LIFE TIME EXTENSION OF PRESENT ANALOGUE I&C SYSTEMS

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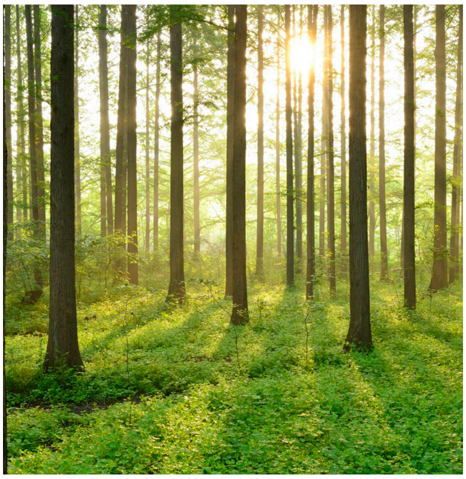

NUCLEAR

Energiforsk

Life time extension of present analogue I&C systems

Experiences from the United States

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Foreword

Energiforsk ENSRIC is a research program focused on safety related I&C systems, processes and methods in the nuclear industry. The three focus areas of the program are emerging systems, life time extension and I&C overall. Information from the program will assist the nuclear industry and the Radiation Safety Authority when analysing how to replace systems and methods - choosing a new technology or finding a way to stay with the present solution - with maintained safety and promoting a low life cycle cost. The program is financed by Vattenfall, E.On, Fortum, TVO, Swedish Radiation Safety Authority, Skellefteå Kraft and Karlstad Energi.

This project has been carried out by Annika Leonard and Anna-Karin Sundquist from Vattenfall, in close cooperation with the reference group. The study was carried out in two phases, starting with a desk study/planning phase to find relevant organizations and contact persons and then a second phase with a tour to meet and interview US organizations.

Energiforsk would like to thank the staff at the visited organizations and the reference group for taking their time to participate and for their contribution to this report.

Reference group:

Fredrik Bengtsson, Ringhals
Christer Johansson, Forsmark
Karl-Erik Ericsson, OKG
Harri Perhonen, Fortum
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Authors' foreword

A moment of reflection.

No man is an island. Not in this work either.

I would like to express my gratitude to the reference group for the project – Fredrik Bengtsson at Ringhals, Christer Johansson at Forsmark and Hannu Malmberg at Fortum – who also accompanied me on the tour around the U.S., added valuable insight to tricky questions and didn't complain about the early morning hours. A great Elf-Orcs team!

My college Anna-Karin Sundqvist at Vattenfall is most important for the creation of this report. I was fortunate enough to take over management of this project from her when her baby Linnea was about to enter this world. Anna-Karin's ideas, contacts and planning made it easy for me to continue the project.

Monika Adsten at Energiforsk, thank you for answering all my questions about expectations, practicalities and layout in a clear and crisp manner.

The learning from this trip has been extensive: for me, my fellows on the trip and the ones we have spread the message to, and it will hopefully be so for the readers of this report as well. There are ways – yet not so well known in Sweden or Finland – of maintaining old instrumentation and control equipment in nuclear power plants!

Sammanfattning

Den säkerhetsrelaterade instrument- och kontrollutrustningen i de nordiska kärnkraftverken består av en mix av teknologier. Större delen är fortfarande av konventionell typ men det finns också ny digital utrustning, system och plattformar. Inom de närmsta åren måste en stor del av dessa system och utrustningar bytas ut eller uppgraderas på grund av olika aspekter av åldring. Detta är en utmaning, och erfarenheterna från tidigare utbyten är tyvärr tudelade.

Ett projekt har tidigare genomförts inom Energiforsk, vilket identifierade uppgraderingsprogrammen inom Westinghouse och General Electric som intressanta. Energiforsk beslutade därför att utreda dessa program mer i detalj. Man ville även studera några amerikanska kärnkraftverk och branschorganisationen EPRI, avseende renoverings- och uppgraderingsstrategier.

En studieresa genomfördes därför, med möten och diskussioner tillsammans med de två utsedda leverantörerna (OEM, Original Equipment Manufacturer), en annan leverantör som erbjuder tjänster till de amerikanska verken och ett kärnkraftverk. Det var inte möjligt att få till ett möte med EPRI, så istället har man studerat EPRI:s material (guidelines). Lärdomarna och erfarenheterna från resan har sammanställts i denna rapport.

En summering av erfarenheterna från studieresan är att kärnkraft-I&C har liknande utmatningar i USA som i Europa. Verken och leverantörerna har en mer utmanande affärssituation nu än förut: överskott på fracking gas genererar låga elpriser, vilket leder till krav på kostnadsminimering inom alla områden. När förnybar energi samtidigt får statliga bidrag blir situationen än mer utmanande för kärnkraftproduktionen. Dessutom har olyckan i Fukushima lett till ansträngningar för kärnkraftsbolagen, även om det inte berört I&C-området så mycket.

Strålsäkerhetsmyndigheten i USA (NRC) har varit väldigt strikt med att tillåta ny digital mjukvarubaserad teknik i kärnkraftsanläggningar. Vid ett flertal tillfällen har energibolag och leverantörer behövt göra förklarande tillägg och relicensiera systemen.

Den ekonomiska situationen och licensieringsförfarandet har lett fram till ett tankesätt ”låt analogt förbli analogt och digitalt förbli digitalt”. Man är ovillig att ändra teknik och design. Istället har man hittat vägar att underhålla den gamla analoga utrustningen.

Strategier

Det har utvecklats strategier för underhåll och förvaltning av anläggningarna (asset management). De två processerna har inverkan på varandra och därför är det fördelaktigt med en kombinerad syn. Ett sätt att hantera underhåll och förvaltning av en anläggning samtidigt är att ha en strategi för Life Cycle Management (LCM). EPRI har utvecklat guidelines och mjukvara för Life Cycle Management och flera leverantörer erbjuder tjänster inom LCM till verken.

Strategin innehåller typiskt tre eller fyra faser:

1. Identifiera kritiska komponenter
2. Prioritera bland dessa kritiska komponenter
3. Lär upp personalen på prioriterade komponenter (exkluderat i EPRI:s guidelines)
4. Välj och implementera en lösning för prioriterade komponenter

Om det är nödvändigt att uppgradera ett system eller en anläggningsdel så är den generella åsikten i USA att man bör modulera uppgraderingen. Den bör göras för små delar i taget, och införandet av en del bör vara oberoende av införandet av de andra delarna. De stora, genomgripande projektens tid är över.

Underhåll av analoga komponenter

Det finns olika sätt att underhålla gammal, analog utrustning: ersätta, reparera, renovera, omvänd konstruktion, eller återtillverkning.

Verken säljer utrustning till varandra. För detta använder de kommersiella databaser som RAPID (www.rapidsmart.com) och POMS (www.poms.com). Databaserna täcker hela USA och några anläggningar utanför USA också (Spanien, Taiwan).

Delar kan också köpas från lager, överskottsbolag, E-bay etc. Komponenter av industristandard måste sedan kvalificeras för nukleär standard. Det görs antingen av anläggningen som köper delen eller av en mäklare (tredjepart) som letar rätt på delen åt anläggningen. Processerna för kvalificering verkar väl utvecklade i USA.

Oavsett om delen är köpt från ett kärnkraftverk eller ett kommersiellt överskottsbolag måste rekvalificering göras. Det finns en osäkerhet kring var delen har befunnits, under vilka förhållanden den har använts och i vilket tillstånd den är.

Produkter eller kretskort kan repareras genom att byta ut enbart de trasiga komponenterna. De kan också vitaliseras genom att rengöras, byta ut komponenter som är kända för att påverkas av åldring etc., vilket går under begreppet ”refurbishing” (renovering). Produkterna eller korten anses som identiska efter en sådan renovering. Det krävs en ekvivalensutvärdering men ingen relicensiering.

En del produkter har en design som leder till problem, t.ex. överhettning nära en specifik komponent på ett kretskort. En sådan produkt kan bli föremål för återkonstruktion (reengineering) eller omvänd konstruktion (reversed engineering). Storlek, anslutningar och funktionalitet (”form, fit & function”) behålls men insidan av produkten omdesignas. Om man håller sig inom vissa gränser, som att inte byta teknologi, anses detta vara ett utbyte som inte kräver relicensiering. En ekvivalensutvärdering krävs dock. Omvänd konstruktion har pågått i ca 20 år, NRC känner väl till dess existens och stödjer det generellt sett, och företagen som utför omvänd konstruktion har granskats av både NRC och NUPIC.

Verken går ibland samman och ber en ursprunglig leverantör eller, om det är juridiskt möjligt, en annan leverantör att göra en återtillverkning av delar som är obsoleta. Samarbete med andra verk är vanligtvis nödvändigt för att det ska vara ekonomiskt lönande.

Som en sista utväg kan man utföra redesign eller uppgradering av systemet. Då krävs relicensiering, en process som tar minst fyra år.

FPGA

För 5-10 år sedan trodde man att tekniken med Field-Programmable Gate Array skulle vara lösningen när man behövde byta ut analog utrustning mot något nyare. NRC har tittat på ämnet och fastslog 2010 att FPGA är mer mjukvara än hårdvara. För att använda FPGA på ett säkert sätt måste man rätta sig efter samma krav på konstruktion, utvecklingsverktyg och verifikation som för mjukvara.

Kompetens

I USA är attityden till nätverkande och samarbete generellt talat mer positiv än i Skandinavien. Kunskap om gammal teknologi, plattformar och produkter bevaras genom samverkan i branschorganisationer, kund-leverantörsallianser, deltagande i konferenser och samarbete i kommittéer. Man håller interna kurser, utvecklar formella mentorsprogram och unga ingenjörer får delta i konferenser om obsolescens eller life time management.

Slutsatser

När man utvärderar lärdomarna från USA måste man ha situationen i Skandinavien i beaktande. I USA är det en stor skillnad mellan 50.59-utbyten och utbyten som kräver en ändring av licensen. För att klassas som ett 50.59-utbyte måste inverkan på säkerhet och säkerhetsanalyser vara minimal. De tillåts inte inkludera en förändring av teknologi och vanligtvis inte en uppgradering av mjukvara. Konsekvensen blir att de amerikanska kärnkraftverken försöker i det längsta att stanna inom samma teknologi: ”låt analogt förbli analogt, och digitalt förbli digitalt”.

I Sverige och Finland är det inte lika stort fokus på att stanna inom samma teknologi. Men den ekonomiska situationen är densamma i både USA och Skandinavien. Fracking gas, låga elpriser och statliga subventioner till förnyelsebara energikällor ger ekonomin hög uppmärksamhet. Därför är alternativ till redesign och uppgraderingar attraktiva även i Skandinavien.

Under mötena och diskussionerna som teamet hade i USA framkom att det finns verkligen möjliga och ekonomiska sätt att underhålla analog utrustning. Slutsatsen i ENSRIC-rapporten [7] säger att det är en absolut nödvändighet att migrera från analoga till digitala lösningar, men föreliggande projekt motsäger det. Om det finns en regelmässigt eller ekonomiskt incitament kan man redesigna, uppgradera eller migrera till en digital lösning. Men det är inte den enda vägen man kan gå. I många fall kan gammal analog utrustning underhållas och behållas.

