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NUCLEAR POWER PLANT CONTROL AND INSTRUMENTATION ACTIVITIES IN FINLAND

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Abstract

Finland has remarkable achievements in nuclear power. The existing four plants have some of the best operating records in the world - high capacity factors, low occupational doses and short refuelling outages. Public opinion was strongly turned against nuclear power after Chernobyl accident, and the previous government decided not to allow for the construction of a fifth nuclear unit during its period of reign. The opposition has however slowly been diminishing. According to the latest polls the opinion is almost balanced. Finnish power companies are going to file an application for a decision-in-principle to build a new plant to the new government appointed in April 1991. A readiness to start new construction project immediately after a positive political decision is made has been maintained during the intermediate period. Continuous research, development, modification and upgrading work provide important components of the good operational history of the Finnish nuclear power plants. Efforts have also been devoted to identifying possible new problems arising from the use of distributed digital C&I technology. The following a short description is summarizing recent activities related to the C&I-systems of the nuclear power plants.

STATUS AND PROSPECTS OF NUCLEAR POWER IN FINLAND

There are two nuclear power plant sites with a total of four operational units in Finland. In the Olkiluoto site there are two ASEA-Atom (now ABB Atom AB) 735/710 MW(e) (gross/net) boiling water reactors (BWR) owned by Teollisuuden Voima Company (TVO). In the Loviisa site there are two Soviet VVER-440 465/442 MW(e) (gross/net) pressurized water reactors (PWR) owned by Imatran Voima Company (IVO). The units produced in 1990 a total of 18.1 TWh of electricity constituting 35 % of the whole production (51.7 TWh) and 29 % of the electricity supplied to consumers (62.5 TWh).

Table 1. Electricity production and supply

	TWh		Share, %	
	1989	1990	1989	1990
Nuclear power	18.0	18.1	30	29
Cogeneration	15.1	16.3	25	26
Hydropower	12.9	10.8	21	17
Condensing & gas turbines	5.2	6.4	9	11
Production	51.2	51.7	85	83
Net import	8.9	10.8	15	17
Total supply	60.1	62.5	100	100

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Finnish nuclear power plants have some of the best operating records in the world - high capacity factors, low occupational doses and short refuelling outages.

Table 2 Capacity factors (%)

Plant	First connection to grid, gross power	1989	1990
Loviisa 1	(2/77, 465 MW(e))	92.4	84.9
Loviisa 2	(11/80, 465 MW(e))	91.8	84.5
Olkiluoto 1	(9/78, 735 MW(e))	81.5	94.4
Olkiluoto 2	(2/80, 735 MW(e))	93.9	92.7
	Average	89.5	90.1

The capacity factor reduction below the average more than 90 % in Olkiluoto 1 in 1989 was caused by the discovery of some blasting sand in control rod driving mechanism after the refuelling outage. The origin of the sand is still unknown. In Loviisa 1 a feedwater pipe broke in spring 1990 causing a repair and inspection outage of more than two weeks on both units.

Table 3. Collective radiation doses (manSv)

	1989	1990
Loviisa	1.80	2.82
Olkiluoto	2.78	1.58

The operating licenses for all the four plants were renewed in 1988 according to the new Nuclear Energy Act, which also was enacted in the same year. The licenses were granted for Olkiluoto plants for a 40 years plant life-time but for Loviisa plants for the time being only until the end of 1998, when an application for a renewal of the licenses has to be filed.

The peak electric power consumption in the year 1990 was 10.4 GW in January, the total supply capacity was that time 13.5 GW providing ample reserve capacity. The capacity increased by about 200 MW during the year and still 900 MW more is under construction; this including one large (MeriPori, 560 MW) coal condensing plant to be ready 1993. This total capacity of 14.6 GW is considered to be sufficient until 1995, but after that about 500 MW of new capacity each year will be needed. Altogether about 4.5 GW of new production or import capacity will be needed until the year 2005. This need is not only for the increase of consumption but also some 300 MW of old plants must be dismantled during this period. The import agreements with Soviet Union (1999) and Sweden (1995) will also terminate during this decade. No permanent plans to buy power from Sweden can be made because of the energy policy uncertainties. For security reasons there are not much possibilities to increase imports from the Soviet Union. About 100 MW of new hydro power potential still exists. The industrial and heat-generating back-pressure power capacity can be increased by about 0.8 - 1 GW during this decade which means that at least 1.5 - 1.7 GW of new basic power production capacity still will be needed before the end of decade.

