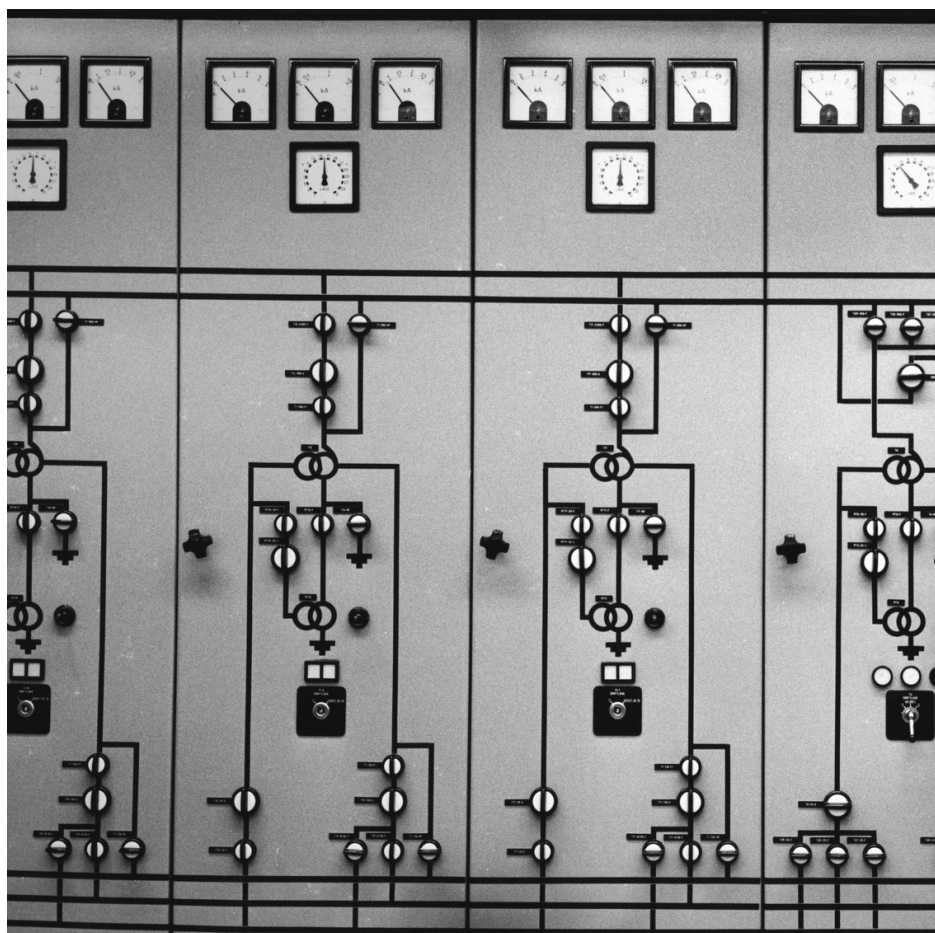


REPLACING OBSOLETE NUCLEAR INSTRUMENTATION AND CONTROL EQUIPMENT

REPORT 2016:307



ENERGIFORSK NUCLEAR SAFETY
RELATED I&C, ENSRIC



Replacing obsolete nuclear instrumentation and control equipment

European reengineering and reverse engineering
experience

ANNIKA LEONARD AND ANNA-KARIN SUNDQUIST

ISBN 978-91-7673-307-3 | © 2016 ENERGIFORSK | Cover picture: Vattenfall

Energiforsk AB | Phone: 08-677 25 30 | E-mail: kontakt@energiforsk.se | www.energiforsk.se

Foreword

There is a considerable amount of instrumentation and control (I&C) systems in the Nordic nuclear power plants that are in the process of being renewed due to different kinds of aging. In some cases, the renewal process is complex due to obsolescent systems or component. Different strategies can be used to solve the problem, and this study was initiated to learn more about the feasibility of these strategies in a Nordic context.

The project was carried out by Annika Leonard and Anna-Karin Sundquist from Vattenfall within the Energiforsk Nuclear Safety Related I&C , ENSRIC program.

ENSRIC is focused on safety related I&C systems, processes and methods in the nuclear industry. Results from the program will assist the nuclear industry and the radiation safety authorities when analyzing 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, Uniper, Fortum, TVO, Swedish Radiation Safety Authority, Skellefteå Kraft and Karlstad Energi.

Sammanfattning

Den säkerhetsrelaterade styr- och kontrollutrustningen i de nordiska kärnkraftverken består av en mix av tekniker och system. Större delen är fortfarande av konventionell analog 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 tidigare projekt inom Energiforsk klargjorde att användning av s.k. återkonstruktion (reengineering) eller omvänd konstruktion (reverse engineering) var mer utbredd än tidigare insetts. Därför skapades detta projekt för att reda ut vad begreppen innebär och vem som kan göra sådana komponenter.

Underhåll av analoga komponenter

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

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 kan krävas en anmälan till strålsäkerhetsmyndigheten, men oftast ingen rekvalificering.

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.

Kärnkraftverken går ibland samman och avtalar med en OEM (Original Equipment Manufacturer) eller, om det är avtalsmässigt möjligt, en annan tillverkare om att återtillverka av delar som blivit obsoleta. Samarbete med andra kärnkraftverk är vanligtvis nödvändigt för att kunna genomföra detta på ett kostnadseffektivt sätt.

Som ett sista alternativ kan man göra en nykonstruktion eller uppgradering av produkten. Godkännande av strålsäkerhetsmyndigheten är då nödvändigt, vilket kan vara en lång process.

Vilken variant av underhåll man väljer avgörs av många olika aspekter. Tekniska möjligheter, kvalitet, avtalsmässiga begränsningar, garantier och support i framtiden, och tillgången till kompetens spelar alla in.

Legala aspekter på vem som äger rättigheterna avgör om återkonstruktion är möjlig, men troligtvis inte för huruvida det är möjligt att utnyttja omvänd konstruktion. Detta måste analyseras från fall till fall. Patent och mönsterskydd är normalt sett inte ett problem för denna sorts produkter.

Slutsatser och rekommendationer

- Vår utredning visar att återkonstruktion och omvänd konstruktion är möjliga alternativ samt att det finns flertalet leverantörer av dessa tjänster. Det är dock

viktigt att komma ihåg att detta inte alltid är det bästa alternativet! Det är vår uppfattning att man bör utvärdera denna strategi tillsammans med andra alternativ när man utreder vad man bör göra med ett obsolet system.

- Vikten av korrekt dokumentation kan inte underskattas. Hur mycket arbete som måste läggas ner i ett projekt börjar och slutar med vad man vet om systemet i projektets början. Därför är det också likaledes viktigt att vid ett projekts slut se till att lämna bra dokumentation efter sig för framtida projekt.
- Läs och utvärdera originalavtalen noggrant.

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.

Maintenance of analogue equipment

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

Products or circuit cards can be repaired by exchanging the faulty components only. They can also be revitalized by cleaning, exchanging components known to suffer from ageing etc., called refurbish.

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.

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. Approval by the radiation authority is then required, a process that could be long.

The summary of this investigation is that reengineering and reverse engineering are used on a regular basis in Europe. Some utilities have used it for decades, other are quite new in the field.

Usually there are no problems with the OEM. There is usually a mutual agreement that the OEM lets go of the product and related IP and that the third party vendor is free to use it and reengineer it. Usually there are no problems with the radiation safety authority either. As long as the reengineered or reverse engineered equipment is verified and qualified (if applicable) correctly, the European authorities don't seem to mind the concepts.

The complexity of the maintenance project increases a lot if there is no or little original documentation available. The techniques can be applied for both safety related and non-safety related components. The degree of demands – requirements, verification, qualification – increases substantially if it is a safety related system. But there don't seem to be any formal hindrances for doing reengineering or reverse engineering on safety related components.

Contractual aspects could restrict reengineering, but probably not reverse engineering. Whether it is possible to use re- or reverse engineering must be analysed on a case-by-case basis. Legal aspects (patents, copyright etc) are usually not a problem.

Conclusions and recommendations

- Our investigation shows that re-engineering and reverse engineering are available options and that there are available companies willing to perform the task. However, it is not clear that it is always the best option! Our strong recommendation is to evaluate this option together with other solutions when deciding what to do with an obsolete system/part.
- The importance of correct documentation could not be emphasized enough. How much effort that needs to be put into a project start and ends with what you know of your system in the beginning of the project. Therefore it is equally important that these project leaves correct and complete documentation.
- Look into the specific original contract with care.

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1 Background

1.1 INTRODUCTION

The Nordic nuclear fleet of today consists of a mix of technologies for I&C equipment. 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 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, [1], the obsolescence 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 strategies. Another subject was to look for new ways for the Swedish and Finnish plants to solve the issue with obsolete I&C equipment.