Även de skandinaviska kärnkraftsanläggningarna behöver en strategi för underhållet. Strategin behöver vara proaktiv eftersom underhållsaktiviteterna kan ha långa ledtider och en typisk anläggning har tusentals obsoleta komponenter. EPRI har guidelines om obsolescens styrning och life time management som kan användas. Det vore lämpligt att lägga till träning av personal i stegen i EPRI:s guideline. Sättet att göra utbyten i små modulära delar och inte allt på en gång bör vara applicerbart på de skandinaviska anläggningarna också.

Produkter med en liten marknad kommer att ha mer obsolescensproblem än de som är installerade på många verk. För att undvika end-of-life och obsolescens behöver leverantörerna en viss mängd kunder. Detta bör man tänka på i verkens inköpsprocesser.

I USA nyttjar aktörerna en del tillvägagångssätt för underhåll av analoga system och komponenter som är nya för de skandinaviska verken. Att använda sig av nationella eller internationella databaser för reservdelshållning är mycket intressant, att använda omvänd konstruktion likaså. Kvalificeringsprocesserna och inköpsprocesserna bör ses över från ett skandinaviskt perspektiv innan man nyttjar dessa tillvägagångssätt.

Den sista slutsatsen är att nätverkande är viktigt. De skandinaviska I&C- och/eller obsolescensingenjörerna borde interagera mer och lära av varandra. Det behövs för att uppnå en kritisk massa av kunskap i en relativt liten region.

Summary

The Nordic nuclear fleet of today consists of a mix of technologies for safety I&C. A large portion of the equipment is still of conventional type but there are also new digital equipment, systems and platforms installed. In the coming years a considerable amount of systems and equipment must be replaced or upgraded because of different aspects of aging. This is a challenge and the experience from recent years is unfortunately mixed.

Through a previous mapping project the upgrade programs provided by Westinghouse and General Electric were identified as interesting. Energiforsk therefore decided to investigate these programs further. In addition, a few U.S. utilities and EPRI was to be studied in the context of renovation/upgrade strategies.

A trip was conducted which included meetings and discussions with the two identified Original Equipment Manufacturers (OEM:s), another vendor offering services to the American utilities and one nuclear power plant. It was not possible to meet with EPRI; instead EPRI material like guidelines has been studied. The knowledge and experience gained from the trip is collected in this report.

A summary of the experiences from the US trip is that nuclear I&C has similar challenges in the USA as in Europe. Utilities and vendors have a more challenging business environment than previously: a surplus of fracking gas generates low electric prices, which turns into requirements to cut costs in all areas. When renewable energy is getting subsidiaries at the same time, the nuclear production is meeting more and more challenges. Also, the incident in Fukushima put stress on the nuclear power companies, even though not so much in the I&C area.

In the US, the authority has been very strict to allow use of new digital software technology in nuclear power plants. There have been many cases where power companies and vendors were required to make additional clarifications and relicense.

The economic situation and the licensing procedure has led to a thinking “analogue stays analogue, digital stays digital”. They are reluctant to change technology and design. Instead, ways of maintaining the old analogue equipment has developed.

<u>Strategies</u>

Strategies have evolved for maintenance and asset management. The two processes have impact on each other, and a combined view is therefore advantageous. The strategy of Life Cycle Management is one way to handle both maintenance and asset development of a plant. EPRI have developed guidelines and supporting software for Life Cycle Management, and the OEM:s offer services for LCM to the utilities.

The strategy typically contains three or four phases:

1. Identify critical components
2. Prioritize amongst these critical components
3. Train personnel on prioritized components (excluded in EPRI:s guidelines)
4. Choose and implement a solution for prioritized components

If an upgrade for a system or plant division is necessary, the general view in the USA is to modulate the upgrade. It should be done in smaller parts, and the realization of one

part should be independent of the others. The time for large, comprehensive projects is gone.

Maintenance of analogue equipment

Different ways of maintaining the old analogue equipment are possible: replace, repair, refurbish, reverse engineer or remanufacture.

The utilities are transferring equipment between them, using commercially run databases like RAPID (www.rapidsmart.com) and POMS (www.poms.com). The databases are countrywide, even plants outside the USA are taking part (Spain, Taiwan).

Parts are even bought from warehouses, surplus stores, E-bay etc. Industrial grade components then have to be qualified for nuclear grade. This is done either by the plant buying the part, or by a broker (third party) finding the part for the plant. Processes for qualification seem to be well developed in the U.S.

Regardless if the part is bought from a nuclear power plant or a commercial surplus store, requalification has to be done. There is an uncertainty about where the part has been, under which conditions it has been used and in what state it is.

Products or circuit cards can be repaired by exchanging the faulty components only. They can also be revitalized by cleaning, exchanging components know to suffer from ageing etc., called refurbish. The products or cards are regarded as identical after these treatments. An equivalence evaluation is needed but no relicensing.

Some products have designs that lead to problems, like overheating close to a specific component on a circuit board. Such a product may be re-engineered or reversed engineered. The size, connections and functionality is retained – form, fit & function – but the inside of the part is redesigned. Within certain boundaries, like staying with the same kind of technology, this is regarded as an exchange that does not need relicensing. An equivalence evaluation is needed, though. Reversed engineering has been going on for approximately 20 years, NRC is well aware of its existence and is mainly supportive, and the companies doing reverse engineering have been audited by both NRC and NUPIC.

Utilities sometimes do a joint venture and ask an OEM or, if legally possible, another vendor to re-manufacture parts that are obsolete. Co-operation with other units is usually necessary to make it worthwhile economically.

As a last option, system redesign or upgrade of a product can be done. Relicensing is then required, a process that takes four years as a minimum.

FPGA

The technology of Field-Programmable Gate Array was 5-10 years ago believed to be a solution for exchanging analogue equipment to something newer. However, the NRC have looked into the subject and deemed 2010 that FPGA is more of software than hardware. To have a safe usage of FPGA, it has to confirm to the same requirements for construction, development tools and verification as software.

Competence

The attitude towards networking and cooperation is generally more positive in the USA than in the Scandinavian countries. Competence in old technologies, platforms and products is retained by collaboration in branch organizations, customer/vendor-alliances, attending conferences and working together in committees. Internal training courses are held, formal mentorship programs have developed and young engineers attend conferences on obsolescence or life time management.

Conclusions

When evaluating the experiences from the USA, one has to consider the situation for the nuclear power plants in the Scandinavian countries.

In the USA, there is a vast gap between 50.59-exchanges and exchanges that needs an amendment of the license. The 50.59-exchanges are exchanges with minimal impact on safety and safety analyses. They are not allowed to include a change of technology and usually not an upgrade of software. As a consequence, the U.S nuclear power plants try to stay with the same technology: "analogue stays analogue; digital stays digital".

The focus on staying with the same technology for the sake of licensing is not as high in Sweden and Finland. But the economic situation is the same in both the USA and Scandinavia. Fracking gas, low prices for electricity and government subsidization of renewable energy sources puts a high attention on economics. Alternatives to redesign and upgrade are hence attractive also in Scandinavia.

The meetings and discussions during the project team's trip to the USA revealed that there are indeed possible and economical ways to maintain analogue equipment. The conclusion of the ENSRIC report [7] was that it is an absolute necessity to migrate from analogue to digital solutions, but this project contravenes that. If there is a regulatory or economic incentive, redesign, upgrades or migration to digital solutions might be done. But it is not the only way to go. Old analogue system can in many cases be maintained and kept.

A strategy is needed for the Scandinavian plants as well; the work has to be proactive since the maintenance action might have long lead times and a typical plant has thousands of obsolete components. EPRI has guidelines on obsolescence management and life time management that can be used. It would be beneficial to add training of personnel to the steps of the EPRI guideline. The way of doing exchanges is small modular parts and not all at once would be applicable to the Scandinavian plants also.

Products with a smaller market will have more obsolescence problems than those implemented on many utilities. To avoid end-of-life and obsolescence, the vendors need a certain amount of customers. This should be kept in mind when procuring equipment.

When maintaining analogue systems or components, the U.S actors are using some for the Scandinavian plants new ways. The use of nationwide or international databases for spare part inventory is most interesting, so is the use of reverse engineering. The qualification and procurement aspects should be looked deeper into (with a Scandinavian perspective) before usage.

The last conclusion is that networking is important. The Scandinavian I&C and/or obsolescence engineers should interact more, to learn from each other. This is needed to obtain a critical mass of knowledge in a relatively small region.

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1 Background

1.1 INTRODUCTION

The Nordic nuclear fleet of today consists of a mix of technologies for safety I&C. A large portion of the equipment is still of conventional type but there are also new digital equipment, systems and platforms installed. In the coming years a considerable amount of systems and equipment must be replaced or upgraded because of different aspects of aging. The Scandinavian plants are in a short while entering Long Term Operation, which is operating longer than the original construction life time. This makes it important to have a clear understanding of the different alternatives of how to handle ageing in a Long Term Operation perspective. Replacing and upgrading is a challenge and the experience from recent years is unfortunately mixed.

In many cases the use of new digital equipment has introduced complexities in the functions, but also in documentation and in licensing issues. On the other hand; the operating experience, availability etc. are in most cases excellent after the digital systems have been commissioned.

There is also an issue regarding cost; new digital equipment has a reasonable price tag as long as only the products themselves are considered. However, when adding on the engineering hours required implementing the system in the nuclear power plant with verified safety, the cost has in many projects escalated far beyond budget.

Hence, there is a need for research around these issues to achieve both safety and reasonable life cycle cost. The issue is obvious for equipment installed decades ago, but it is of course also important for new equipment where there are choices to be made that influence the future safety and cost.

Aging of I&C equipment and systems is not just isolated to the hardware and supply of spare parts. It is just as much a question of knowledge and documentation, both at the plant and from the supplier's side.

Knowledge of the various options is very important when it comes to deciding strategies for I&C systems in the power plants.

A renovation and/or upgrade program can be an alternative to replacement. Internationally this is a trend and several operators and suppliers have initiated strategic programs for this. Such programs have been developed at least in Germany, France and in the US.

Through a previous mapping project, [7], the upgrade programs provided by Westinghouse and General Electric were identified as interesting. Energiforsk therefore decided to investigate these programs further. In addition, a few U.S. utilities and EPRI was to be studied in the context of renovation/upgrade strategies. Another subject was to look for new ways for the Swedish and Finnish plants to solve the issue with obsolete I&C equipment.

Also, within ENSRIC a U.S. conference in the beginning of 2015 regarding obsolescence has been attended and reported, [23]. One conclusion from the report is: “While the technology is developing rapidly forward in the digital world, it seems that more and more plants and units wants to do so "small" changes as possible, and this has given a big market for remanufacturing of obsolete equipment and even a second-hand market.

To some extent this trend is being driven by the difficulty and high cost of licensing of digital I&C and HMI primarily those in the United States."

To go further with the investigation, a trip was conducted which included meetings and discussions with the two identified Original Equipment Manufacturers (OEM:s), another vendor offering services to the American utilities and one nuclear power plant. It was not possible to meet with EPRI, instead EPRI material like guidelines has been studied. The knowledge and experience gained from the trip is compared to the experience from the two earlier ENSRIC works mentioned above, and collected in this report.