Construction of new nuclear production capacity proves to be the best solution based on analyses concerning economy, environmental emissions, fuel availability and reliability. A schedule has been drawn up for increasing nuclear power rapidly during this decade. If the Finnish Parliament can make a decision in principle by the beginning of 1992, it will be possible to have a new plant operational in 1998 at the earliest. Apart from this plant, further capacity is still needed in the later half of the 90'ies. Decision on such additions can be made only after the nuclear power question has been finalized. The Coordinating Council of the Power Producers is investigating various alternatives. If the decision on nuclear power is delayed or if new nuclear power is eliminated entirely, then the potential of developing electricity-intensive industries will be reduced considerably with the implication that the planned industrial base of the country must be re-evaluated.

In February 1986, the two Finnish nuclear utilities, IVO and TVO, established a new limited company PEVO (Perusvoima Oy), with the task to develop new nuclear capacity in the country. In the next month, PEVO applied to the State Council for a decision-in-principle on building new nuclear plant capacity of about 1000 MW(e). A positive decision was then expected before the end of 1986. Public opinion in response to the Chernobyl accident, however, put the effort on hold and the government appointed in 1987 made a declaration of not building new nuclear power plants during its period of reign. In the mean time, PEVO and its owners have been involved in two technical programs related to the proposed new nuclear capacity. One involves a consideration of the plant alternatives presented in the original decision-in-principle application, and the other involves a review of advanced light-water reactor technologies. A readiness to start the construction of a new plant immediately after a positive political decision has thus been preserved.

The new Finnish Nuclear Energy Act requires a decision-in-principle to construct a nuclear power plant to be made by the State Council and to be approved by the Parliament. National elections held in March 1991 indicated considerable shifts in relative strengths of parties in the new Parliament. The Center Party and the Green Coalition, who have been against nuclear power (especially the latter), gained more support meanwhile the Conservative Party, the strongest advocate of nuclear power, suffered rather bad losses. For the time being it is hard to say whether nuclear power will appear on the agenda in the Parliament and the new State Council. PEVO is however ready to file the application for the decision-in-principle in May this year. From an objective point of view it is hard to see how Finland could sustain its industrial structure and a high standard of living and still be able to comply with its international commitments to reduce SO_2, NO_x and CO_2 emissions without new nuclear power plants.

MODIFICATION, UPGRADING AND DEVELOPMENT WORK AT EXISTING NUCLEAR POWER PLANTS

One important factor behind the good operation history of the Finnish nuclear power plants is connected to a continuous development, modification and upgrading work, which is proceeding in all existing plants. In the following a short description is given on recent activities related to the C&I-systems of the plants.

C&I system development and upgrading

At the TVO's Olkiluoto plant unit 1 the low power feedwater control system has been replaced with an ABB Master application during the refuelling outage in spring 1990. At unit 2 a similar replacement will take place in this spring. These are the first applications of distributed digital automation systems in Finnish nuclear power plants. Although these systems are not safety classified, the commissioning was done as if it were, to get experience about the licensing of these new systems also for safety related applications.

As a part of plant life extension work, a systematic renewal of relays and push buttons has been started at Olkiluoto plants.

In Olkiluoto the weather measuring instrumentation will be renewed during 1991. The dose rate measurement system will be extended on-site in 1991 and at the 5 km radius from plant in 1992.

In Loviisa the C&I system changes are mainly related to the changes in process systems

Process computer systems

Mainly due to the maintenance problems and restrictions in computing capacity both IVO and TVO have renewed their plant and process computer systems during the recent years. The configuration and tasks of the computer systems are slightly different in IVO's and TVO's plants and therefore the time schedules and details of the updating projects differ.

In Loviisa plants, the old centralized ARGUS-500 process computers with a total of 7500 inputs per unit were replaced with a cluster of VAX/VMS-computers connected through an Ethernet local area network. The new system is delivered by Afora Oy (now ABB Stromberg Power Co). The control room interface is realized by using high-resolution full-graphic color displays. This is the first high-resolution display system used in nuclear power plants. The field connections of the old system were retained and 1500 new inputs were added. All the other parts of the system were renewed. The software for the computers has been rewritten completely. IVO has written some part of application programs (including a graphics software package IVOGKS which fulfills GKS and X-Window standards). IVO has also realized the process displays and reporting system. IVO was also responsible for all applications such as reactor and BOP calculation programs.