A general summary of the experiences from the US trip is that nuclear I&C has similar challenges in the USA as in Europe. In the US, the utility owners to much larger extent than in Scandinavia have been using reengineering and reverse engineering for obsolete parts or components. This arose the interest of Energiforsk and hence a project was created in order to investigate which possibilities there are for Scandinavian utilities to use these technologies too.

1.2 ABOUT ENERGIFORSK AND THE ENSRIC PROGRAM

Energiforsk AB (Swedish Energy Research Centre) is a research and competence company, see [2]. Since 1st of January 2015 it consists of the research activities in Elforsk, Fjärrsyn, Värmeforsk and Svenskt Gastekniskt Center AB. Energiforsk has four areas:

- Hydro Power and Nuclear Power
- Power grid, solar power and wind power
- Heating, cooling and cogeneration
- Transports and fuel

Within the Nuclear Power area, there are five programs:

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

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 authorities 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 of reengineering and reverse engineering from Europe, including this report, are part of the focus area “Life Time Extension of Present Systems”.

1.3 SCOPE

The objective is to retrieve experience from reengineering and reverse engineering both from a utility perspective and from companies that have commercial services and re- or reverse engineered products on the market. The information and experience retrieved shall be used to draw conclusions in the following areas:

- Could a potential risk be introduced in the plant if a re- or reverse engineered equipment is installed?
- How could a re- or reverse engineered equipment be verified to have the same functional performance as the original equipment?
- What kind of qualifications / license activities are necessary?
- What kind of legal or procurement issues need to be considered?

The study shall include the following tasks:

1. Identify companies and utilities that have experience from re- or reverse engineering.
2. Identify what kind of legal issues that has to be considered.
3. Identify how functional requirements are identified.
4. Identify how other requirements are identified.
5. Identify what kind of verification that has been used to show the fulfilment of identified requirements.
6. Identify any qualifications/license activities that have been performed.
7. Compile the information and draw conclusions.
8. Propose measures to be taken when re- or reverse engineered equipment is the alternative for obsolete equipment.
9. Propose actions for the next phase in this area.

2 Abbreviations and acronyms

ENSRIC	Elforsk Nuclear Safety Related Instrumentation and Control
EPRI	Electric Power Research Institute
IAEA	International Atomic Energy Agency
INPO	Institute of Nuclear Power Operations
IP	Intellectual Properties
KKB	Kernkraftwerk Brunsbüttel (NPP)
KKK	Kernkraftwerk Krümmel (NPP)
KTA	Kerntechnische Ausschuss, the German Nuclear Safety Standards Commission
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
OKG	Oskarshamnsverkets Kärnkraftgrupp (NPP)
PIM	Pooled Inventory Management
POMS	Proactive Obsolescence Management System
RAB	Ringhals AB (NPP)
RAPID	Readily Accessible Pars Information Directory
RG	Regulatory Guide (by NRC)
SSM	Swedish radiation safety authority
SQURTS	Seismic Qualification Reporting and Testing Standardization, EPRI program
STUK	Finnish radiation safety authority
VGB	German branch organization similar to EPRI

3 Alternatives of maintenance for analogue equipment

In this project it has become obvious that there is no universal definition for the terms used. Therefore definition of the terms used *in this report* are explained below. Seven R:s have been identified as ways of dealing with obsolete equipment: Replace, Repair, Refurbish, Re-manufacture, Re-engineering, Reversed engineering and Redesign.

It is not always a clear line between the different methods, it is matter of subjective decision. Things to consider are: what are changed? How many parts? How vital are they to the function? Is there a change of technology?

The most important thing, however, is to be clear upon the definition with the one you talk to!

3.1 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, or 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, PIM (Pooled Inventory Management) as well as POMS (Proactive Obsolescence Management System).

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, a part of Curtiss-Wright. 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.

POMS is run by Rolls-Royce and is a database and search engine that connects to the members maintenance databases and thereby have the knowledge of the members amounts of spare parts. Thru POMS the members could also buy products found in the database. 130 nuclear units are members.

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

There are also a user groups like Nuclear Utility Obsolescence Group, NUOG and the newly founded European Nuclear Utility Obsolescence Group, E-NUOG, where members could meet and exchange experiences and information about obsolescent components and systems.

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.

3.2 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 or by the utility itself.

In the US the component has to be exchanged with something called an EPRI equivalence. That is an in advance decided list, done by EPRI, with components that are to be considered equivalent. This system is not generally valid in Europe, but could serve as an inspiration for suitable equivalent components. There is no unified European, or even Nordic way of dealing with these kinds of exchanges.

If the broken component has become obsolete, EPRI equivalence component could be used when repairing. Repairing is a reactive action, doing something to fix an existing problem.

3.3 REFURBISH

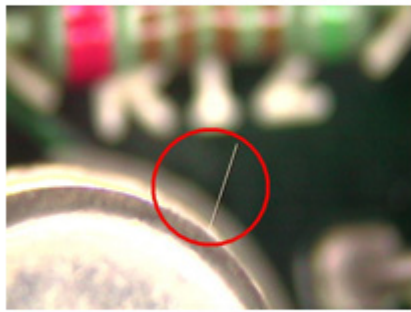
If repairing is a reactive way to maintain, refurbishing is a more proactive way. When a circuit board is refurbished, an as-found inspection and testing is performed. Components are evaluated with historical failure rates. Broken as well as age sensitive components are identified and exchanged. The 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.

One example of the line between refurbish and repair: when removing whisker, removing one would be considered refurbish since it is for precaution, removing a lot of whiskers would be considered repair since then a problem is solved. See Figure 1.

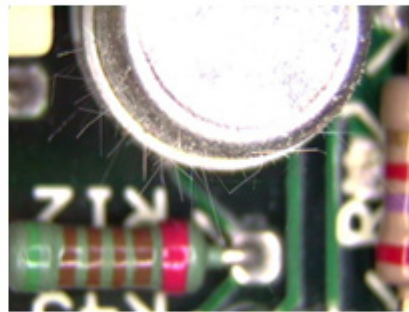
Whisker – Shapes of growth

Low contamination



→ Removal of whisker

Heavy contamination



→ Exchange the component

16 000-1000000000 00000000



Figure 1 Removal of one whisker = refurbish. Removal of many whiskers = repair.

3.4 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, an equivalent component has to be found before manufacturing, see EPRI equivalence above.

Small manufacturing runs are expensive, 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.

There seems to be large demand on re-manufacturing of the obsolete equipment from different NPPs. This includes ABB Combi-X products utilized at Swedish NPPs or Eagle products utilized in the Czech Republic or the United Kingdom, for instance. A rumor says that in the USA even one of the new builds demanded Eagle system due to fact that the rest of the fleet of the same owner already has an Eagle system.

3.5 RE-ENGINEERING

Re-engineering is when a third party manufacturer or OEM uses original requirements, specifications and documentations to produce new items. Some modifications might be done, typically within physical construction and/or mounting. The logical functions and layout of interconnections between discrete components are usually kept.

One example of the line between refurbish/repair and reengineering: if you change one component on a card it is either “refurbishment” (if you do it proactively) or “repair” (if you do it reactively after it is broken) and regarded as a 1:1-exchange, that is – not a change. If you would change all of the components on a card, which is usually not recommended, it would probably be seen upon as “reengineering” and a change. If you change the printed board, it is “reengineering” and regarded as a change – not a 1:1-exchange.



Figure 2 Reengineered Foxboro H-line module

3.6 REVERSED ENGINEERING

Reverse engineering is when a third party manufacturer or OEM takes an item apart to understand its functions. No or only some original requirements, specifications and documentations are available. Modifications might be done. If they are smaller and only within physical construction and/or mounting, the activity is called a replica reverse engineering. If the logical functions and layout of interconnections between discrete components are modified, or larger modifications are made within the physical construction and/or mounting, the activity is called a black-box reverse engineering.

For both replica and black-box reverse engineering, the functionality, size and outer connections are the same as for the old item.

One example on the line between replica and black box: changing a box with a closed floor to separated cards which allows an air flow is a replica reverse engineering.

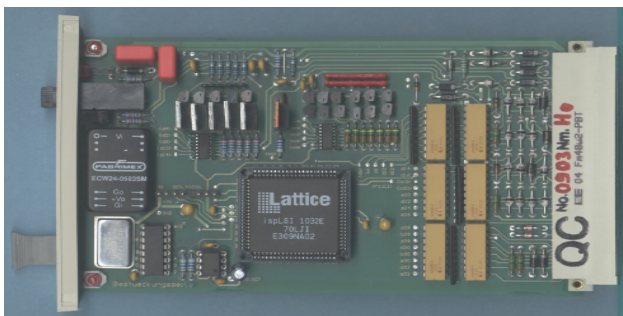


Figure 3 Reverse engineered Iskamatik B card

3.7 REDESIGN

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.
- 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 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.