A general summary of the experiences from the US trip is that nuclear I&C has similar challenges in the USA as in Europe. The utilities and vendors have to struggle in a more challenging business environment than previously: a surplus of fracking gas generates low electric prices, which turns into requirements to cut costs in all areas. When renewable energy is getting subsidiaries at the same time, the nuclear production is meeting more and more challenges. Also, the incident in Fukushima put stress on the nuclear power companies, even though not so much in the I&C area.

Another fact is that the fleet of US nuclear power plants is coming older. The I&C technology they are using is getting obsolete and they are endangering the power plant life time. This causes a need to either to renew I&C systems and components or to find other ways to extend the existing systems and components life times.

In the US, the authority has been very strict to allow use of new digital software technology in nuclear power plants. There have been many cases where power companies and vendors were required to make additional clarifications.

Both authority requirements and more tight economic environment in nuclear business have forced vendors and power companies to revise the ideas and strategies how I&C life time will be managed.

1.2 ABOUT ENERGIFORSK AND THE ENSRIC PROGRAM

Energiforsk AB (Swedish Energy Research Centre) is a research and competence company, see [8]. Since 1st of January 2015 it consists of the research activities in Elforsk, Fjärrsyn, Värmeforsk and Svenskt Gastekniskt Center AB. Energiforsk has nine areas:

- Nuclear Power
- Hydro Power
- Energy systems and market
- Forest industrial energy
- Energy gas and liquid fuels
- Fuel based electricity and heat production
- District heating and district cooling
- Energy consumption including transports
- Power grid, wind power and solar power

Within the Nuclear department, there are four programs:

- Elforsk Nuclear Safety Related Instrumentation and Control, ENSRIC
- Vibrations
- Strategic monitoring
- Civil constructions

ENSRIC is a research program focused on safety related I&C systems, processes and methods in the nuclear industry. The three focus areas of the program are emerging systems, life time extension and I&C overall. Information from the program will assist the nuclear industry and the Radiation Safety Authority when analysing how to replace systems and methods - choosing a new technology or finding a way to stay with the present solution - with maintained safety and promoting a low life cycle cost. Participation of a mix of junior and senior participants in the program is encouraged to facilitate knowledge transfer.

The vision of the nuclear I&C research within Energiforsk is that the activities should contribute to safe and robust I&C systems that promotes low Life Cycle Cost. The results will be used in the decision making process when choosing the technology pathway forward and also to make the implementation and maintenance process of safety I&C more efficient. The information obtained can be used in the decision making whether to renovate the existing technology in a component/system or to convert to a new technology. The program should also constitute an arena for discussion on nuclear I&C issues for plant owners, authorities, vendors and researchers.

The main focus of the program is on safety classed I&C systems, both digital and conventional analogue and relay based systems. Activities carried out can be on maintaining present systems and on replacing present systems with new equipment. Competence building activities are also included in the program. Many of those who work with I&C issues in the nuclear industry are to be retired within a few years, so there is a need for skills transfer. Because of this the research program will promote, on all levels, a mix of senior and more junior participants.

The activities are financed by Swedish and Finnish nuclear power plant owners and the Swedish Radiation Safety Authority. A steering group consisting of representatives from the financiers has been appointed, and they are responsible for the individual project decisions and follow up. Additional expert groups, for example reference groups, are appointed when needed.

Activities and projects initiated can result in reports, guides, seminars, knowledge databases, and mapping of ongoing research, depending on the need.

The project of gaining experience from the U.S and this report are part of the focus area “Life Time Extension of Present Systems”.

1.3 SCOPE

The scope of this project is to obtain a deeper understanding of some OEM:s programs for renovation/upgrade, the strategies of a few U.S. utilities and EPRI activities within the area. The result shall be used to deepen the knowledge about the alternative “Life time extension”, it shall bring knowledge in not just technology but also within licensing, implementation and commercial arrangement around these programs.

The project shall obtain understanding of how effects of aging can be handled to promote a long cost effective lifetime with maintained safety. The results can be used when assessing if a system can be renovated using existing technologies in a safe and cost effective way.

In the end this knowledge will be used by the Scandinavian utilities to assess if this is a viable method for handling aging of the existing I&C systems.

The project should:

- Screen available methods for prolonging the lifetime of existing systems.
- Investigate the potential to fulfil safety requirements.
- Map the potential use in Nordic nuclear power stations.
- Look into the potential to obtain a cost effective lifecycle.

The aging of I&C related polymers (cables etc.) is not included in this research program, since there are a number of activities ongoing in this area in other forums.

2 Abbreviations and acronyms

CPLD	Complex Programmable Logic Device
ENSRIC	Elforsk Nuclear Safety Related Instrumentation and Control
EPRI	Electric Power Research Institute
FPGA	Field-Programmable Gate Array
FSAR	Final Safety Analysis Report
IAEA	International Atomic Energy Agency
INPO	institute of Nuclear Power Operations
IP	Intellectual Properties
ISG	Interim Staff Guidance (by NRC)
LAR	License Amendment Request
LCM	Life Cycle Management
LTR	Licensed Topical Report
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NUOG	Nuclear Utility Obsolescence Group
NUPIC	Nuclear Procurement Issues Committee
OEM	Original Equipment Manufacturer
OIRD	Obsolete Item Research Database
PIM	Pooled Inventory Management
POMS	Proactive Obsolescence Management System
PSR	Periodic Safety Review
PWROG	Pressurized Water Reactor Owners' Group
RAI	Request for Additional Information
RAPID	Readily Accessible Pars Information Directory
RG	Regulatory Guide (by NRC)
SER	Safety Evaluation Report
SSC	Structure, System or Component
SSM	Swedish radiation safety authority
STUK	Finnish radiation safety authority
V&V	Verification and Validation

3 USA-trip

A team of four went to the USA in April 2015. The participants were represents from Vattenfall (Project and Services), Ringhals nuclear power plant, Forsmark nuclear power plant and Fortum (Nuclear Engineering and Co-owned Nuclear). The companies visited were two OEM:s (Westinghouse Electric Company - Nuclear Services, and General Electric Hitachi – Nuclear Energy), one vendor doing reversed engineering (Argo Turboserve Corporation (ATC) - Nuclear) and one nuclear power plant (Hope Creek).

- Westinghouse Electric Company, Pittsburgh, PA.
- ATC, New Jersey, NJ.
- Hope Creek NPP, Salem, NJ.
- General Electric Hitachi, Wilmington, NC.

The trip took place during one week in the second half of April, 2015.

4 Licensing

In the US, the licensing procedure is different to the Swedish and Finnish. The processes for Life Time Extension and Plant Development are shortly described below.

4.1 LIFE TIME EXTENSION

The American utilities have time limited licenses from the American authority (NRC), typically valid for 40 years. After that, the nuclear power plant must have a renewed time limited license, typically valid for 20 more years. The renewal license might be issued up to ten years before entering 40+. Some plants are looking into the possibility to run up 80 years after construction, but they are still in an early stage of the plans. The regulation the American utilities have to conform to regarding licensing is 10 CFR 52 Licenses, Certifications, and Approval for Nuclear Power Plants. (10 = Energy, CFR Code of Federal Regulations)

The Swedish utilities have licenses that are not time limited. Instead the Swedish authority (SSM) relays on and evaluate periodic safety reviews (PSR:s) that the plants do every 10th year. The PSR covers the upcoming ten years. The review covering the passage of the original construction lifetime is of special interest and determines whether the plant is allowed to run in a Long Term Operation. If the authority's evaluation is that the plant should not run in Long Term Operation, it issues an injunction.

The Finnish utilities have time limited operation licenses from the Finnish authority (STUK). They are typically valid for 10 or 20 years. In addition, a similar periodic safety review as in Sweden has to be done after every 10 years of operation. This review shall be done no matter if the current operation license is valid for 10 or 20 years.

4.2 PLANT DEVELOPMENT

The Swedish plants are subject to both radiation regulations supervised by SSM and the Swedish environmental code supervised by the County Administrative Boards "Länsstyrelserna". The plants are supposed to follow the development in technical and scientific areas, as stated in the recommendations from SSM [9], and to show that they use the best possible (achievable and with reasonable costs) technology, as stated in the environmental code [10].

The Finnish plants follow similar principles for plant life time management as in Sweden.

The American plants are restricted to the license issued at the construction of the plant. To change technology, upgrade or do other plant, system or component changes that require a change in the Technical Specifications incorporated in the license, the license has to be amended. The amendment is usually limited to the system or components that are changed, but can expand if the reviewer at the authority thinks it is appropriate. The Technical Specifications corresponds to the "Säkerhetstekniska förutsättningar" (STF) in Sweden and "Turvallisuus tekniset käyttöehdot" (TTKE) in Finland. The renewal is steered by the regulations in 10 CFR 50 Domestic Licensing of Production & Utilization Facilities, especially Appendix B Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, and Part 50.59 Changes, Tests and Experiments [16]. The changes have to be approved by the authority before installation in the facility and verified after installation. The working load for an amendment is heavy, and hence the utilities try to avoid it as much as possible.

If the technological change does not require a change of the Technical Specifications it may not be necessary to renew or amend the license. This is stated in Part 50.59 of 10 CFR 50 [16]. The change also has to be <u>minimal</u> regarding

- frequency of occurrence or consequence of an accident which is previously evaluated in the Final Safety Analysis Report (FSAR)
- likelihood or consequence of malfunction of a structure, system or component (SSC) important to safety previously evaluated in the FSAR
- creating a possibility for a different type of accident then previously evaluated in the FSAR
- creating a possibility for a malfunction of a SSC important to safety with a different result then previously evaluated in the FSAR
- exceeding or altering the design basis limit for a fission product barrier
- departing from the methods of evaluation described in FSAR used in establishing design basis or in safety analyses

Changes done according to 10 CFR 50.59 are summarized each year and reported to the authority. They do not have to be approved before installation.

What is said above about plant development also goes for spare parts. If a spare part is used and the inventory has to be completed by finding a new one, there might be a lack of it on the market – it might have gone obsolete. This is quite common for old analogue components and circuit boards. The distinction between equivalence changes and changes needing approval is vital even in this case. Going from an analogue to a digital box may require an amendment of the license. Replacing a broken capacitor with a more modern one would be regarded as a 50.59-change.

4.3 NEW REQUIREMENTS

The incident in Fukushima Daiichi 2011 has not resulted in many changes regarding regulations for I&C equipment. However, supervision of the spent fuel pit is one such change.

When it comes to lead in circuit board, it is not an issue in the U.S. The nuclear power industry has a dispensation from the Restriction of Hazardous Substances Directive.

4.4 THE AMENDMENT PROCESS FOR DIGITAL SYSTEMS

When planning for an upgrade project, the Interim Staff Guidances (ISG:s) released by NRC gives a frame work. ISG -06, [5], deals with the licensing aspects of digital I&C system modifications in operating plants. The ISG is not intended to be as substitute for NRC regulations, but to clarify one way that a licensee may efficiently request NRC approval to install a digital I&C system.