The connection of the new system to the process was realized at unit 1 during the refuelling outage in summer 1988 and at unit 2 in summer 1989. The new system was (for testing and software development purposes) in use at the unit 1 in parallel with the old one since November 1988 and was changed to be a master at unit 1 in May 1989 and at unit 2 in January 1990. At the simulator the new computer system was in parallel operation since January 1989 and operators were trained to use the system. The VAX-clusters at each unit and at the simulator are connected together with bridges which makes data transfer between plant units and simulator possible. On-line process data can now be presented also to other user groups outside the control room.

The process computer renewal project has been one of the largest of its kind so far realized. The project was carried within its scheduled time and cost frame and the system fulfilled all expectations. The first delivery consisted only of the old system functions, but now the plant has an effective and flexible platform on which different new control room displays and computerized operator support functions are easy to realize.

A critical safety function monitoring (SPDS) application was implemented in the process computers on both units in summer 1990 after extensive testing and validation on simulator. Other new functions already implemented include a comprehensive plant history and trend display system, operating point displays, materials stress monitoring, logic system status displays, zooming, panning and window functions etc. Also a couple Early Fault Detection (EFD) applications developed originally at the Halden Project are in test use on both units; high-pressure feedwater preheater leak detection since January 1990 and supervision of feedwater measurements since February 1991. A new development project on detection and location of primary and secondary system leaks based on mass and energy balances is under way.

At the TVO plants the process computers consists of a Norsk Data NORD multicomputer configuration with a distributed process interface. The computers were replaced and upgraded during the 80'ties to reflect the state of the art without radical functional development. As a last step the replacement of the man-machine interface (MMI) in the control room has been planned. This replacement project was initiated in the late 1990 and will be completed before the refueling outage in 1992. As a part of the project, a SPDS function will be implemented to support the use of symptom oriented emergency operating instructions. Installation in control room parallel to the old system should be ready in October 1991. After a long testing the old system is scheduled to be removed in autumn 1992. All the present functions (among them computer supported control rod maneuvering) will be transferred and developed on the new MMI which is based on ergonomic design principles well established today. The turbo-generator vibration monitoring computer system will also be renewed during 1991-1992.

The new MMI is based on workstation technology and the workstations communicates with the present process computers over an Ethernet local area network. The role of the present process computer will be reduced to perform front-end functions towards the process and a system handling the communication with other computers. In a distant future it is foreseen that the present process computers will be replaced with distributed hardware communicating with the process and providing the MMI services to the control room. The MMI functions will be realized with high resolution screens (1280x1024) and screen hard copy devices will be used for operator support. The system has been ordered in February 1991 from ABB Strömberg Power Co and it is based on the distributed Afora PMS process computer concept (also used in the Loviisa power plant). The number of display stations in the control room will be increased from the present four to seven. Display stations will also be provided for the Technical Support Center and in a later development stage in the Emergency Operation Facility.

Training Simulators

IVO has had a plant-specific full-scope training simulator for its Loviisa plant in operation since the year 1980. The simulation computers and simulator process computer were replaced with a VAX/VMS-system a few years ago. Before that and since then continuous development and upgrading has been carried out.

In addition to the training of operators, the Loviisa simulator has extensively been used for various research and development work as well as for plant analyses and testing. These tasks have included eg. human factor analyses for the PSA-studies, analysis of thermal shock during emergency core cooling, testing of operation procedures and new process computer functions.

The operators of the TVO plants have earlier been trained at the Barsebäck-1 simulator at KSU AB in Studsvik, Sweden. In January 1988, however, TVO ordered its own full-scope training simulator from Singer Link-Miles Simulation Corporation (now 3S Technologies). The simulator was installed at the plant site around the turn of the years 89-90. Training started in March 1990. The simulator is mainly intended for training and retraining of control room operators, but a usage for general support activities is also foreseen.

Severe Accident Management

The present Finnish safety guide on the design principles of nuclear power plants requires severe accidents to be taken into account in the design of the containment. In 1986 this requirement was extended to apply also for existing plants. The utility companies have started back-fitting the plants to cope with this requirement. The actions include a validation of the existing containment instrumentation in its possibilities to stand the containment conditions after a severe accident as well as adding some new instrumentation. As a result of the new requirements, some instrumentation cable penetrations will also be renovated the Loviisa plant.

At the Olkiluoto plant, a filtered containment venting system from KWU has been installed and taken into operation in 1989. In Loviisa a new containment cooling system will be installed which is spraying water on the steel containment in accident situations.