3.8 SAFETY/NON-SAFETY

In this report there are numerous mentions of the terms "safety" and "non-safety". The reasons for not being more specific - Cat A/B/C, 1E/2E, "safety related system according to IAEA", etc - is that the authorities requirements are different in different countries and therefore it is not of much use to be more specific. The knowledge, and the responsibility, of the correct requirements for each system always lies with the owner. Therefore the terms are not relevant here, but the important thing to remember is to communicate what is expected from the vendor regarding this specific part.

4 Reengineering and Reverse engineering

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 has been done 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.

There is an overlap between the concepts of reengineering and of 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 too 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, like in Figure 4, due to small orders.

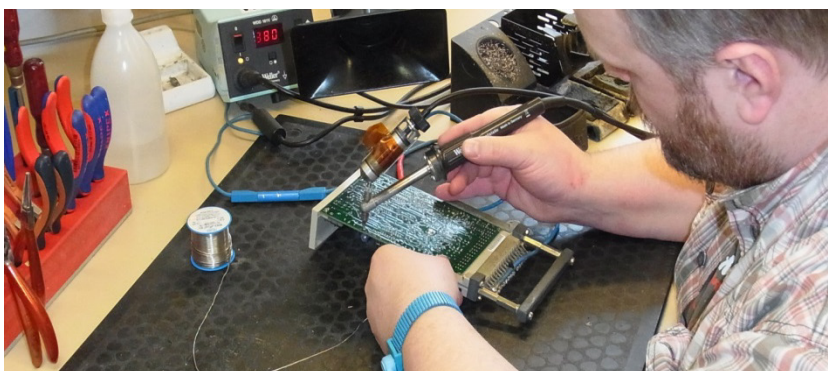


Figure 4 Hand fabrication of circuit board

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. Functional, environmental

and other requirements are instead collected from discussions with the customer, from investigations of an original piece of equipment, and from the experience of the supplier. New documentation is then produced by the reverse engineering company. A state machine and/or logic analyzers might be used to find the functions of the equipment. Nothing is known of the piece of equipment in before and no original documentation is available. From looking at the product, conclusions are drawn on the functionality. The modification is therefore called reversed engineering.

To do reversed engineering, at least one specimen of the product is needed. It will be used for measure distances, verify schematics, identify potential problematic parts (hot spots, scratch marks, go through historical failure data etc.). It might also be used for type testing. 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.

Usually, a first sample is used for testing and to be tried out before implementation of the rest of the order. In that way any hidden requirements, like robustness and sensitivity, might be visible.

In between the stated definitions of reengineering and reverse engineering, 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.

If someone else than the OEM is to do the reversed engineering or reengineering, 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 probably 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.

EPRI has issued a guideline on the subject:

- EPRI TR 107372 Guideline for Reverse Engineering at Nuclear Power Plants [7].

NRC has issued a notice on the subject:

- Notice 2014-11 Recent Issues Related to the qualification of safety related components [8].

The impression is that there is not much competition on the market of reverse engineering. Not very many companies do this.

5 Vendors, utilities and authorities

The project have talked to several vendors and utilities in order to see what needs and possibilities for these technologies there are. In this chapter there is a brief summary of those meetings.

5.1 RAB/OKG/TVO NPP:S

The Nordic NPPs have little experience with reverse and re-engineering. At Ringhals there is an electronics department that could do advanced refurbishment, but as the utilities grow older the need for being able to buy spare parts increase.

Several of the Nordic plants run tests on remanufacturing with for example Combimatic/Combitrol/Combiflex equipment.

Re-manufacturing have been done for ABB components, MOBREAY or Foxboro from Schneider. Refurbishment is mainly performed in-house by their own electronic department.

Ringhals also is a member of POMS and of the newly established European NUOG mentioned above.

5.2 VATTENFALL GERMANY'S NPP:S

Vattenfall's NPP:s in Brunsbüttel (KKB) and Krümmel (KKK) have been using reengineering for many years now, and are perfectly happy with the services of WIL, see section 5.11. They will continue to use them even after the E.On / Uniper transition.

5.3 ELECTRABEL'S NPP:S

Belgian energy company owned by GDF Suez who owns the Belgian NPPs Doel och Tihange. They have extensive experience from both re-engineering and reverse engineering and have used several suppliers.

Electrabel have for example made reverse engineering to an equipment that did not work correctly and where they could not reach an agreement with the original supplier to support it. Doel did the qualification themselves and Tractabel, the corporate engineering company, did the testing.

They have also used the possibility to let a third party supplier re-manufacture a product with the consent of the OEM.

The experience from Electrabel was that a small local vendor with no nuclear experience could be good enough for non-safety systems and that large, maybe even foreign, vendors was to prefer when it came to safety related equipment.

Doel have an obsolescence group that makes the strategies regarding how to treat obsolescence. Their experience is that for such a group the key to success is to be multi-disciplinary.

Doel and Tihange have also used the possibility to draw advantages of equipment they have qualified by selling the qualification to other utilities.

5.4 TEMELIN NPP

Temelin NPP use re-design and refurbishment, from Westron among others. They have re-designed one safety component, a PS-70 power supply from Westron. Doing this they came across a hidden requirement concerning passive cooling that was present on the original part. Their strategy on hidden requirements is to solve the problems as they occur. They do not use re-design on non-safety systems, but replaces the whole system instead.

Temelin NPP has recently started cooperation with Sizewell NPP in UK in order to make Westinghouse remanufacture obsolete components for their Eagle I&C system.

Temelin NPP does not have extensive experience with obsolete components since their systems are quite new, they foresee however already that they would like to prolong the NPP lifetime from 40 to 60 years.

5.5 SOUTH UKRAINE NPP

According to telephone meeting with South Ukraine they do not work with re-engineered parts. They do however use Westron as a supplier and possibly refurbished re-engineered parts certified by the OEM. Ukrainian rules and standards are very different from Nordic ditto, including definitions and classifications of safety- and non-safety systems, therefore it is very difficult to make comparisons and to draw any conclusions from this.

5.6 WESTRON

Westron is a subsidiary of Westinghouse located in Ukraine. When doing business in Western Europe and the North America they use the Westinghouse name, otherwise they use Westron.

Westron have several years of experience from doing re-engineering, re-design and refurbishment. They handle both safety- and non-safety components and have access to some testing facilities, not seismic though.

They have support and warranty on their products according to contract and deliver user guides and training in order for the customer to be able to do in-house maintenance if wanted.

Westron is also used by Westinghouse as supplier.

5.7 QUALTECH AND SCIENTECH

Qualtech and Sciencetech are two subsidiaries of US-based Curtiss-Wright. Curtiss-Wright (~8000 employees) has a nuclear division with ~2000 employees. Within that division you can amongst others find Enertech, Nova, Qualtech and Sciencetech. Qualtech works primarily with qualification, Enertech with mechanical equipment, Sciencetech both with the database RAPID/OIRD and with analogue I&C-equipment.

The I&C group of Sciencetech, situated in Idaho, have been in business for 30 years and employs around 75 people. They repair and refurbish cards and do reengineering and reverse engineering (replica, not blackbox). They reengineer systems as well, i.e heat tracing system for pipes. They work not only on cards, but also on racks and cabinets, and may improve the design of them. Obsolescence is just one part of the activities,

they also supply new parts, for instance electrical penetration and grey boot connectors, to both new and old plants. They offer analyses of Reliability, Availability and Maintainability (RAM) for systems or components.

Qualtech, situated in Cincinnati and Huntsville, focus on qualification of components and systems. They qualify reverse engineered and reengineered components, and also upgrade/qualify industrial grade equivalences to safety grade. They do equipment qualification, environmental qualification, seismic testing, commercial grade dedication and custom fabrication and manufacturing.

Regarding testing of I&C equipment, Curtiss-Wright have facilities in Cincinnati, Toronto and Idaho Falls for functional, environmental and seismic testing. They manage the EPRI program on Earthquake testing (SQRSTS).

Curtiss-Wright does business with NPPs in Belgium, Sweden, Finland, Holland, Spain, UK, Switzerland and Romania. They currently have no office in Europe. Outside of Europe they have sold to Brazil, Mexico, Korea and Canada. An estimation is that 75% of the nuclear sites in the US have reengineered Curtiss-Wright products.

Qualtech and Scientech are 10CFR50-certified and audited by NUPIC.

5.8 VEW

VEW is a local business in Bremen with 16 employees and 37 years in business. They work with electronics for both nuclear and non-nuclear plants, for example special equipment for Airbus, electronics of the mirror measurement for ESO (European Organization for Astronomical Research in the Southern Hemisphere) and modifying slot machines in Prague to work according to Czech regulations. They have done work in India, Morocco, and Tunisia.

VEW do reengineering and reverse engineering, but don't repair or refurbish cards (except for their own). They keep all their manufactured cards in stock, which is available on a website. They work on cabinets and casings as well. So far they have only done non-safety equipment. They have specialized in measuring devices and small scale manufacturing, often with very special needs.

VEW is not KTA¹-certified but in a process of becoming.