ISG -06 states a four-phase review approach with the NRC:

- Phase 0: Pre-application (concept)
- Phase 1: Initial Application (plans and methods)
- Phase 2: Review and Audit (testing results and analysis)
- Phase 3: Implementation and Inspection (licensee implementation)

Depending on the novelty of the project or equipment, a graded approach is used. An exchange to equipment for which there is a previous Licensed Topical Report (LTR) is regarded as " Tier 1" and don't need as much deliverables as "Tier 2" or "Tier 3" exchanges. "Tier 2" is defined as an exchange to equipment with a previous LTR with minor modifications. "Tier 3" is the case when there is no previous LTR available.

Phase 0 Pre-application includes one or more meeting with no pre-conditions. Guidance is documented in meeting minutes. It should cover purpose, schedule of submittals, identification of phase 1 and 2 deliverables, Defense-in-Depth and Diversity, significant deviations from current guidance, determination of appropriate "Tier" and other complex topics (if any). This open dialogue with the regulator has been in practice for four years. The aim is to obtain more streamlined reviews, which also seem to be the result.

Phase 1 Initial Application contains specific deliverables like: system description, development processes (for both hardware and software), software architecture, Environmental Qualifications, Defense-in-depth and Diversity, Communications, Methodologies, compliance with IEEE-603 Criteria for Safety Systems [3] (endorsed by RG 1.153 [12]) and to IEEE 7-4.3.2 Criteria for Digital Computers in Safety System of Nuclear Power Generation Stations [4] (endorsed by RG 1.152 [11]), Technical Specifications and Secure Development Environment. Some of the mentioned information might not be available at the time for the initial application, but it is still possible to start the review process. For digital I&C projects there is a strengthened focus on processes, while regulations for electrical projects tend to be more technical specific.

Phase 2 Review and Audit is a continuation of the review in phase 1, but an as-build review, and includes specific deliverables like: qualification test plans and test results (electromagnetic and radio-frequency interferences, seismic etc.), V&V plan and results, software safety analysis and Factory Acceptance Test plan and results. Phase 2 has a 12 months minimum lead time, and results in a decision on approval.

Phase 3 Implementation and Inspection contains start-up testing in accordance with the plan submitted in phase 2, inspection by the regional authority staff, changes after approval in phase 2 (which must be 50.59 changes).

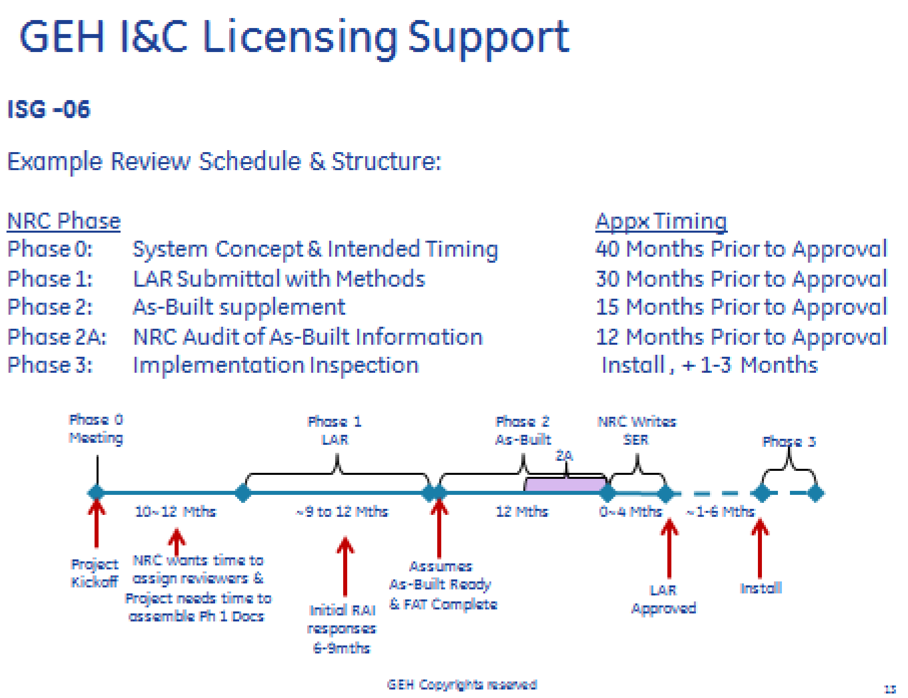

Figure 1 Time schedule for digital I&C project in the USA

The time scale for a system upgrade project with all phases is around four years, see Figure 1. This means the asset management has to plan digital I&C projects well ahead in time.

The OEM:s have typically aligned their processes with ISG -06. Documents are produced in the same time, with the same names, as in ISG -06. This streamlines the projects. For international projects, plants outside the U.S., the OEM has to compare the NRC-based process with local regulations.

4.5 10 CFR 50.59 OR AMENDMENT?

Vendor supplies the nuclear power plant with documentation, test results, maybe a construction license and so on to support the decision whether the change is according to 50.59 or not. But the vendor does not decide, that is up to the licensee – the utility. The authority can question the decision afterwards and issue an injunction for approval/amendment.

The first determination that has to be done is whether the equipment is safety or non-safety. Some equipment are not safety, but could make an impact on safety ones if they malfunction or fall down during an earthquake. The US class of "safety-related" per 10 CFR 50.2 [24] is:

> "Safety-related structures, systems and components means those structures, systems and components that are relied upon to remain functional during and following design basis events to assure:
>
> (1) The integrity of the reactor coolant pressure boundary

(2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or

(3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the applicable guideline exposures set forth in § 50.34(a)(1) or § 100.11 of this chapter, as applicable."

The IAEA glossary [6] defines safety items, non-safety items and safety-related items. Plant equipment is said to consist of:

1. Structure, system or component (SSC) important to safety
    a. Safety related SSC
    b. Safety Systems
        i. Protections System
        ii. Safety Actuation System
        iii. Safety System Support Features
2. SSC not important to safety

Items or SSC:s *important to safety* are defined as: "An item that is part of a safety group and/or whose malfunction or failure could lead to radiation exposure of the site personnel or members of the public." They include:

- Those structures, systems and components whose malfunction or failure could lead to undue radiation exposure of site personnel or members of the public;
- Those structures, systems and components that prevent anticipated operational occurrences from leading to accident conditions;
- Those features that are provided to mitigate the consequences of malfunction or failure of structures, systems and components.

Safety systems are defined as:" A system important to safety, provided to ensure the safe shutdown of the reactor or the residual heat removal from the core, or to limit the consequences of anticipated operational occurrences and design basis accidents."

Safety related items or SSC:s are defined as: "An item important to safety that is not part of a safety system."

For safety equipment, regulations are given in Regulatory Guides like RG 1.152 Criteria for Use of Computers in Safety System of Nuclear Power Plants [11] and RG 1.168 Verification, Validation, and Audits for Software Used in Safety Systems of Nuclear Power Plants [13]. They point to standards like IEEE Std 603 Criteria for Safety Systems [3] and IEEE Std 1012 System and Software Verification and Validation [14].

Licensee guidance on regulation application can be found by reading NUREG 0800 Standard Review Plan [15] and ISG -06 Licensing process Interim Staff Guidance [5].

One key to the decision is "*form, fit and function*". If the shape and size, the connections and the functionality are not altered, the change will be regarded as 50.59. The concept of form, fit & function permeate all of the instrumentation and control of the nuclear branch. Another key is to retain the technology; for example not go from analogue to digital. No new failure modes should be introduced and the functionality should not be disturbed.

There is definitely an assessment of what can be regarded as a 50.59-change based on its criteria. It might also differ between what the plant considers a 50.59 change and what NRC considers one. The authority will get a summary of all the 50.59:s during the year, and could state - post installation - that an exchange should not be allowed to be considered a 50.59. It could lead to injunctions, fines, enhanced inspections, decreased credibility, lower "regulatory margins", or in the worst case shut down.

There seems to be no additional specific guideline for digital technology on how to determine what is a 50.59 exchange and what is not.

5 Strategies

One OEM questioned their owner's group – plant system engineers and corporate engineers in the U.S and Europe – about maintaining or upgrading. For safety systems, the most respondents stated that the vital issue is to have a *stated strategy* regarding maintain versus upgrading.

It is clear that the total cost of a system or piece of equipment is not limited to the purchase sum. One also has to consider costs for:

- Licensing
- Safety analysis
- Design Change Packages
- Simulator
- Training
- Operation and Maintenance procedures
- Installation
- Commissioning
- Maintenance, spares and repairs

The need for strategies is apparent.

5.1 NUCLEAR POWER PLANT STRATEGIES

It is a timely process to reengineer and revers engineer, and perhaps to find a used part as well. Some newly manufactured parts have long lead times as well. If the part is vital to the plant, there should hence be a strategy set for that part *before* it breaks down.

An estimate mentioned several times by different sources during the trip is that 20-30% of all components in a nuclear plant are obsolete – not on the market anymore. That means that thousands of components are obsolete on a plant. Including the critical components that are not obsolete, the number rise even more. The work should hence be done in an orderly way, otherwise "the squeaky wheel gets the grease".

A life cycle management (LCM) for equipment comprises both ageing and/or maintenance management (useful life of current I&C system and its maintenance) and asset management (comprehensive long term program for modernization). Maintenance and asset management both influences each other, which is mirrored in the concept of life cycle management.

LCM develops a plan, consider implementation and thereafter monitor the equipment. The goal is to manage plant material condition, optimize operating life and maximize plant value while still maintaining safety. When used, it is said to provide early identification and reduction of risks and vulnerability to power production resulting from long term aging and degradation that may not be addressed in existing maintenance programs.

Software is developed by EPRI to support LCM and decisions for Long Term Operation, see references [1] and [2].

The steps in life cycle management and asset management, also viewed in Figure 2, are:

1. Critical I&C systems identification
    a. Important functions, critical (high/low)
        i. Effect on performance
        ii. Effect on efficiency
        iii. Stakeholders / personnel turnover
    b. Non-critical
    c. Run-to Maintenance
2. Prioritization, obsolescence and reliability risks
    a. System evaluation attributes
        i. System health, condition reports, actual and predicted failure rate, impact on power generation, NRC/INPO attention, regulatory impact, operation and maintenance costs, spares and availability, vendor support, …
        ii. Performance (plant, system, component, program)
3. Training of system caretakers
    a. Developing and keeping system knowledge and expertise
4. Recommended actions and priorities

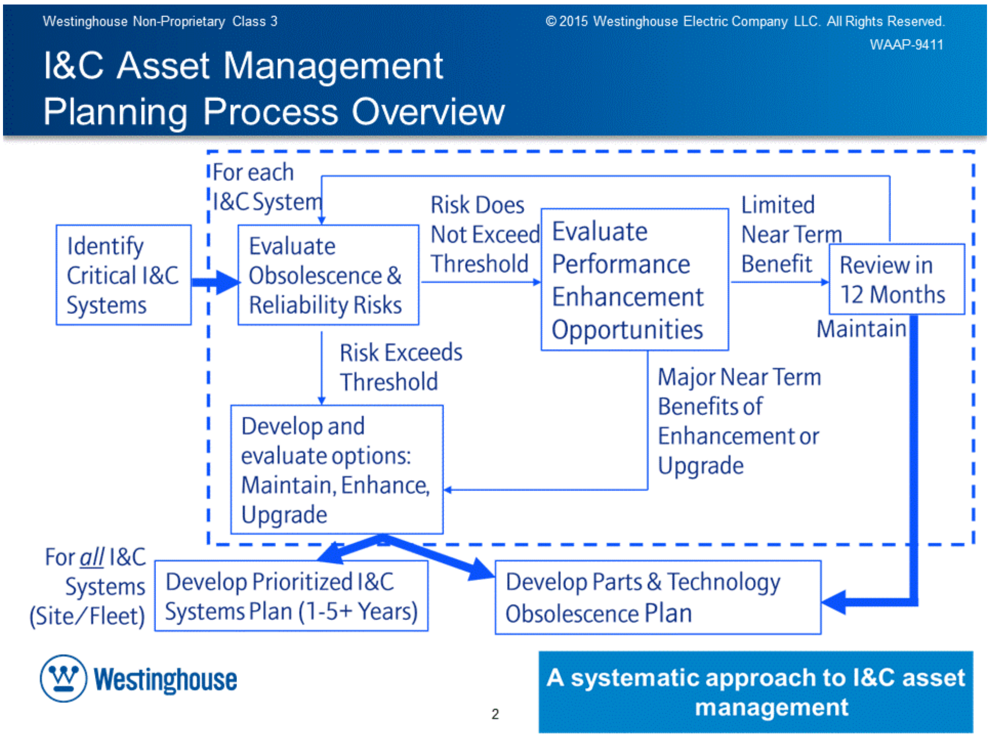

Figure 2 Asset (and Life Cycle) Management, as set out by Westinghouse.