The power companies have also, in response to the regulatory authorities, checked and reconsidered the safety classification of I&C-systems and equipment. The transmission of data on plant status and releases to the authorities has also been intensified.

IVO is sending the spent fuel back to Soviet Union, but TVO has not yet any agreement on the final disposal of spent fuel. Therefore, TVO has started studies on finding a proper place of repository for the spent fuel in the Finnish bedrock. Five sites are now under study. In 1992 two or three will be selected for further study and the final site will be selected in 2000. Test drilling has been done and new unique instrumentation and measuring methods have been developed for assessing bedrock integrity and ground water flows. A systematic measuring program has been initiated and new measurements will be developed.

TVO is also building a repository cave for low- and intermediate-level wastes, which will be taken into operation in the beginning of 1992.

EXAMINATION OF C&I CONCEPTS FOR A NEW NUCLEAR POWER PLANT

Four nuclear power plant vendors are preparing offers for the fifth nuclear power unit. ABB Atom Ab from Sweden is offering their 1180 MW BWR-90 system. The C&I system offered for these plants is the ABB Master automation system. Franco-German Nuclear Power International (NPI), formed together with French Framatome and German Siemens, is offering a 1110 MW PWR plant named NPI-1000 and a 1330 MW Konvoi-type PWR plant. A new C&I concept based on Siemens technology will be developed for this concept; the first reference application for this automation concept will be the Staudinger coal condensing plant operable in 1993 in Germany. German Siemens is offering a 1115 MW and a 1350 BWR plant. The C&I concept for these plants will probably be the same as in NPI's PWR plants. Soviet Atomenergoexport is offering a 1040 MW VVER-91 PWR plant, which have been developed together with IVO. The automation concept for this plant is not yet known, but it will be of a modern design.

The C&I concept for the new nuclear power plant will most probably be based on modern distributed digital automation technology. The latest experience from Chooz-B plant in France (EdF has announced that they will abandon the P20 system developed together with CEGELEG) shows that the adoption of this technology is cumbersome. Utility companies IVO and TVO together with the licensing authority STUK (Finnish Centre for Radiation and Nuclear Safety) and research organization VTT (Technical Research Centre of Finland) have started projects to study the problems connected to the licensing and use of this new technology. Main task for IVO and TVO is the specification of requirements for C&I systems while STUK and VTT mainly concentrate on definition of licensing procedures. One result of the study is that the existing international standards and practices are developed for conventional C&I technology and do not support the verification and validation of digital systems. Some new standards eg. by IEC and ISO are addressing these problems, but are not providing the necessary guidance. An international effort would be needed to complete and harmonize the standards, guidelines and practices for the new technology. IAEA could take an active part in initiating such an effort.

RESEARCH ACTIVITIES AT VTT

Nuclear research and development work in Finland outside the power utility companies is mainly done at the Technical Research Centre of Finland (VTT). This work is financed from VTT's own budget, by governmental projects and by contracts from the utility companies. This work has, starting from the year 1990, been coordinated in three research programs:

- Operational safety of nuclear power plants (YKÄ),
- Structural safety of nuclear power plants (RATU) and
- Nuclear waste management.

Activities in connection with C&I is included in the YKÄ-program and is mainly carried out at the Laboratory of Electrical and Automation Engineering (SÄH). In the following a short description on these activities is given.

Characterization, assessment and development of operational skills

The development of the cognitive and co-operational skills of the operators of heavily automated production plants and processes includes many difficulties and conflicts. Producing the necessary competency for the operators through their whole professional career is therefore of most importance.

Based on earlier experiences and observations from a series of simulator training experiments a more complete picture on the operator competence and its basic components has been established and new methods for development and assessment of the operational skills are developed. Based on interviews of different groups of operational staff a picture of the development of the safety culture and skill, motivation and responsibility along working career will be formed and a comprehension about the operators own view on risk management defined. Results will be used for definition of a theoretical model for continuous development and training activities and included practices.

Validation and Licensing of Digital I&C-systems

New distributed programmable digital automation systems are conquering the major part of the automation system market and they are in the future also coming to the nuclear power plants. The licensiability of these systems for the use in safety related systems and functions is still an open question, because there are no generalized and systematic methods for the evaluation of the reliability of these systems. Many new problems such as the data transfer capacity of the system buses and the reliability of software arises.

Development of methods for licensing evaluation of digital automation systems was started already in 1985 in restricted amount but has been severely delayed. In 1990 the work was intensified when the decision about a new nuclear power plant again actualized. The work is done in cooperation with licensing authorities and utility companies as described in the previous chapter.