5.9 NOVAMETRIC

Small Swedish vendor specialized in electronics and special solutions. They have no experience from the nuclear industry, but could possibly be of help regarding non-safety equipment and small scale component exchange. They have for example specialized in old solder techniques. During 2015 an Energiforsk bachelor thesis was done together with this company.

5.10 WESTINGHOUSE

For re-design and re-engineering purposes Westinghouse has bought majority share in Westron, see above. Westron does the engineering work and manufactures the

¹ See chapter 10.2

equipment. If necessary or if requested by customer, Westinghouse could provide qualification and certification to USA or European standards (Commercial Dedication).

Westinghouse has their own obsolete program described more in the earlier report from the US market, ref [9].

5.11 E.ON WIL (FORMER VATTENFALL IPS)

German manufacturer that started as a maintenance services for the in-house NPP:s of Brunsbüttel and Krümmel in 1975 then belonging to the local energy company HEW. Later, they expanded with external customers in the 1990's. From 2006 to 2016, WIL was part of Vattenfall and was called IPS (Industrial Plant Services), but from April 2016 they belong to E.On. WIL has 23 employees and work on long term agreements for NPP:s in Germany, Spain and Belgium. They have also experience from work for NPP:s in Switzerland, Brazil, Holland and Sweden.

WIL is part of the Engineering division of E.On Kernkraft. They are KTA²- and 10CFR50- certified, from the years 1984 and 2008 respectively. They have specialized in having the original documentation, like original drawings and handbooks, which they collect in their own archive. With this they could then re-design obsolete parts. WIL do reengineering, refurbishing and repairing of cards and systems. They generally don't do reverse engineering since this would demand extensive testing and re-qualification as well as it would add new requirements according to German rules. They have a large spare part storage; the spare parts could be owned by the plants or by WIL, but stored by WIL at their facility. Type tests are part of their services. They reengineered 2500 modules in 2014, a bit less in 2015 due to the coming transition to E.On, in their workshops in Hamburg and Brokdorf. The Brokdorf workshop is not approved for external business.

WIL develop and produce testing equipment and perform testing as a service. They have mostly experience from safety classed equipment and have access to special test equipment. They could also do testing of new requirements on old components.

Their long term agreement consists of two parts; one part is a "membership" fee in order to keep stock and competence, and one part in order to place orders, minimum order included. They have their own statistics database of failures which could be used for members to see failure rates. It is also possible to benefit from qualifications done by someone else, quality certificate could be found in the VGB³ database.

5.12 AUTHORITIES SSM AND STUK

Both the Swedish SSM and the Finnish STUK have little experience of reverse and re-engineering, but since the need for these kinds of spare parts grow, the need for an opinion in these matters grow.

Questions that are thought of are:

What is considered a design change. The reliability on the present system and comparison towards the alternative to do nothing ("save as is"). How about effects on CCF? What about the traceability when buying from a third party supplier? Another matter that is important to be able to account for is what kind of complexity that is

² See chapter 10.2

³ See chapter 10.2

introduced? What are the consequences if the introduction of re-engineered/reversed engineered part is not successful?

A part could not be considered original if the manufacturer has changed and then there should be a suitability analysis done to be able to determine the consequences of replacing that part.

In Sweden SSM have sent a letter of information to the NPPs asking to be informed of re-engineering, reversed engineering or remanufacturing projects at an early stage.

5.13 OTHERS

We have during this investigation heard of other companies that offer this kind of services in one way or another, and utilities using it, but we have not been in contact with them.

- ABC Parts (Belgium)
- K+S Services (Belgium)
- Cegelec (France/Belgium)
- Pereneo/Spherea (France)
- E-NUOG
- EDF NPP (France)
- Ascó NPP (Spain)
- Almarez NPP (Spain)

6 Requirements

Regardless of if you need a spare part from an OEM or a third party supplier it is always important to have good knowledge of the requirements. The more thorough work there is behind the requirements, the bigger are the chances of receiving what you really need. However when it comes to old parts it might be difficult to find the original requirements, maybe they have never been written down anywhere. Therefore requirements have to be investigated and scrutinized in order to not find any “hidden” requirements in the last minutes (or even when it is too late!). When the original requirements are not available, the reversed engineered requirements have to be accepted by the end user.

Regarding difference between requirements for safety and non-safety systems, the interviewed companies declared that there is a big difference. Safety systems (systems important to safety) are strongly regulated by authorities so the requirements are higher and stronger. This could affect the use of re- or reverse engineering.

6.1 FUNCTIONAL REQUIREMENTS

All functional requirements are usually the same for re-engineered product as for their old original predecessors. Rules and standards are according to valid legal requirements.

6.2 HIDDEN REQUIREMENTS

Hidden requirements are the most difficult part of making a requirement specification. This is especially important when changing components technology. According to some of the companies the project interviewed this is a big problem, according to others it is not. It seems to be a matter of competence, the ones with extensive experience knows why a certain component holds a certain spot and therefore understands what it can be replaced with.

Another way of finding hidden requirements is extensive testing of both the original equipment and/or the new sample equipment. The problem is that testing, especially in the right environment and for long time effects, could be impossible.

One difficult issue is tolerance for electrical transients and EMC. Old equipment is in general more robust, but this is often not a requirement, but first seen when used in its normal environment.

Another difficulty is temperature and heat installation. Actual temperature can rise inside a cabinet with the bad choice of components and thereby destroy other components in the same cabinet.

Circuits with same functionality but smaller dimensions (common with modern chips) can follow higher frequencies than old circuits for example. The small chip doesn't filter high frequencies the same way bigger do and therefore might cause oscillations.

6.3 NEW REQUIREMENTS

More or less everyone the project talked to agree upon that in Europe it is common to add new requirements to the old ones when making spare parts. Opposite to the US

licensing method the European licensing is not as static, but rather continuously modernizing over time. This means that if a new spare part is needed it is relevant to add modern requirements for that part. That could mean changes to the spare part compared to the original part and that is a change that you need to handle according to local rules and regulations. Depending on what this means for that specific part it could also mean the best thing to do is to not make any changes.

In general, the industry standards and national regulations are followed. There are no specific requirements for re-engineering or reverse engineering.

6.4 VERIFICATION

Once the requirements are known it is not difficult to make the verification against them, the main problem with verification is if there is insufficient input of valid requirements to test against. Software products are more difficult to test due to the often large amount of unknown functions and/or combinations, analogue components are easier. The important thing to remember is that this is in no way different from normal procedures.

In the case of the black box approach thorough testing is needed both for finding requirements, as well as for verifying them later. Often is the problem with verification what makes a black box approach impossible. It could for example be very difficult to prove that the failure modes are the same.

In Finland there is a system of type testing and a reengineered part needs a new type testing and could not rely on the old type testing for the original part.

In general, verification are made in accordance with quality plans and verification and validation plans defined by the individual projects. Participants have their own plans and procedures how to perform verifications and how to ensure that those verifications were sufficient. At Ringhals NPP this problem is solved on a project level, not on the equipment level. Westron's approach is to minimize the probability of missed errors by making tests that follow all bifurcations in operational logic, as well as more extensive verification of the most critical operating conditions.

7 Qualification

It seems to be common to think of qualification of spare parts in the same way as qualification of any other parts in a nuclear facility. Each country have different rules, but in some way the vendor normally have to be qualified as a nuclear provider before business can take place. After that the parts itself needs to be qualified according to the requirements for that specific part. The problem with old components is that the original requirements are not always known and even if known they sometime prove to be insufficient. This means that a thorough investigation on what requirements that should apply first needs to be done. After that it is possible to know what qualification needs to be done.

Some of the vendors the project talked to have their own testing environments, others use third party testing. In general it seems to be rather easy to do the testing, as long as it is completely clear what requirements you are testing for.

However, the more complex the project is, the harder it is to qualify the new equipment. An I/O card exchange was mentioned as an example of a small change that would be easy to qualify. A black box reverse engineered module was mentioned as an example of a change that would be hard to qualify; a module that was qualified in the US was tried to get qualified in Finland as a black box, but then all states (internal states with memory led to 2^{62} states) would have to be tested if it should be qualified as a black box. A replica reverse engineered module was regarded as easier to qualify. Also, noncomplex items like pressure transmitters could be black box reengineered or reverse engineered without complicated qualifications.

In general, it is the utility that has the responsibility for the qualification. The radiation authority is regulating the NPP and has demands on qualification for them, but they are not regulating the vendors. The vendor might have more insight, though, and could be assisting. Some vendors help out with the qualification paper work; others leave it all to the utility.

Qualification of reverse engineered or reengineered equipment doesn't differ from qualification of new equipment. Focus areas, work processes, audits and controls are all the same.

OKG is to some extent cooperating with the German NPP in the group about obsolete equipment. If German spare parts are used, they have to be evaluated to follow the Swedish rules even if they are KTA-qualified.

