasks related to the approval of the design and manufacturing of mechanical components and structures falling under safety classes 3 and 4. STUK has also audited the manufacturers, testing and inspection organisations approved by it and verified that their performance meets the requirements of YVL Guides 3.4 [9] and 1.3 [10].

STUK observed the preparatory work made on the plant site by performing inspections of excavated rock faces and by overseeing the construction of seawater intake and discharge structures. STUK approved the plans for the construction of these structures in July 2004. The approvals were at the time conditional as the review of the plant's design basis was still under way. STUK also inspected the coupling of the so-called technical ring running round the Olkiluoto 3 site with the construction site. The technical ring contains e.g. electricity supplies, firewater supplies and drain connections for the construction site.

STUK has conducted regulatory oversight of the construction of the plant by means of regular visits to the plant site. STUK has inspected the readiness for all concreting operations that are relevant to safety, and issued permissions for starting the concreting operations. In 2005, STUK performed 4 inspections of readiness for concreting. As far as steel structures are concerned, STUK's oversight has focused on the manufacturing of the steel liner.

Assessment of performance of organisations involved in construction

Assessment of TVO's operation

The assessment of TVO's performance at the preparation and Construction License stage was based on an assessment of TVO's quality management system, the quality of documents prepared by TVO and the review of the results of safety assessments prepared by TVO. At the Construction Licence stage STUK also audited TVO's project activities in Olkiluoto. The audits focused the project management and resources, handling of safety issues and project management procedures, quality management and management of documents. As a result of the audits, STUK required more specific procedures particularly in the assessment of safety and handling of safety issues, such as identification of safety issues, their handling within the organisation and decision-making. STUK also reviewed the safety provisions of the operating units (OL1 and OL2) against any possible risks arising from the construction of Olkiluoto 3. TVO has taken appropriate measures to improve its operations as suggested by STUK.

At the construction stage, corresponding audits will be performed regularly as part of the Construction Inspection Programme.

Assessment of plant vendor and its subcontractors

The assessment of the performance of the plant vendor started already at the Construction License stage and has continued during the construction stage. The assessment is based on the review of the quality management systems, quality plans and manuals describing the activities, on audits to verify activities as well as on interaction with the plant supplier in meetings.

At the Construction License stage STUK participated in almost all TVO audits of the activities of the plant vendor. The purpose of the audits was to verify the competence of the plant vendor to provide high-quality design and construction. The audits focused on quality management, procedures of project management and design activities in various fields of technology.

STUK also performed its own audits of the design activities of the plant vendor in the autumn of 2005. These covered the plant vendor's requirements management, handling of design changes, management of interfaces between different technological fields, layout design, and radiation safety, as well as the utilisation of the probabilistic safety analysis in support of detailed design. Certain development needs were identified in the audits and the plant vendor started improvement of the work processes in compliance with issued recommendations.

STUK participated already at the Construction License stage as an observer in audits of the plant vendor's main safety-related subcontractors. In the construction stage, STUK has by March 2006 participated in about 30 audits conducted by TVO of equipment suppliers. The purpose of the audits has been to verify the competence of the suppliers to participate in the new plant project. Need of development has been found in the performance of several equipment suppliers. In order to correct the situation, suppliers have, for instance, been required to prepare special Olkiluoto 3-specific quality plans.

Construction Inspection Programme

In early 2005, STUK started an inspection programme for the construction stage. The inspection programme is prepared every six months, and it focuses on the assessment of TVO's activies in order to ensure the high quality of the new nuclear power plant project. The programme is focused on the project's main functions, such as management, quality management, project management, and handling of safety issues, as well as quality assurance, training and radiation safety. Various fields of technology are also inspected.

As a result of the Construction Inspection Programme, STUK has been able to get a concrete and realistic visio of TVO's project management, resources, handling of safety issues and quality management, as well as its activities that support these main functions. The performance of TVO has been found satisfactory in terms of management, although some development needs have been identified. For example, STUK has required that the internal audit activities of the project shall be further developed and that TVO must verify that the quality systems of subcontractors who manufacture safety-critical components meet the quality management requirements specified in IAEA's safety standard. On the basis of inspections of the leadership system, TVO has been required to improve its handling of safety issues and the control of construction. TVO has submitted plans for corrective actions on the basis of the comments made as a result of inspections.