Deep Knowledge in Power Plant Control and Operation

Knowledge based systems (KBS) are potentially applicable in many tasks in operating power plants as indicated for example by the proposals to apply KBS technologies in operator support systems. Problems similar to those encountered in KBS development are encountered also in formal development of process automatics.

The key issue in nuclear power plant applications is dependability. KBS dependability is based on the validity of the knowledge base and on the soundness of the inference algorithms. To achieve the first goal the knowledge base must be founded on generally accepted principles governing the plant behavior and on validated plant design documents. Thus there must be a comprehensible, tractable transformation from general laws of physics and from the plant documentation into the formalism used in the knowledge base. Thus constructing a knowledge base can be considered as modelling the plant. Contrary to for example simulation models the models use in KBS's must allow efficient mechanized formal reasoning.

The term "deep knowledge" reflects the use of the first principles of system behavior. The term "qualitative modelling" reflects the fact that the requirement of efficient automatic reasoning seems to lead to extensive use of qualitative type of knowledge on the first principles.

In deep knowledge systems the knowledge representation primitives and the principles of reasoning are tightly coupled and they must be developed together. The inference principles must based on mathematical logic.

The on-going work in VTT in co-operation with OECD Halden Reactor Project (HRP) concentrates on developing the principles of deep knowledge systems and on their applications in formal verification of the automation systems and perhaps also operator support systems.

Management of the risk and performance of a nuclear power plant

In a Nordic co-operation project (NKS/SIK-1) the use of living probabilistic safety analysis methods (Living PSA) and safety indicators based on operation experience data for the evaluation and improving of operational safety of the plant is defined and demonstrated. A living PSA concept and a safety indicator system will be defined and tested together with utilities and safety authorities.

Information Technology Support for Emergency Management (ISEM)

VTT is participating in the international ISEM-project scheduled for 1989 - 1991. The main financing of the project is from CEC within the European Esprit II research program. The other members of the consortium are from Belgium, Denmark, Finland, Italy, Spain and Sweden. The prime contractor is Risö National Laboratory in Denmark.

The project is aimed at the development of an information system capable of supporting the complex, dynamic and distributed decision making needed in the management of emergencies eg. in the nuclear and chemical industries, in the transportation of hazardous materials and in natural disasters.

The project objective is to explore, describe and develop architectures for decision support systems suited for emergency management of rare but severe events in large organizations. Tools supporting system specification and design, knowledge acquisition, system development and maintenance through the full life-cycle are developed. The collection of these tools will be considered as an application generator. Two demonstration systems i.e. nuclear and chemical industry will be designed, implemented, tested and evaluated. Finally guidelines and strategies for proper use of the project results (architectures and software tools embedded in the application generator) in a variety of industrial sectors will be developed.

Advanced Simulation System APROS

The advanced simulation system APROS, which has jointly been developed by VTT and Imatran Voima Company (IVO), has been extended to cover many fields of applications. Standardized models of nuclear reactors, thermo-hydraulics, automation systems, chemical reactions, boilers, electrical systems, etc. have been included in the software package.

The graphical user interface intended for model development and instructor operations has been transported to X-windows workstation environment. Software for emulation of control room displays on PC equipment has been developed to facilitate affordable training simulators. Much effort has been made to produce easily transportable software, which benefits parallel and vector processing features of new computer hardware.

The calculation of the thermo-hydraulics has been extended from the homogeneous 3-equation model to 5- or 6-equation models for separate phases. The single component calculations have been extended to multicomponent thermodynamics including chemical reactions.

In the nuclear field, a comprehensive and detailed nuclear plant analyzer has been constructed for the Loviisa nuclear power plant. Its capability was fully demonstrated when simulating the feedwater pipe break shortly after the real incident. A fully 3-dimensional dynamic nuclear reactor model is presently developed to complement the one dimensional fast calculating model.

APROS is intended for studies of restricted system interactions and for convenient simulation of the entire power plant. It can be used during the whole life cycle of a plant, starting with design simulation runs for engineering purposes, detailed analysis of safety related topics, for evaluation of operation manuals and safety guides, for testing of commissioning procedures, for training of operators, for testing of plant upgrades, and for identification of changes in plant due to ageing or malfunctions.

A comprehensive verification effort of the code has started. A large number of recorded transients from international test facilities will be simulated. The same input definitions can be used for the different thermodynamic solvers.