The Belgium NPP:s Tihange and Doel cooperate on qualification work. Seismic requirements differ a bit between the two. Qualification tests are performed that are applicable for both, governed by the NPP owner Electrabel. Requirements are set by Tractabel, the engineering company within the group.

One example of handling qualification regarded qualified PLC:s. To avoid having to audit and qualify the supplier every 3rd year to be able to buy a new one whenever it was needed, the NPP bought two extra PLC:s and used them for qualification (including following the software design closely) and then kept five in stock.

The Finnish regulation YVL E7 requirement 335 stipulates that if a new vendor is used for a part, a new type approval has to be done. This is applicable to the main supplier, not to sub-contractors. Also, the quality management level demand includes

traceability for modules and components on a higher level but not for discrete capacitors and alike.

YVL E7 requirement 335

335. *A spare part is not considered an original part, but a replacement spare part in the meaning of para. 334 if:*

- *the performance values of the spare part related its safety function have deteriorated*
- *the spare part deviates in terms of the way of function, any software part or structural characteristics from the original*
- *the spare part does not match the original part in terms of environmental condition endurance*
- *the quality management level of the spare part does not fulfil the original level*
- *the manufacturer of the spare part has changed.*

Ringhals NPP has its own in-house electronic department which judges all planned changes and prepares an equivalence report which helps to make a decision if it is an 1:1-exchange or not.

When it comes to reverse engineering on safety related or non-safety related equipment, the opinions are wide spread.

At one hand, when no original documentation is available, it is almost exclusively non-safety related equipment that comes in question. It is a too costly to produce proper documentation and do all needed testing to be able to qualify "from scratch".

Companies that work on non-safety related equipment don't have to be qualified⁴, which saves paper work, auditions, etc. for the company and in the end saves costs for the customer.

On the other hand, however, there is also the opinion that for non-safety related equipment, reverse engineering is not needed since it can easily be replaced with another brand, model or type. And of that reason, reverse engineering is mainly used for safety-related equipment. One company of the visited ones only worked on non-safety related equipment, the other two did approximately the same amount safety related as non-safety related or maybe somewhat more safety related.

To sum up, qualification of a reengineered or reverse engineered piece of equipment is not regarded as a big problem. At least not more difficult than to qualify a newly manufactured piece of equipment. It involves notifying the authority, thorough testing and qualification paper work but not to a greater extent than when buying new parts. It is in many cases easier to verify a reengineered analogue item then a new digital one.

⁴"1E-leverantör" in Swedish

8 After-market

8.1 MAINTENANCE AND SUPPORT

Reengineered and reverse engineered parts need maintenance and support from the supplier like parts from an OEM. This is an important, but maybe overlooked issue for the utilities.

Most vendors offer support on their reengineered or reverse engineered pieces. It is possible to have a long term (~30 years) agreement with some suppliers. Some vendors prepare programs for their customers to maintain existing technology in operation until the end of life of the customers' power plants.

Support by a smaller company doesn't have to be more risky than by a large company. The life time of smaller reengineering companies could be shorter than for an OEM with a large corporate behind them. But large companies have a tendency to merge, split up, be bought by others etc. which might lead to that the promises of support are not that valuable.

Some NPP asks for 20 years of support when they buy new parts, and if the reengineering or reverse engineering company cannot offer the same deal, the plant might have to compensate with a larger spare part stock.

Usually a reengineered or reverse engineered equipment is repairable in-house, depending on the particular equipment and capability of the plant. Some utilities have very capable electronic departments with educated and experienced personnel. No special tools are required to maintain a re- or reverse engineered equipment, just those standard already available ones. In some cases existing procedures have to be updated or additional training for maintenance personnel has to be arranged (especially if a new technology has been utilized in the reverse engineered equipment).

Hence, maintenance and support is available, but the extent differs between vendors and items purchased.

8.2 TRAINING

Not all of the companies that we have talked to offer training together with their products, but some do. This is something that is agreed upon when signing the contract. The conclusion is the same as for maintenance - this is something that differs between vendors and items purchased.

9 Legal aspects

9.1 CONCLUSIONS

There are many legal issues related to reengineering and reverse engineering. Whether it is possible to use re- or reverse engineering in Scandinavia must be analysed on a case-by-case basis.

The nuclear power plant will be required to disclose detailed information that most probably in the contract has been considered to be confidential, to be able to reengineer a product or system together with an external contractor. If there are any contracts still in effect, they will stipulate how the parties may disclose confidential information. Some contracts allow for this information to be disclosed to a third party in order to reengineer an item. If the contract does not allow the disclosure of vital information for the process of reengineering, an agreement should be sought with the rights holder.

The process of reverse engineering and reengineering could also encounter problems with patents, design rights and copyrights.

However, as the products/systems that may be of interest for the process of re- or reverse engineering in Sweden most probably were procured in the 70's or the 80's, the main concern will be any contractual restraints still effective between the parties.

Patents are frequent in the nuclear industry. However, they only last for 20 years. Thereafter, the patent will not hinder the process of re- or reverse engineering. As the products/systems that would be of interest for the process of re- or reverse engineering in Sweden most probably were procured more than 20 years ago, patents are probably no longer a hinder.

If there are design rights or copyrights encountered in the process of re- or reverse engineering, they should not pose a problem, if managed in the correct manner. It should be possible to work around those rights.

Finally, the Swedish Protective Security Act⁵ may apply to the process of reengineering, if the process requires the disclosure of information classified under this Act.

This section provides a general overview of the legal issues associated with re- or reverse engineering. However, it is not meant to fully explore this issue or provide legal advice related to any single case. Any legal concerns about re- or reverse engineering should be addressed on a case-by-case basis.

9.2 CONTRACTUAL RESTRAINTS, CONFIDENTIALITY CLAUSES AND PROPRIETARY DATA

A way to restrict access to information related to reengineering in the nuclear industry is to agree in a contract on the information being confidential. Purchase contracts for products and systems for the nuclear power plants include contractual restraints for both parties. One common restraint is the *confidentiality clause*, also known as "proprietary data clause" or "right of use clause". The essence of this clause is to restrict the purchaser/nuclear power plant to disclose information to third parties.

⁵ In Swedish: säkerhetsskyddslagen (1996:627)

Confidential data is usually defined as technical data that embodies trade secrets, such as design procedures or techniques, chemical composition of materials, or manufacturing methods, processes, or treatments, including minor modifications thereof, provided that such data:

- Is not generally known or available from other sources without obligations concerning their confidentiality,
- Has not been made available by the owner to others without obligations concerning their confidentiality, and
- Is not readily available to the public without obligations concerning confidentiality.

The nuclear power plant may be able to *utilize the data* for any purpose as long as the *information is not disclosed to third parties*. This would include reengineering and manufacturing of an item for the sole use of the utility in possession of the confidential data. However, the item should not be sold to another utility. No third party should be contracted for the reengineering. All such confidentiality clauses should be thoroughly reviewed prior to any reengineering process.

As the items that would be of interest for reengineering were procured more than 30 years ago, the question is *whether the contracts still are applicable*, or if the provisions of the contracts have lapsed, due to not having been claimed or renewed for more than ten years. Swedish law is unclear in this aspect, whether a confidentiality provision will lapse after ten years of inactivity or not.⁶ However, it is likely that the Swedish Act on limitation⁷ should be applied also on these types of contractual provisions, resulting in these confidentiality clauses not being applicable after more than ten years of inactivity. Prior to the re- or reverse engineering of an item, the purchase contracts, as well as the relationship between the contractual parties, should be thoroughly reviewed.

It is possible that, at least for some products, all information needed for the re- or reverse engineering, has become *publicly known*. The nuclear power plants are then not bound by any contractual restraints related to publicly known information.

In some contracts, the nuclear power plant has been allowed to disclose confidential information to third parties for “the design and execution of any modification therein or extension thereof or *replacements* therefor”. Such provision allows confidential data to be disclosed to a contractor for the purpose of reverse engineering. However, as the contractual provisions can differ, any such contract must be thoroughly reviewed prior to any use for reverse engineering.

Finally, it is a possibility for the nuclear power plant to *agree* with the holder of the confidential information that the information may be used for the purpose of reengineering. Such agreement should be in writing. However, the contractor has no obligation to accept such agreement.

In conclusion, the contracts and the contractual relationship between the nuclear power plant and the contractor should be thoroughly analysed before the process of re- or reverse engineering is initiated.

⁶ For example: Stefan Lindskog, Preskription, om civilrättsliga förpliktelsers upphörande efter viss tid, andra upplagan, sid.77 ff.

⁷ In Swedish: preskriptionslagen (1981:130)

9.3 TRADE SECRETS

Information needed for the process of re- or reverse engineering may, in addition to being confidential in accordance with the contract, qualify as being trade secrets. A trade secret is protected information, not only through contract, but also through the Swedish Act on the Protection of Trade Secrets.⁸ To unlawfully disclose a trade secret is a criminal offence.