If the LCM is performed for a common fleet, some advantages are:

- Enables multiple systems to share resources
- Minimizes personnel training requirements
- Minimizes spare parts inventory
- Phased approach minimizes rework for subsequent modifications
- Provides operational benefits via common user interface during all phases
- More cost efficient for long term plant operation

Life cycle management includes obsolescence as well as reliability and availability for the plant. Guidelines on obsolescence are more mature than those on life cycle management. EPRI:s strategy for obsolete equipment based on three tiers seen in Figure 3 and reference [17]. If the identification phase and prioritize phase are broaden a bit to include all critical issues instead of obsolescence issues only, the strategy can be used also for life cycle management. For further description of the obsolescence work, see chapter 6.2.

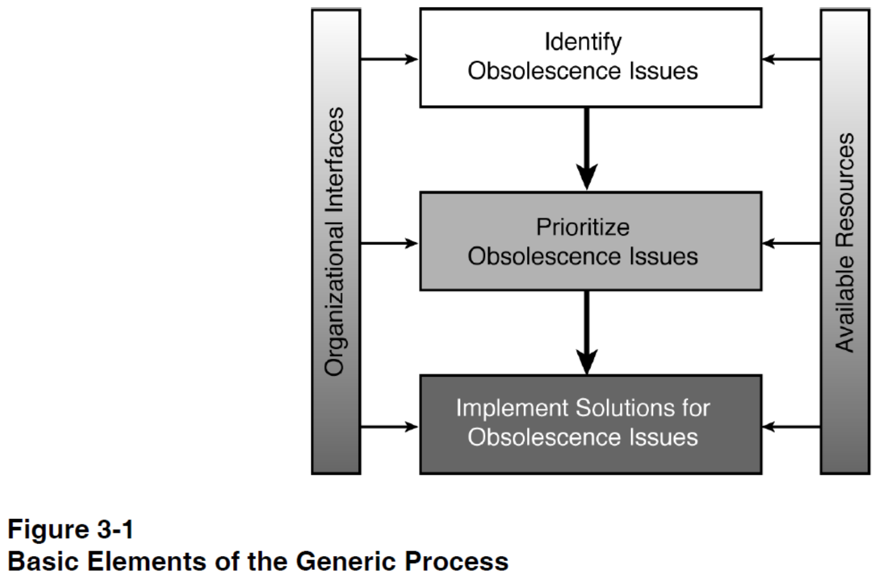

Figure 3 The basic strategy of Obsolescence Management. Picture from EPRI TR 1019161: Proactive Obsolescence Management [17].

With the broadened scope of identification, it will include to determine whether the solution of today fulfils the requirements. If it does not, the solution would probably be an exchange to a new product or upgraded system. Maintenance would not be enough. An exchange, redesign or upgrade means that an amendment of the license has to be done.

It the requirements are fulfilled, the identification has to determine whether an exchange or upgrade is advantageous of other reasons, like less wear on the equipment and hence increased availability of the plant.

If the requirements are fulfilled and there is no other reason for redesign or upgrade, maintenance is an option. The solutions available for maintenance, as outlined by both EPRI and the nuclear power plant and vendors visited, are:

1. Replace: Buy an identical new part from the OEM (if still manufactured) or locate existing "Like for Like" replacement products
2. Repair: exchange broken components with new identical ones.
3. Refurbish: revitalize the I&C equipment to extend its operational condition.
4. Re-manufacture: make a new run of manufacturing, with the OEM or with a third party.
5. Reengineering or Reverse engineering:
    - Identical replication.
    - Black box approach: retain identical function, dimensional and mounting arrangement but design new internals.
6. Redesign of components: if none of the solutions mentioned above is possible.

In above mentioned list, options are listed from top to down in order of cost and complexity. The concepts are further explained in chapter 6.

The life cycle management is much more straight forward if there is an underlying I&C architecture. Especially for digital systems, as it is not possible to test them for all situations. In larger projects, like newbuild of nuclear power plants and major system exchanges, it is seen as crucial to have architecture and to divide requirements formally in a V&V-manner.

When deciding on appropriate solution, an aspect to bear in mind is how unique you can accept to be. Products with a small market will lose their support by the OEM before those with a large market. Competence will also be harder to find. Another aspect to bear in mind is the expected life time of the vendor, the life cycle management of their products, and the expected end of life time of the product. And for sure it will always be more costly of you are unique.

5.2 ORIGINAL EQUIPMENT MANUFACTURER STRATEGIES

For the platforms where there is a large market, there is no obsolescence problem, the OEM representatives stated. They have no end of life, as the OEM sees it. The problem is with the platforms with the smaller number. To be able to support outdated parts and platforms, the OEM has to have personnel with the right competence. Here cooperation and deals could come handy. For a small and outdated platform one vendor has an agreement with the customers to keep competence within the company, for a fee. The newer platforms are designed with ageing and long term support in mind, with higher costs for support and license as a result.

In later years, the OEM:s have seen a shift towards maintaining I&C equipment instead of upgrading, driven by uncertainty in regulations and the economic situation. Also, for safety systems it is not possible of regulation reasons to reduce the number of employees and hence save money even if new technology would admit it. So the incentive to introduce new technology is low.

A few products have gone out of business and support because competitors have taken over. Usually there is not one specific strategy per component. One obsolete component might have several strategies, depending on the case.

Most of the vendors offer a I&C asset and life time management to the customers that don't have their own, which can include decision help for strategy choices, to develop a prioritized I&C system plan (1-5+ years). The basis for the life time management is that there shall be clear plan before starting to make decision about the renewals. The work is moderated by the vendor but actually done by the utility. This kind of strategy projects are more and more becoming partnership projects.

There are internal research and development projects with the OEM:s to determine which components or designs are more vulnerable to ageing and obsolescence. Another way is to go to the end users and look through the utilities reports after incidents. They are often lagging in time though. Taking part in organizations and owners' groups and cooperation with other companies, for instance on conferences, is another source. The letter one seems to be of highest importance, owners' groups are most useful.

If a supplier to the OEM goes out of market, the OEM sometimes buy the intellectual properties (IP) of the supplier. They can then either manufacture the component themselves or let another supplier do it. The OEM look for long time agreements with their vendors.

To summarize, the life cycle management of the products is in great focus with the OEM:s.

6 Components

6.1 INVENTORY OF SPARE PARTS

Some OEM have developed a frame work for spare parts handling for the utilities. Apart from engineering and support, they also offer storage and quick shipping of spare parts. This would save spare part facilities and build-up of value at the plant. The old or broken part is sent back to the OEM to find the apparent cause, refurbish and sell. Typically this is applied to assemblies, not single components. It requires an initial fee and a set amount of exchanges items each year. Another service could be an inventory management system for the OEM:s equipment in a plant, built on graphics. The user friendly interface displays obsolescence issues, gap between wanted and actual number of a specific spare part etc. As for today, no Environmental Qualification requirements are in the inventory management system.

A standard way of dealing with parts or platforms that will go obsolete is that the OEM communicates with their customers in forehand so they can buy a last lot and set aside in their inventory.

6.2 OBSOLESCENCE WORK AND TOOLS

Obsolete equipment is defined by INPO (Institute of Nuclear Power Operations) as: Items in plant service that are no longer manufactured or supported by the original manufacturer or that are otherwise difficult to procure and qualify.

There are a handful of guidelines for Obsolescence management issued from American organizations:

- INPO NX-1037- Obsolescence Program Guideline [18]
- EPRI TR 1015391 – Obsolescence Management, a Proactive approach [19]
- EPRI TR 1016692 – Obsolescence Management, Program Ownership and Development [20]
- EPRI TR 1019161 – EPRI Plant Engineering Support – Proactive Obsolescence Management, Program Implementation and Lessons Learned [17]

The following obsolescence strategy is suggested by EPRI and used at the nuclear power plant the team visited.

1. Identify
2. Prioritize
3. Implement solutions

At one of the OEM:s, an extra step has been added: training of personnel.

1. Identify
2. Prioritize
3. Training of system caretakers
4. Implement solutions

The training and other efforts made to retain competence are discussed in chapter 8 below.

6.2.1 Identify

The first step in obsolescence management is to identify which components are obsolete. As mentioned before, approximately ¼ of all components on a nuclear power plant are obsolete. With digital equipment, the development goes with a rapid pace. Within 1,5-2 years, components are off the market. It has happened that equipment is obsolete already at the time for installation.

At the plant visited, the obsolescence department continuously follow and investigate the state of the plant's components. The work is aided by commercial tools like RAPID (Readily Accessible Parts Information Directory) and POMS (Proactive Obsolescence Management System). These are databases with parts, part numbers, known obsolescence issues, different ways to solve the obsolescence and so forth. The databases are run by commercial companies, Scientech and Rolls Royce, respectively. The content is supplied by the utilities mainly. At certain times the vendors are asked to complement and/or correct the information about their items. The databases are used by all American nuclear power plants and some nuclear power plants in other countries as well. The value of the databases are dependent on that all users also contribute and upload information. The same parts may be in both databases, which sometimes means that the information upload has to be done twice.

RAPID has two parts, where OIRD (Obsolete Item Research Database) is handling obsolescence solutions. There are some 130-140 thousand obsolete items in the database, approximately 60 thousand solutions and 10-15 thousand equivalency evaluations.

The Proactive Obsolescence Management System (POMS) is a service designed to determine what installed equipment is no longer supported by the manufacturer. This is done by collecting equipment information from member utilities and contacting each manufacturer of installed equipment on a regular basis to determine if the model number is still supported. This information is made available to members through a web-based application.

The two databases work together to minimize double work. Information from the utilities can be added to RAPID, which then automatically uploads it to POMS.