A trade secret is defined as information concerning the business or industrial relations of a person conducting business or industrial activities which that person wants to keep secret and the revelation of which would be likely to cause damage to him from the point of view of competition. It may, for example, be a manufacturing process, a method of treating or preserving materials, a pattern for a machine or other devices, or a list of customers.

Trade secrets are protected property unless acquired by proper means. Proper means include:

- Discovery by reverse engineering, that is, by starting with the known product and working backward to determine the methods by which it was developed. For reverse engineering to be lawful, the acquisition of the known product must be by legal means, such as purchase of the item on the open market.
- Discovery by independent invention.
- Discovery under a license from the owner of the trade secret.
- Observation of the item in public use or on public display.
- Obtaining the trade secret from published literature.

Anyone who wilfully and without authorization accesses a trade secret shall be sentenced for trade espionage to fines or imprisonment for up to six years. The infringement may also result in liability for damages.

Documents obtained in relation to a nuclear power plant's purchase of a product or system to the plant may be protected both by a contractual confidentiality clause, and by the Swedish Act on the Protection of Trade Secrets.

9.4 PATENTS

A patent is a right granted to an inventor by the government to exclude others from making, using, or selling the invention for a period of up to 20 years. Granting a patent is not granting the positive right for the inventor to make, use, or sell the invention, but only the right to prevent others from doing so. The inventor only obtains the legal right to sue other parties for infringement of the patent. Generally, the consequence of patent infringement is monetary compensation to the patent holder.⁹

Even though many of the products and systems in nuclear power plants are old technology, patents can still be an issue for the process of reverse engineering. Both components and processes may be protected through a patent. A new patent cannot prevent someone from copying an old technology, where the technology is not protected by the new patent. However, a new patent can protect an improvement on the old technology.

⁸ In Swedish: lag (1990:409) om skydd för företagshemligheter

⁹ In Sweden, the Swedish Act on Patents, in Swedish: Patentlag (1967:837), regulates the area.

All patents and applications are registered with a Patent and Trademark Office¹⁰. An issued patent contains all the specifications and drawings needed to manufacture the item.

If a product or system is protected through a patent, the nuclear power plant may not use the patented technology in its re- or reversed engineered product or system unless the party holding the patent grants a *license*.

In Sweden, it constitutes a *criminal offence* to infringe in a patent. Such infringement may result in fines or imprisonment for up to two years. Lack of knowledge of the patent or the law is not an excuse.

Patents can be a major problem for the process of re- or reverse engineering. However, once patents have expired, the technology becomes public domain and can be manufactured or produced by anyone without concerns for patent litigation. The majority of products and systems being candidates for re- and reverse engineering in the nuclear power industry were most probably *designed over 20 years ago*. Patents on such items should have expired and should not pose any obstacles to re- or reverse engineering. However, even when the patent protection has expired, it is of greatest importance that a thorough investigation is made into other possible rights.

9.5 DESIGN RIGHTS

New products and processes are mainly protected through patents. However, when the inventor creates a new form or design for a product, it is possible to protect the design through a design right¹¹. The design right is generally gained by being granted by the Trademarks and Patents Office¹², but can also be gained without formal registration. Industrial products may gain such protection. The creator of the protected design can use the right to prevent others from using the same design.

Generally, the process of re- or reverse engineering does not involve products that are protected through design rights. However, if such rights are encountered, it should be possible to work around the design right, i.e. by using a different design. In case the protected design must be used in the process of reverse engineering, a thorough analysis of the right should be made and written permission should be obtained from the creator.

9.6 COPYRIGHT

A copyright is an exclusive right granted to authors to print, publish, or copy their artistic or intellectual productions. The right is given to authors in an effort to promote the progress of science and useful arts by securing, for limited times, for authors the exclusive right to their work. In Sweden, the Swedish Act on Copyright¹³ states that anyone who has created a literary or artistic work (for example a work of architecture or applied art) shall have copyright for that work.

¹⁰ In Sweden: Patent- och registreringsverket, PRV

¹¹ In Swedish: mönsterskydd

¹² In Sweden: Patent- och registreringsverket, PRV. In the EU: European Patent Office, EPO.

¹³ In Swedish: Lag (1960:729) om upphovsrätt till litterära och konstnärliga verk

The copyright includes the exclusive right to exploit the work by making copies of it and by making it available to the public, in original or an altered manner, in translation or adaptation, in another literary or artistic form, or in another technical manner.

The copyright term is the life of the author plus 70 years after the author's death.

It is possible to argue that some of the products in a nuclear power plant could be protected through copyright. If copyrighted materials are encountered in the re- or reverse engineering process, the possibility to work around the copyright should be analysed. The copyright is given in relation to the design and form of the item. If the copyrighted material is required in the process of re- or reverse engineering, written permission should be obtained from the author (if deceased, the holder of the copyright).

However, generally, the process of re- or reverse engineering does not involve copyrighted materials.

10 Field trip

During a week in late April a group of four left for meetings with three companies in Germany. The participants were represents from Vattenfall (Projects and Services), Ringhals nuclear power plant and Olkiluoto nuclear power plant.

Fredrik Bengtsson	Ringhals NPP
Annika Leonard	Vattenfall
Mika Sinkkonen	Olkiluoto NPP
Anna-Karin Sundquist	Vattenfall

10.1 COMPANIES VISITED

Visits were paid to Sciencetech/Qualtech, VEW and WIL. Participants of the respective meeting were as follows.

Curtiss-Wright

Pär Christenson	Curtiss-Wright, sales represent for Belgium and the Nordic countries
Keith Porter	Sciencetech, Sr Manager International and OEM Sales
Darryl M. Deist	Qualtech, Director of International Business.

VEW

Vereinigte Elektronikwerkstätten GmbH	
Norbert Köpp	CEO
Sebastian Wagner	Authorized agent

WIL

Lothar Menching	head of WIL
Thomas Paffrath	customer management, WIL
Oliver Elvers	head of I&C workshop of WIL

Also attending the meeting with WIL was:

Kernkraftwerk Krümmel (KKK)

Frank Wiegand	head of Electronics department
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Kernkraftwerk Brunsbüttel (KKB)

Michael Saß	head of Electronics department
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10.2 GERMAN PREREQUISITS

10.2.1 KTA

<http://www.kta-gs.de/>

The Nuclear Safety Standards Commission (KTA) has the task, to issue nuclear safety standards for these topics in the area of nuclear technology where a consensus between experts of the manufacturers and the operators of nuclear power plants, of authorized experts and state officials is apparent and to support their application. Presently, the KTA Program of Standards is comprised of 97 different standards.

10.2.2 VGB

<https://www.vgb.org/en/>

VGB PowerTech e.V. is the European technical association for power and heat generation. As voluntary association VGB PowerTech brings together companies, for which the operation of power plants and the corresponding technologies form an important base for their business. The committees of the competence center "Nuclear Power Plants" deal with the exchange of experience, especially in the fields of safety, plant operation, plant engineering, radiation protection, post operation, decommissioning and regulatory issues. The exchange of experience also includes the exchange on an international level. It undertakes research relevant to nuclear plant safety

10.2.3 Nuclear regulatory authority

The "regulatory body" in Germany is composed of federal government and Länder government authorities. On the federal level the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and the Federal Office for Radiation Protection (BfS) are the regulatory authorities in charge.

Source: <http://www.ensreg.eu/country-profile/Germany>

10.3 RESULTS

10.3.1 NPP experiences

KKK and KKB shared how they choose what to reengineer. Usually the NPP firstly produces a long list of its obsolete equipment. Databases like RAPID or POMS can help to identify obsolete parts. Secondly they prioritize and sort out a shortlist of vital but obsolete equipment. Thirdly, for each part on the shortlist they analyze the options; leave as it is, replace, repair, refurbish remanufacture, reengineer, reverse engineer, redesign. The analysis should include an economical risk assessment. Fourthly, the optimal solution is implemented.

HOW TO CHOOSE SOLUTION

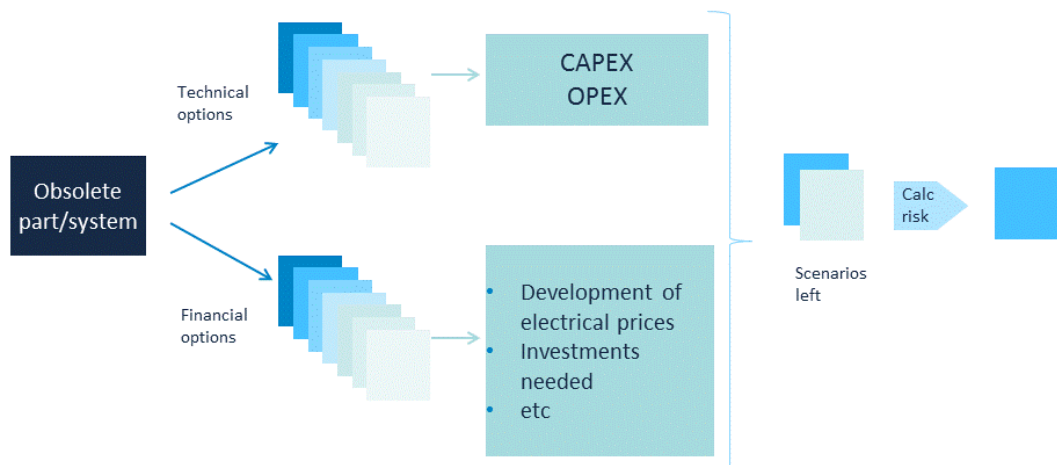


Figure 1 Process of choosing what to reengineer or reverse engineer.