Organizations dealing with obsolescence in the USA are for instance NUOG (Nuclear Utilities Obsolescence Group) with a focus on systems, reliability and reducing station risk, PWROG and owner's groups with the OEM:s.

6.2.2 Prioritize

With some thousands of obsolete components, it is not possible to find solutions for all at once. Therefore, the plant has to prioritize the work.

The obsolete components are given "points" in a program named Flock. Aspects like safety, fire, maintenance instruction, plant availability etc. all give points. A high score means obsolescence has a high consequence. The program is shared between the American utilities, and contains about 22000 items. It is connected to RAPID.

The obsolescence department looks deeper into the state of the top ten components from Flock. They investigate whether the component is in fact obsolete. There might be individuals out on E-bay, google, industrial grade ware houses etc. They also try to set a cost on the different solutions of the obsolescence (replace, refurbish, reengineer, or upgrade) for these components. The result is a Critical Spares Program.

The prioritizing process by EPRI is depicted in Figure 4.

6.2.3 Implement solutions

The solutions available for obsolete equipment, as outlined by both EPRI and the utility and vendors visited, are:

1. Replace: locate existing "Like for Like" replacement products
2. Repair: exchange broken components with new identical ones.
3. Refurbish: revitalize the I&C equipment to extend its operational condition.
4. Re-manufacture: make a new run of manufacturing, with the OEM or with a third party.
5. Reengineering or Reverse engineering:
    - Identical replication.
    - Black box approach: retain identical function, dimensional and mounting arrangement but design new internals.
6. Redesign of components: if none of the solutions mentioned above is possible.

For details, see below.

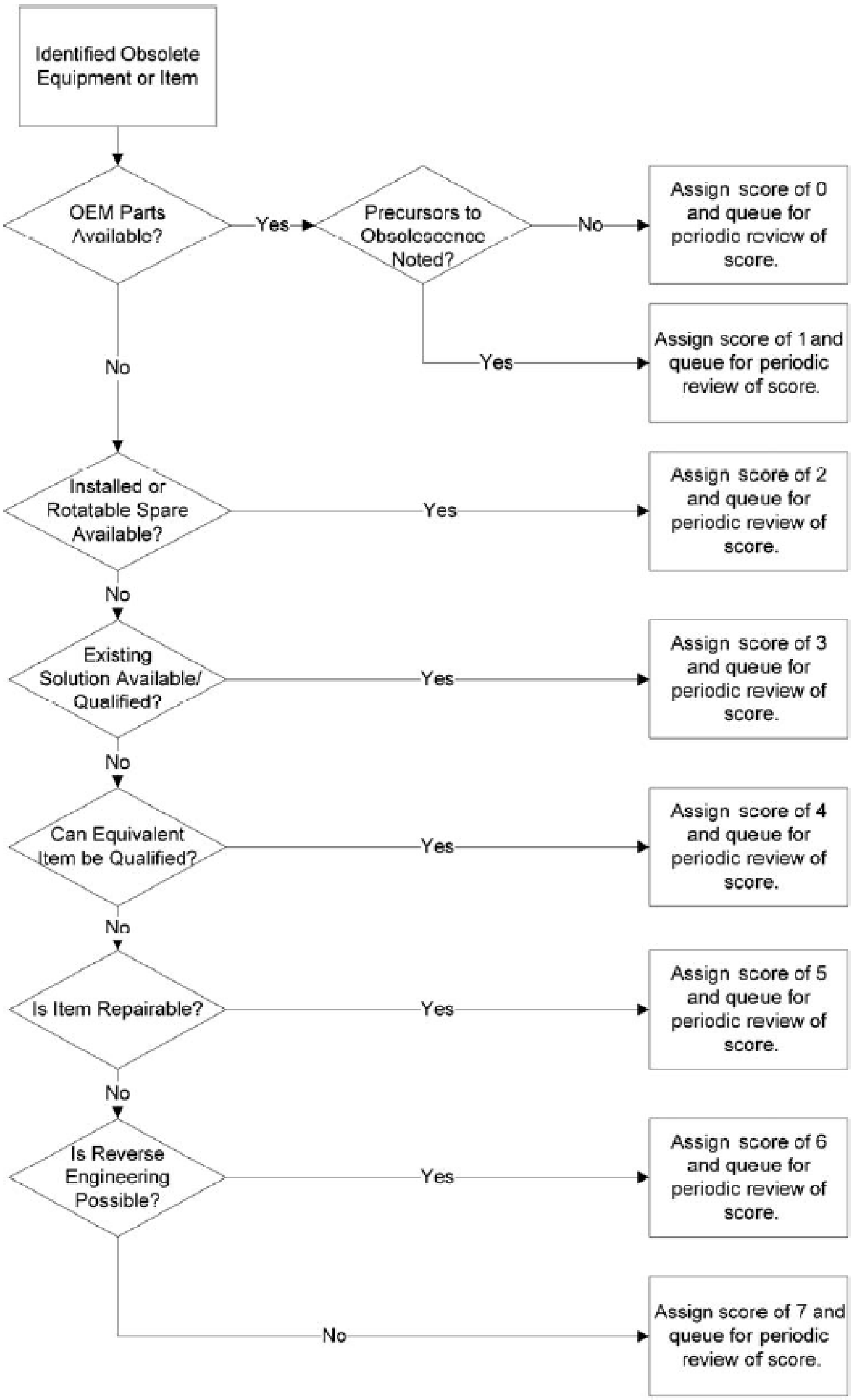

Figure 5-1
Prioritization Ranking Scheme

Figure 4 Scores for prioritizing obsolescence work. Figure from EPRI TR 1019161 Proactive Obsolescence Management [17].

6.3 REPLACE

Parts that are obsolete (not manufactured or supported by the OEM any more) might still be available in other places: warehouses at other vendors, spare part storage at other nuclear plants, plants that have shut down, fossil power plants, chemical process industries. Some parts can also be found in commercial industries or on open-markets like E-bay.

These parts may be used or un-used, nuclear grade or industrial grade. In either case, the receiver has the responsibility to before installation make sure that the part is fit for its function, that all documentation is there, and that the part is correctly qualified. Items procured may need to be refurbished, qualified, and/or dedicated if the original dedication package is not available.

The main tools for replacement are the databases RAPID mentioned above and PIM (Pooled Inventory Management). RAPID started around twenty years ago, and have approximately 8 million items in its virtual inventory for power plants. In 2013, there were 65 American nuclear power sites (102 plants) and 15 non-American nuclear power sites (34 plants) participating in the database. The other countries were Spain, Canada, Romania, Mexico, Brazil, Korea, Argentina and Slovenia. In addition, there were 526 fossil or hydro plants participating, mainly from the USA, but a few from Canada as well. Some 30 vendors also participated, including Westinghouse, General Electric and ATC. There is an annual fee to be part of RAPID. The database is run by Scientech.

The utility can use RAPID itself, or ask a third party to act as a broker. The broker can then assist in qualify non-safety equipment to safety, if needed.

The PIM program is a collaborative program to procure and store long lead-time and high-cost equipment that includes 23 owners of U.S nuclear generating units. The program is organized under the Pooled Equipment Inventory Company, which is a not-for-profit company and open to all U.S nuclear generating units. The database is currently run by the Southern Company. PIM members are obliged to replace any used part from the program within a predetermined time. PIM equipment is stored and maintained in a warehouse that meets the 10CFR50 app. B quality assurance program.

Some vendors have warehouses dedicated for old equipment. They buy outdated parts from utilities for a symbolic sum, stock it in their warehouse and when they find a buyer for the part the original owner gets a share of the money.

Some companies specialize in finding obsolete equipment on other markets. For example, old, since long obsolete, 386 computers needed as a maintenance client can be found using google or E-bay, and then transformed (refurbished, QA-verified, properly documented) to an appropriate condition. The utilities turn to these companies for assistance when an upgrade is unwanted.

6.4 REPAIR

Circuit boards can be repaired, exchanging the broken component with an identical one (same properties, same manufacturer). This can be done either by the OEM or, if the product is out of support, by another vendor. If the broken component has become obsolete, EPRI equivalence component has to be found before repairing.

To repair a card is regarded as a 50.59 action.

6.5 REFURBISH

If repairing is a reactive way to maintain, refurbishing is a somewhat more proactive. When a circuit board is refurbished, an as-found inspection and testing is performed. Components are evaluated with historical failure rates. Broken as well as age sensitive components are identified and exchanged. The circuit board is cleaned up and the container/box/front cover is exchanged if needed. Then the board is tested, calibrated, burned-in and qualified. An EPRI Equivalency is generated and qualification and dedication is done if necessary.

Refurbishment can mean various actions, from component replacement to repairing the whole part.

6.6 RE-MANUFACTURE

Parts that are not manufactured any more by the OEM can be remanufactured. A small special run can be done either by the OEM or by another vendor. The other vendor would purchase the right to support and manufacture the part and obtain documentation and manufacturing devices from the OEM. If some components of the part have become obsolete, EPRI equivalence components have to be found before manufacturing.

Small manufacturing runs are expansive, and hence it is valuable to do joint orders with other utilities. Keeping track of other customers is then important, by participating in owners' groups or branch organizations or direct contact between utilities.

Remanufacturing can be either end-user or vendor driven. It is regarded as a 50.59 action.

6.7 REENGINEERING AND REVERSED ENGINEERING

It is not a clear line between reengineering and reversed engineering. Both concepts are about to look into an old product, find the weaker spots in the design, redesign those and produce a new unit. The new unit will have the same inputs, outputs, failure modes, size, and the same type of technology (analogue, typically). Weaker spots might be power supplies, old and large capacitors, components that are placed to close together and develop too much heat for the cooling, bottom boards with cables instead of integrated circuits, connectors on secondary cards, drive lines based on chain mechanism, electronics placed in or on an equipment that is to be placed in high radiation surrounding, heavy weight, and so on. The new unit is mostly hand fabricated, due to small orders.

If there are original requirements and documentation for the product still obtainable, it is easier to make sure the new part has the same properties as the old one. Also, knowledge and competence with personnel that has designed or manufactured the old product is an advantage. When this is the case, the modification of the product is called reengineering.

If there are no requirement specifications or other documentations available, the product has to be taken apart to understand its function. From looking at the product, conclusions are drawn on the functionality. The modification is therefore called reversed engineering.

In between these two, there is a spectrum of cases. Some information might be available, but not all. The original requirement specification might be existing but incomplete. Schematics might or might not be available. The original paper work can be in order but no personnel with experience of the old product is still employed.

For simplicity, the process of redesigning a product in this way is called reversed engineering for the rest of this report.

The history of reversed engineering started in the military development, to reduce costs. In the nuclear branch, the reason to use reversed engineering is to reduce costs, and to find a solution to obsolete equipment. It is most suitable for products with a low technological complexity. It is said to be hard to do reversed engineering for digital equipment (CPU:s, OS-systems etc.). Examples on reverse engineered items that were shown are different kind of circuit boards, Traversing In-core Probe (TIP) drive mechanism (including exchanging the chain drive line), High Pressure Coolant Injection (HPCI) Motor Controller, Turbine Speed controller. Reversed engineering is preferable if there is a history of failures for the item – redundancy can then be added – or if there are many identical items on the plant, since the initial cost for reverse engineering is quite high. It seemed like reversed engineering is used mainly for non-safety equipment and not for safety systems. Some vendors do reversed engineering on safety related equipment as well.

If someone else than the OEM is to do the reversed engineering, one has to consider patent rights, copyrights and intellectual properties (IP). The product would have to be out of manufacturing and support with the OEM, otherwise another vendor would not do reversed engineering for it. Even OEM:s might have to consider these aspects, if any of their suppliers of components are out of business or their production line is down. There are one or two handfuls of non-OEM vendors doing reversed engineering in the USA.

NUPIC and NRC do audits on reversed engineering vendors.

EPRI has issued a guideline on the subject:

- EPRI TR 107372 Guideline for Reverse Engineering at Nuclear Power Plants [21].

NRC has issued a notice on the subject:

- Notice 2014-11 Recent Issues Related to the qualification of safety related components [22].

To do reversed engineering, one specimen of the product is needed. It will be used for measure distances, verify schematics, identify potential "problem children" (hot spots, scratch marks, go through historical failure data etc.). Apparently, it is not uncommon that the schematics do not image the card or product properly. Also, as much documentation as possible should be handed over: requirements, inputs and outputs, schematics, data sheets of components. From there, a prototype is prepared.

There are two ways of approaching the task of redesigning; either design a product that is almost a replica of the old one, see Figure 5, or look at the product as a black box and from the known inputs and outputs come up with a fresh design.

When the prototype is produced, equivalence by EPRI is established saying that the products are functionally the same and the modification can be regarded as a 50.59 change. Tests are performed with seismic, thermal ageing, radiation, EMC, vibration and so on. A third party may be involved to make sure the equivalency is correct. If the product is used in safety systems, the formal requirements of this verification are harder, i.e. an independent verification & validation department. However, equivalence evaluation might not be necessary if the replica-approach is used.

Even with the equivalence evaluation, the responsibility for classifying the new unit as a 50.59 or not is with the end user, the plant. The reversed engineering company can support and produce the documentation needed, but the decision is always with the plant.

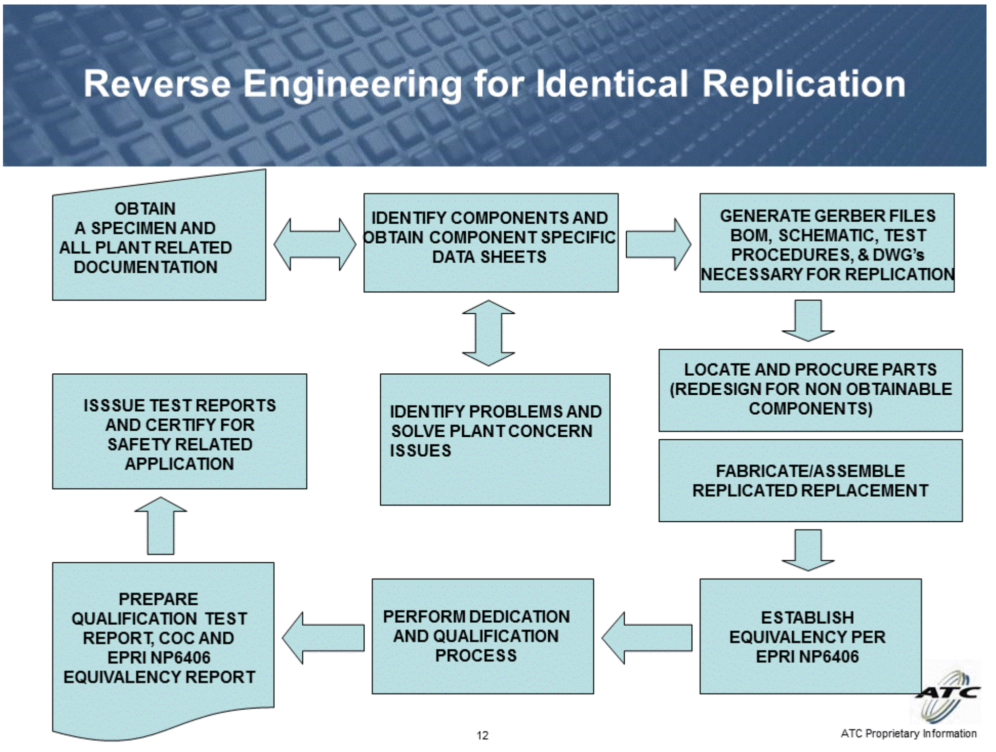

Figure 5 A description of work path using reverse engineering for replication.

6.8 REDESIGN / UPGRADE

With all the focus on maintain the old equipment and keeping the old technology, there are some circumstances that could make a redesign or upgrade interesting:

- If the old equipment doesn't fulfil the requirements. In the U.S., they don't foresee any such new requirements coming.
- If there are economic benefits with a new technology, like increasing availability for the plant with continuous supervision, or safety benefits like decreasing the risk for radioactive pollution (i.e. fuel damages).
- If it is impossible to maintain the equipment in the ways described above.

A technology change (analogue to digital) or software upgrade would need an amendment of the license and approval by the authority before installation. The new equipment may affect the original design of the plant, which has to be analyzed and approved by the authority.

A redesign can be carried out either by the OEM or by another vendor who then would need all documentation from the plant and the OEM and perform testing on the old equipment. Crucial to redesign is identifying all new failure modes and any differences in functionality.

Qualification and dedication will have to be performed. For digital upgrades, a complete software verification and validation has to be performed as well.

6.9 AGEING

The components most vulnerable to ageing were considered to be:

- Capacitors.
- Connectors
- Plastics
- Optical components

For I&C systems, a bathtub curve illustrates the amount of failures with age, see Figure 6. Significant failures begin after approximately 14 years. Most I&C systems are replaced within 20 years.

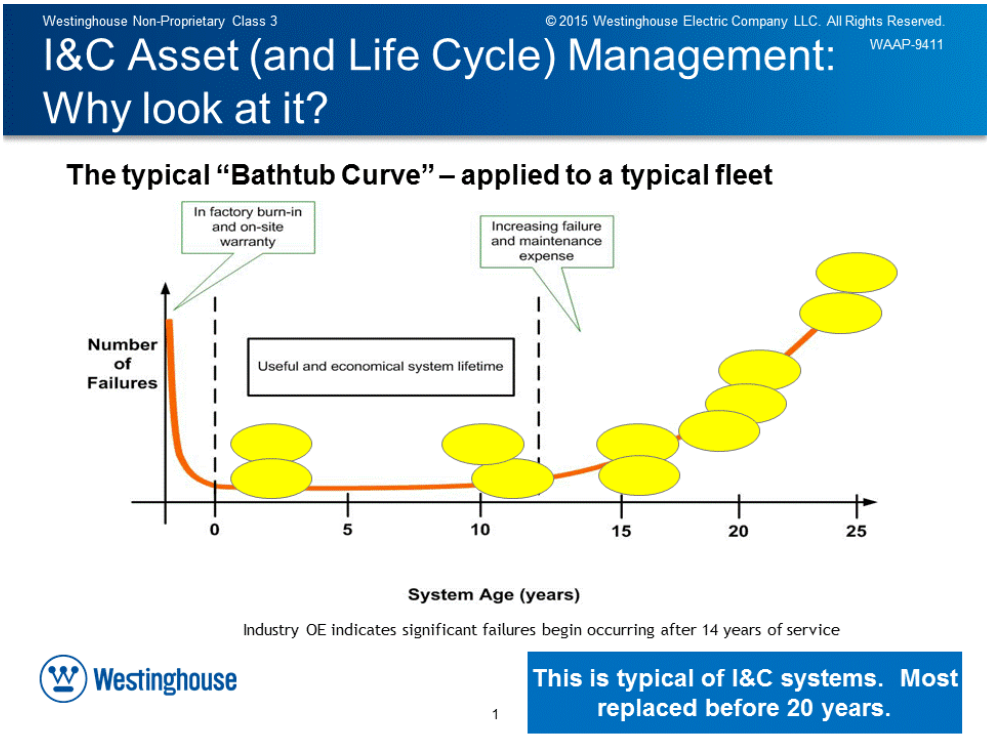

Figure 6 The bath tub curve, showing expected number of failures of an I&C system. Significant failures begin after 14 years.

The focus on decreasing the ageing phenomena by for instance reducing temperature or humidity seemed to be relatively low with the companies visited. More emphasis was on tracking ageing phenomena and vulnerable components, using failure data.

6.10 FPGA

FPGA (Field-programmable Gate Array) is a technology that is of lower complexity than software but higher than hardwired equipment. There has been problem with licensing FPGA in the USA. After a period of uncertainty, NRC now regards it as software. Apparently, the situation is the same in the U.K. This leads to a heavy burden of regulations regarding life cycle, construction, construction tools, testing, independence and so forth. Therefore, the plants and vendors are reluctant to use the technology. However, there seem to be no problems with the technology itself.

CPLD (complex programmable logic device) is another technology considered simpler than FPGA but is also considered as software by NRC.

There is some interest with the companies that were visited about FPGA in the Scandinavian countries.

6.11 COUNTERFEIT COMPONENTS

Counterfeit or fake products do exist: documents that look original but are copies; parts that are said to be "new" are actually used and refurbished; test results from tests that are not performed. It is a real risk for the utilities and vendors.

One way to minimize the risk is to rigorously inspect all discrete components; check the logos, part numbers, sign of usage etc. Another is to check the product's way from manufacturer to customer. All the whereabouts of the part should be traceable. A third way is to test the part according to specification and notice any unexpected behavior, like temperature changes or usage of a lot of current. A fourth way is to be precise when ordering and make sure to mention words like "new", "unused", "original" and similar.

7 Qualification

A question arose about extending the systems lifetime by repairing and refurbishing and how the authority reacts on that. Apparently, there has been a discussion with NRC about this and they see it as a good alternative to upgrading.

NRC has however issued a notice on the subject:

- Notice 2014-11 Recent Issues Related to the qualification of safety related components [22].

For reengineered of reverse engineered or redesigned products, the following actions are usually taken:

- All design documents are reviewed by a person who has not been involved in the work. Also, the quality assurance department will review all design documents,
- Qualification test procedures are prepared by the designer. The quality assurance will review these procedures.
- For every manufactured and tested component, there will be separate qualification results documentation released.

8 Competence

When a technology gets old, the students don't learn about it at school. The younger personnel that come to the utilities or vendors don't have the knowledge of, say, analogue equipment. The older personnel did learn about the old technology in school, and have worked with it and gained experience. But they are – naturally – getting older and will eventually retire.

For the nuclear power plants, this is even more enhanced by the fact that the majority of the personnel was employed when the plant was constructed and built. The demographic of those companies is in the contraction phase. For the vendors, the situation is more of "feed and bleed" and they are not as vulnerable to personnel retiring.

The OEM:s have developed formal programmes to deal with this problem. The programmes include different kinds of mentorship:

- A junior-senior partnership for replacing a critical person that will retire. The mentorship runs for approximately five years.
- A junior-senior partnership to secure competence for a specific product or technology. The mentorship runs for six to twelve months.