10.3.2 Brands, systems, platforms

All three companies seem to work with whatever platform the customer asks for. For reengineering, it is more depending on the documentation the customer can pass on.

Platforms that have been reengineered or reverse engineered are for example:

Siemens	Jaquet
▪ Iskamatic ▪ Simatic ▪ DM, EDM ▪ Transidyn ▪ Simadyn ▪ Teleperm	Sulzer
BBC	Schneider-Electric
▪ Decontic	▪ Foxboro, some problem to get hold of IP though
AEG	General Electric
▪ Logistat ▪ Geamatic	ABB
Hartmann & Braun	▪ Bailey
▪ Contronic ▪ Transducer ▪ TK240, TK250 ▪ Control room registrator	Emerson/Westinghouse
Endress + Hauser	▪ Rosemount ▪ WDPF
Herfurth	Areva
	Alstom
	Hagan
	Rados

Honeywell is an exception, they will not let their equipment be reengineered or reverse engineered, as they don't want to be associated with the nuclear market at all.

10.3.3 Documentation needed for reengineering

Original documentation of test results, requirements, drawings, etc. is vital for reengineering of safety related equipment. For German NPP:s, WIL requires "KTA Maintenance documentation", which is a formal set of documentation, to do reengineering work. For non-safety related equipment, however, they can more or less do whatever they want and don't require any specific documentation. But as usual – the more information the customer can provide, the better the result.

Examples are:

- functional description
- technical data sheet
- circuit diagram
- part list
- component placing plan
- testing instructions and inspection sequence plan
- rules and specifications at the time of development / production
- type test documentation
- datasheets of the original components
- work instructions

10.3.4 Technical aspects on reengineering and reverse engineering

One company prefers to use wired components if possible.

Typical components that are causing problems are switches, connectors and capacitors.

10.3.5 Testing

All companies visited have testing facilities. Two of the companies have their own earthquake testing facilities, the third uses a third party for seismic testing. At least one uses subcontractors for radiation testing.

The independence of the testing personnel varies. For non-safety related equipment there is not always an independent department performing the tests, but it is different people involved in the development and the testing, respectively. One company has independent testing organizations.

IEEE is on their way to certify testing laboratories.

EPRI has a seismic testing program SQRSTS. The members of the program can view and use the result of other members' testing.

The level of support during or performance of Factory Acceptance Tests (FAT) and Site Acceptance Tests (SAT) differs from supplier to supplier.

10.3.6 Qualification

It is easier to get approval by the authority for reengineered analogue equipment than for software based upgrades. For example, software based equipment has to be proven to be robust against solar explosions. Siemens could not show this for their S7 system, which was then not approved by the German authority for the emergency diesel control. One way is to have an analogue safety system with a digital front end; no software would then be part of the safety task.

One company doesn't see any business for them in doing qualifications, and hence leaves it to the customer. The other two offers qualification as part of their services. In addition, those suppliers buy commercial grade products and qualify them for nuclear grade. This could be the case when an OEM used to have a product qualified for nuclear use but ceased selling the qualified version and only sells the industrial grade version, or when conventional power plants are closing down and give away their components.

One company have direct contact with the authority, the others let the NPP have that contact.

The qualification demands differ from country to country.

One supplier offers help with safety demonstration and licensing, a division of the company is devoted to this.

10.3.7 Reuse of qualifications

Qualification documentation, like test results, produced for one specific piece can be reused by other plants. Depending on who owns the qualification documentation, it can be sold to other plants. Also, a number of NPP:s can get together – on their own initiative or coordinated by the supplier – and order a common test from the supplier.

Databases like POMS or RAPID, or organizations like NUOG, could give information about NPP:s using the same kind of equipment.

Some companies have templates for their qualification documents that resembles KTA and OEM papers in layout and words.

10.3.8 Support and maintenance of produced items

One company gives 10 years support and guaranties that the customer would get spare items from the stock. Another company qualifies its equipment for 40 years and gives 1-1.5 years of guarantee and support as long as they are in business.

10.3.9 Procurement of reengineering or reverse engineering

Reengineering can be procured either on a long term contract with an annual fee, or on piece by piece ordering with fixed prices from a catalogue. One price model includes a discount on the first produced piece, as the development costs would be too high otherwise, and instead the newly designed piece will be sold to other customers as well which will cover up the discount.

The size of order reflects on the price, naturally. One company estimates that 10 ordered pieces would make the reverse engineered equipment cheaper than the original.

As comparison, it was mentioned that reengineering typically takes about a couple of months to half a year for a piece of equipment. If reverse engineering of black box nature is needed, it would take about half a year to a year.

Equipment reverse engineered by a third party might be sold by the OEM as a replacement of their old equipment.

1E equipment is more costly to reengineer, due to technical support documents, regulator documents etc that need to be produced.

Bases that the customer typically need to deliver for reengineering of an obsolete card:

- Module type
- Version
- I&C-system
- For how many years will service be needed
- Are there any regulatory requirements (KTA, 1E, ...)
- What original technical documentation that is available
- How many modules are there in plant
- How many modules are there in stock
- Anticipated annual demand

10.3.10 Relation with OEM

If the design is changed, like in black box reverse or re-engineering, it seems to be no problem with the OEM or patents. If the design is kept, like in replica reverse or re-engineering, there could be problems with the OEM, though, depending on what the original contract says.

Original contracts might restrict passing on information to a third party – a confidentiality clause – which might prohibit reengineering. But that is not the case when doing reverse engineering, since no documentation is passed on then.

If the OEM doesn't manufacture or support an item any more, the reengineering company might buy the immaterial properties (IP) like type tests, drawings and descriptions from the OEM. Quite often the OEM is happy to solve the customers problem and keep the customer in business but not have to deal with the product any more, and hence is willing to sell the IP. Usually the plant makes the deal with the OEM about the IP, not the third party supplier. It is also possible that some NPP:s go together and buy the IP from the OEM.

In some cases, the OEM buys the reverse engineered version of an obsolete item from the third party supplier.

10.3.11 Competence

It is a common experience of the visited suppliers that it is hard to find competence in the field of analogue technology. Some companies take apprentices, to overcome the problem of attracting young educated people. Some take an active part in branch activities like users groups, EPRI or its German counterpart VGB, and conferences; others don't.

10.4 CONCLUSIONS

The German NPP:s are using reverse and re-engineering as a practice. There is an acceptance for it by the German authority, even though it is often regarded as "changes" and hence needs approval. There are some, but not many, German companies performing reverse and re-engineering.

Reengineering and reverse engineering is performed both for safety related and non-safety related systems.

The formal demands for reengineering or reverse engineering ought to be varying depending on what system is in question. For non-safety related system, the demands should be set lower than for safety related. This goes also for the supplier, a local smaller firm with not so much nuclear experience might be an optimal choice for a 2E-system. And for a 1E-system, a company with many years in the nuclear business and certified by KTA, NRC (10CFR50) or national equivalents should be used. Different types of companies serve different kind of purposes, especially when the economics are in focus.

The need for documentation for reengineering seems to be possible to work around if some or a few are missing. To easily get a good result for a qualified equipment, most of the documentation has to be there, though.

There might be a publicity risk of using reverse or reengineered products, as they could be interpreted as "fake products" by the common people.

Pay attention to support and guaranty times when procuring reengineering or reverse engineering.

11 Summary and conclusions

11.1 SUMMARY

The summary of this investigation is that reengineering and reverse engineering are used on a regular basis in Europe. Some utilities have used it for decades, other are quite new in the field.

Usually there are no problems with the OEM. There is usually a mutual agreement that if the OEM does not itself want to continue with the product, the OEM releases the product and related IP and that the third party vendor is free to use it and reengineer it.

Usually there are no problems with the radiation safety authority either, as long as the reengineered or reverse engineered equipment is verified and qualified (if applicable) correctly. The European authorities don't seem to mind the concepts.

The complexity of the maintenance project increases a lot if there is no or little original documentation available.

The techniques can be applied for both safety related and non-safety related components. The degree of demands – requirements, verification, and qualification – increases substantially if it is a safety related system. But there don't seem to be any formal obstacles for doing reengineering or reverse engineering on safety related components.

Contractual aspects could restrict reengineering, but probably not reverse engineering. Whether it is possible to use re- or reverse engineering must be analyzed on a case-by-case basis.

Legal aspects (patents, copyright etc) are usually not a problem.

11.2 CONCLUSIONS AND RECOMMENDATIONS

Reengineering and reverse engineering are possible alternatives for obsolescence and maintenance. They should be evaluated **together** with other alternatives for life time extension like remanufacturing and redesign.

Reengineering and reverse engineering may be used for both safety related systems and non-safety related ones.

- Safety related: often the only choice since it is not easy to replace with a different part (even if the functions are the same).
- Non-safety related: easier, since the testing is easier and no qualification has to be done. More vendors to choose from. On the other hand, more alternatives to re- and reverse engineering are available – replace i.e.

Reengineering is easier than reverse engineering. It is easier to build and verify a new piece when you know the original ideas behind the construction, and have test results to compare with. It is also easier to get qualified.

Examine the original contract for the equipment procurement carefully. Contractual aspects could restrict reengineering, but probably not reverse engineering. Whether it is possible to use re- or reverse engineering must be analyzed on a case-by-case basis.

It is recommended to use a graded approach when choosing reengineering or reverse engineering vendor. High formal demands on safety related equipment; high flexibility and inventor skills demands on non-safety related ones.

Increase the effort regarding safety classified systems, and decrease the effort regarding non-safety systems.

Make sure to explain the difference between the chosen solution and to do nothing. What are your alternatives? Today both plant owners and authorities are much more reluctant to introduce a new, most likely digital, system in an old plant.

When making even a small change of technology, one of the most important aspects is to be aware of new, and old, failure modes.

The choice to do reverse engineering or re-engineering relies on a number of parameters and all of them have to be weight together. The art of choosing is not new, it is what always is done in a pre-study, but in this report we suggest to add a couple of more choices. A reversed engineering project could at its worst be just as costly as a total renewed system, if there is a lack of most of the information etc. There could not be a general rule for when the use of reversed engineering is appropriate, but it is always a matter of conditions that applies to a particular project.

- Our investigation shows that re-engineering and reverse engineering are available options and that there are available companies willing to perform the task. However, it is not clear that it is always the best option! Our strong recommendation is to evaluate this option together with other solutions when deciding what to do with an obsolete system/part.
- The importance of correct documentation could not be emphasized enough. How much effort that needs to be put into a project start and ends with what you know of your system in the beginning of the project. Therefore it is equally important that these projects leaves correct and complete documentation.
- Look into the specific original contract with care.

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Appendix A: Question list used in the project

RE-ENGINEERING SURVEY

Introduction

Energiforsk is a Swedish joint research organization aimed at research and development in the energetic area which represents different Nordic organizations like Vattenfall (Ringhals NPP, Forsmark NPP), Fortum (Forsmark NPP, Oskarshamn NPP, TVO NPP), E.On (Oskarshamn), Swedenergy as well as SSM (Swedish Radiation Safety Authority).

Energiforsk ENSRIC is a research program focused on safety related I&C systems, processes and methods in the nuclear industry. Information from the program will assist the nuclear industry and the Radiation Safety Authority when analyzing how to replace existing obsolete systems while maintaining safety and promoting a low cost during the whole life cycle.

Within ENSRIC program, we at the Vattenfall are currently performing a survey with objective to retrieve experience from reverse engineering / redesigning of the obsolete I&C equipment, both from utility perspective and from companies that have commercial services and reverse engineered or redesigned products already on the market.

We would very much appreciate if you can provide us with answers to the questions below. You can either write your answers and send them back to us by email or we can arrange a meeting and discuss those areas of interest personally or via teleconference.

Market survey questions

1. Which kind of equipment production did you utilize?

Please select one or more of the following:

- a) Reverse engineering.

New equipment has been created and manufactured completely from the scratch based on the sample of the original one, with no access neither to original requirements / specifications nor to the original documentation.

- b) Re-engineering.

New equipment has been manufactured by a third-party manufacturer using available original requirements, specifications and documentation.

- c) Re-design.

New equipment has been newly designed and manufactured by third-party manufacturer according to available requirements and specifications. New equipment utilizes completely new design or even technology but matches the original functionality, external shape, size and connectors / interfaces.

- d) Re-manufacturing.

New equipment has been manufactured again the same way as the original one by the original manufacturer according to his own old documentation, requirements and specifications.

e) Refurbishment.

Instead of manufacturing a new equipment, the original one has been revitalized by the means of cleaning, replacing non-working parts and readjusting / testing.

f) Other – please specify.

2. Could you provide us with a list of manufacturers or vendors of such equipment you utilized or you were in contact with?

Legal issues questions

3. Could you send us the agreements you have regarding purchase of equipment that could be of interest to redesign, please?

We understand that this may be a sensitive matter to send us a copy of your agreements or their parts, so we are ready to sign a NDA first (Non-Disclosure Agreement) if demanded by you or your legal department.

4. Are there any other agreements that you know of that could be of interest to our research?

5. What legal issues have you found or do you interpret to be the hardest to fulfil for reengineering to work?

6. Do you cooperate with other plants to make deals with the vendors for obsolete equipment, like remanufacture cards or letting go of the rights of the obsolete equipment?

Qualification

7. How do you see on reengineered equipment, a change in the plant or a 1:1-exchange?

8. Does reengineered equipment affect the permits or licenses for the NPP?

Requirements questions

Whenever within our questions below we say “new equipment”, we mean a new equipment delivered as a result of redesigning, reengineering or reverse engineering.

9. How do you handle the requirements at all?

This is a general question: we would like to see any ideas about requirements you have for redesigned or re-engineered equipment in general, e.g. your general approach.

10. Was a new equipment implementation affected by new rules/standards?

It is possible that there are new rules nowadays imposed by authority or new standards exist today, which did not exist or which were different at the time when the original equipment was delivered and installed. Did you experience such problems?

11. Is there any difference between your requirements for Safety System (Cat A / 1E)

and Non-Safety System redesign / reverse engineering?

12. Any experience with refurbishment?

We are interested to know what problems may occur if individual spoilt parts of the original equipment will be just replaced by nowadays parts manufactured with a different (more recent) technology. This is a special question for the case when we just replace broken parts in the original equipment – e.g. refurbishment instead of a full reverse engineering / redesigning.

Functional and other requirements

13. How do you define functional requirements?

For example demanded functionality, power supply restrictions, I/O limitations, requested operational environment, etc.

14. How do you handle “hidden requirements”?

We mean possible impact to existing plant systems caused by implementation of a new equipment, which can have particularly different behavior in comparison to the original one. For example different heat dissipation, power supply requirements and limitations, EMC durability, EM transmission (noise), different environmental limits, different accuracy, different time-response, etc.

15. How do you cope with rules and standards?

This question includes requirements automatically applicable due to official standards or imposed by a law. For example radiation durability, seismic durability, EMC, environmental safety, etc.

Verification

16. Which verifications are necessary to be performed?

We would like to see who issues or defines those demands for verifications as well.

17. Describe please your verification process in general.

Do you perform verifications yourselves (in-house) or was it done by equipment's manufacturer or by another external service provider? Who defines verification procedures and acceptance criteria? If independent review required, how do you ensure the independency of reviewers?

18. Do you have any special requirements for verification personnel?

For example education, special training, experience, license, etc.

19. Which tools are required for performing verification?

For example special laboratory, special equipment or software, simulators, etc.

20. How to ensure that performed verifications were relevant and sufficient and that results are acceptable to proceed with the verified equipment?

21. What about those verifications where it was not possible to test all theoretically existing statuses of the verified equipment?

We mean a situation when there is so many possibilities and statuses that only part of them can be tested / verified at the reasonable time, so only special selection of statuses or values may be verified (operational range, critical points, limits, etc...).

22. What was difficult to verify?

Please describe if you experienced any difficulties during the verification process.

23. Is there any difference between verifications for Safety System (Cat A / 1E) and Non-Safety System?

Maintenance and support

24. What are the conditions for support?

We would like to see how long and which way the manufacturer provides a warranty support and also post-warranty support, how long do you expect that spare parts would be available, also if there are some training and documentation provided.

25. What about long-time support including the decommissioning phase of the plant?

This question includes a new equipment and its spare parts availability from the long-term point of view.

26. Is a new equipment repairable in-house, do you have your own spare parts in stock?

We are interested if, in the case of malfunction, a new equipment can be repaired by a local maintenance team (by opening a box and fixing just a broken spoilt element) or if it would be necessary to replace the whole equipment at once.

27. Did a new equipment implementation cause any special demands for maintenance?

For example special training for a maintenance team, necessity to replace existing maintenance tools or to purchase new ones, updating existing procedures or creating new procedures, etc.

REPLACING OBSOLETE NUCLEAR INSTRUMENTATION AND CONTROL EQUIPMENT

Is it possible to maintain old analogue instrumentation and control equipment?
Yes, there are several ways!

This report reveals how maintenance is done in Europe, and what the Nordic nuclear power industry can learn from that.

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