Mentorships are costly, but worth the investment, the representatives of the OEM:s said. Some mentorships can be funded by owners' groups or other organization. Some may have a "retainment fee" for the customers. For some platforms or products, the OEM retaining competence is part of the purchase agreement.

There were no formal mentorships at the nuclear power plant visited.

NCR requires that power companies shall have a plan or system to manage personal professional competence, but they do not state which kind of system. The power companies can define which kind of system should be used and what should be the basis for the competence management. At the nuclear power plant visited there was no common competence management system. Instead the different departments had different processes to track personnel skills.

In general, it can be said that at the American nuclear power plants, the personnel competence management is done based on the company's economic situation. The companies in general have not prepared and are not willing to pay for the long time competence management. This is somewhat surprising, taking the demographic for the plants in consideration.

Other actions taken by utilities or vendors are:

- Recruiting people with a special interest in analogue systems and equipment.
- Create an open atmosphere where needed information always is available. Archives with manuals and data sheets.
- Internal training programs.
- Job rotation. Maintenance engineers on operational shifts etc.
- Let younger engineers attend conferences and meetings, to listen and learn.
- Keep the employees for a long time, which might be improved by benefits or an attractive location.
- Old personnel are offered to stay and work on hourly basis after retirement

- Support co-operations like PWROG and other owners' groups.
- Taking active part in co-operations and committees. Gain knowledge, get information on what is coming, networking.
- Have a corporate view on competence. Specific competence might be shared between units within the same group, or between units belonging to the same organization.
- Equipment with a long time without failures are not worked with at the plants, and competence for that equipment is hence fading. Utilities' personnel can then take part in training programs and/or Factory Acceptance Tests with the vendors.
- Design new products with components from stabile markets – military market for example, and not cell phone market. Competence on that component will then last longer with the suppliers and new employees.

9 Summary and conclusions

9.1 SUMMARY

Analogue equipment does not necessarily have to be upgraded to digital for maintenance to be possible. In the USA, the licensing procedure and the economic situation has led to a thinking "analogue stays analogue, digital stays digital". They are reluctant to change technology and design. Instead, ways of maintaining the old analogue equipment has developed.

9.1.1 Strategies

Strategies have evolved for maintenance and asset management. The two processes have impact on each other, and a combined view is therefore advantageous. The strategy of Life Cycle Management is one way to handle both maintenance and asset development of a plant. EPRI have developed guidelines and supporting software for Life Cycle Management, and the OEM:s offer services for LCM to the utilities.

The strategy typically contains three or four phases:

1. Identify critical components
2. Prioritize amongst these critical components
3. (Train personnel on prioritized components)
4. Choose and implement a solution for prioritized components

If an upgrade for a system or plant division is necessary, the general view in the USA is to modulate the upgrade. It should be done in smaller parts, and the realization of one part should be independent of the others. The time for large, comprehensive projects is gone.

9.1.2 Maintenance of analogue equipment

Different ways of maintaining the old analogue equipment are possible.

The utilities are transferring equipment between them, using commercially run databases like RAPID (www.rapidsmart.com) and POMS (www.poms.com). The databases are countrywide, even plants outside the USA are taking part (Spain, Taiwan).

Parts are even bought from warehouses, surplus stores, E-bay etc. Industrial grade components then have to be qualified for nuclear grade. This is done either by the plant buying the part, or by a broker (third party) finding the part for the plant. Processes for qualification seem to be well developed in the U.S.

Regardless if the part is bought from a nuclear power plant or a commercial surplus store, requalification has to be done. There is an uncertainty about where the part has been, under which conditions it has been used and in what state it is. This is done by the plant receiving the equipment.

Products or circuit cards can be repaired by exchanging the faulty components only. They can also be revitalized by cleaning, exchanging components know to suffer from ageing etc., called refurbish. The products or cards are regarded as identical after these treatments. An equivalence evaluation is needed but no relicensing.

Some products have designs that lead to problems, like overheating close to a specific component on a circuit board. Such a product may be re-engineered or reversed engineered. The size, connections and functionality is retained – form, fit & function – but the inside of the part is redesigned. Within certain boundaries, like staying with the same kind of technology, this is regarded as an exchange that do not need relicensing. An equivalence evaluation is needed, though. Reversed engineering has been going on for approximately 20 years, NRC is well aware of its existence and is mainly supportive, and the companies doing reverse engineering have been audited by both NRC and NUPIC.

Utilities sometimes do a joint venture and ask an OEM or, if legally possible, another vendor to re-manufacture parts that are obsolete. Co-operation with other units is usually necessary to make it worthwhile economically.

As a last option, system redesign or upgrade of a product can be done. Relicensing is then required, a process that takes four years as a minimum.

9.1.3 FPGA

The technology of Field-Programmable Gate Array was 5-10 years ago believed to be a solution for exchanging analogue equipment to something newer. However, the NRC have looked into the subject and deemed 2010 that FPGA is more of software than hardware. To have a safe usage of FPGA, it has to confirm to the same requirements for construction, development tools and verification as software. The consequence is that plants and vendors chose not to use FPGA. If they have to do all the work associated with software projects, they might as well implement software – not FPGA - with all its advantages.

Complex Logic Programmable Devices are also considered as software by NRC. Twelve NPP:s installed CLPD, deeming it as a 50.59-exchange that do not need relicensing. But NRC thought differently, and a qualification of the product had to be done a posteriori.

9.1.4 Competence

The attitude towards networking and cooperation is generally more positive in the USA than in the Scandinavian countries. Competence in old technologies, platforms and products is retained by collaboration in branch organizations, customer/vendor-alliances, attending conferences and working together in committees.

NUOG, EPRI and INPO are important organizations in this aspect, the working committees of NRC as well. Owners' groups for specific OEM:s are significant for transferring knowledge and competence between end users and vendors.

Younger employees lack education in old technologies. To compensate for this, internal training courses are held, formal mentorship programs have developed and young engineers attend conferences on obsolescence or life time management.

9.2 CONCLUSIONS

When evaluating the experiences from the USA, one has to consider the situation for the nuclear power plants in the Scandinavian countries.

In the USA, there is a vast gap between 50.59-exchanges and exchanges that needs an amendment of the license. The 50.59-exchanges are exchanges with minimal impact on safety and safety analyses. They are not allowed to include a change of technology and usually not an upgrade of software. As a consequence, the U.S nuclear power plants try to stay with the same technology: "analogue stays analogue; digital stays digital".

The focus on staying with the same technology for the sake of licensing is not as high in Sweden and Finland. The Swedish plants are supposed to follow the development in technical and scientific areas, as stated in the recommendations from SSM, and to show that they use the best feasible (achievable and with reasonable costs) technology, as stated in the environmental law. The Finnish plants follow similar principles for plant life time management as in Sweden.

But the economic situation is the same in both the USA and Scandinavia. Fracking gas, low prices for electricity and government subsidization of renewable energy sources puts a high attention on economics. Alternatives to redesign and upgrade are hence attractive also in Scandinavia.

The meetings and discussions during the project team's trip to the USA revealed that there are indeed possible and economical ways to maintain analogue equipment. The conclusion of the ENSRIC report [7] was that it is an absolute necessity to migrate from analogue to digital solutions, but this project contravenes that. If there is a regulatory or economic incentive, redesign, upgrades or migration to digital solutions might be done. But it is not the only way to go. Old analogue system can in many cases be maintained and kept.

A strategy is needed for the Scandinavian plants as well; the work has to be proactive since the maintenance action might have long lead times and a typical plant has thousands of obsolete components. EPRI has guidelines on obsolescence management and life time management that can be used. It would be beneficial to add training of personnel to the steps of the EPRI guideline. The steps are then:

1. Identify
2. Prioritize
3. Training of system caretakers
4. Implement solutions

The experience gained during this trip may affect the strategies for I&C in a Long Term Operation perspective. Some of the strategies build up during the last 15 years have as a focus that the only available solution is changing platforms and that means new technology in the most cases. With our new knowledge supported with further analyses, the strategies probably have to be rewritten.

The way of doing exchanges is small modular parts and not all at once would be applicable to the Scandinavian plants also.

Products with a smaller market will have more obsolescence problems than those implemented on many utilities. To avoid end-of-life and obsolescence, the vendors need a certain amount of customers. This should be kept in mind when procuring equipment.

When maintaining analogue systems or components, the U.S actors are using some for the Scandinavian plants new ways. The use of nationwide or international databases for spare part inventory is most interesting, so is the use of reverse engineering. The qualification and procurement aspects should be looked deeper into (with a Scandinavian perspective) before usage.

When choosing a solution for a critical analogue system, the following should be considered:

1. Does the existing system or component fulfill today's requirement including Human System Interface? If not, redesign or upgrade is necessary.
2. Is it possible to maintain the current system or component? Replace, Refurbish, Re-manufacture, Reverse Engineer.
3. Don't introduce unique solutions. Observe others and don't be first.
4. Try to maintain the original function in the existing systems and implement new functions in separate systems.
5. If upgrade is needed try to maintain the boundaries as they are.
6. Stay with technical standard used at the utility and do not introduce a new platform.

Networking is important. The Scandinavian I&C and/or obsolescence engineers should interact more, to learn from each other. This is needed to obtain a critical mass of knowledge in a relatively small region. We could learn a lot from our American colleges in this respect.

9.3 RECOMMENDATIONS

The project has the following recommendations for future work in Energiforsk, at corporate level in the energy companies and at the utilities.

9.3.1 Energiforsk and/or corporate level

Look into reversed engineering, refurbishing and replacing. Legal issues, qualifications, procurement has to be evaluated before in could be used for the Scandinavian plants. It could probably be a good alternative to do a pilot case. Because of company confidentiality, a pilot case maybe should be done within a company group and not with Energiforsk.

Look into the use of databases for spare parts, like RAPID and PIM, and for obsolescence solutions, like OIRD/RAPID and POMS. Some plants have already shown interest in these databases and might investigate the possibility. It would probably be wise to take a branch perspective first, and this could be organized by Energiforsk. Perhaps it is more efficient to have smaller databases within one site (multiple plants) or within a corporate group (multiple sites) or nationwide (Swedish sites, Finnish sites). Perhaps the shared inventory should not be limited to the nuclear branch, but also include hydro power with old plants and equipment maintenance issues.

Look into FPGA, now knowing that NRC deems it as software. Is it a dead end in the Nordic countries because of that or do the different licensing processes make it feasible to use this new technology? A follow-up within Energiforsk seems beneficial.

Look into how to strengthen the cooperation with vendors and other actors. To keep the competence alive in a small market, cooperation is vital. Energiforsk could act as a moderator to initiate new branch forum or conferences on life cycle management or obsolescence.

Form a guideline for the Scandinavian actors on life cycle management and obsolescence, based on EPRI:s guidelines.

9.3.2 Nuclear Power Plants

Be proactive with maintenance, make a strategy and decide on solutions for the most critical components. This is very important, and should not be overseen.

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LIFE TIME EXTENSION OF PRESENT ANALOGUE I&C SYSTEMS

Is it possible to maintain old analogue instrumentation and control equipment? Yes, there are several ways! This report reveals how maintenance is done in the U.S. and what the Scandinavian nuclear power industry can learn from that.