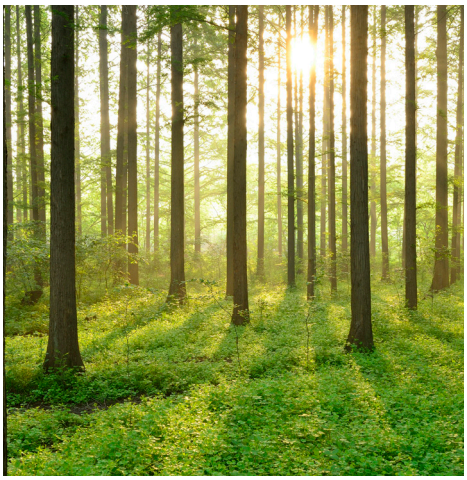
WIRELESS IN NUCLEAR APPLICATIONS SEMINAR REPORT

REPORT 2018:514



NUCLEAR

ENERGIFORSK NUCLEAR SAFETY RELATED I&C – ENSRIC

Energiforsk

Wireless in nuclear applications

Seminar report

ARTO LAIKARI

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

Foreword

Wireless technology has traditionally not been used in nuclear applications, mainly due to restrictions in safety and security. The development of wireless applications has however been very strong during the last years, and the technology is widely used in other industries.

A seminar was held in March 2018 featuring presentations on wireless installations in nuclear applications, research projects, coming wireless technologies and cyber security. The program was planned by Arto Laikari, senior researcher at VTT Technical Research Centre of Finland and Monika Adsten at Energiforsk. This report offers an overview of what was presented, the full presentations are found on www.energiforsk.se.

This study has been carried out within Energiforsk's ENSRIC - Energiforsk Nuclear Safety related I&C research program, financed by Fortum, Karlstads Energi, Skellefteå Kraft, Teollisuuden Voima, Uniper, Vattenfall and the Swedish Radiation Authority.

Sammanfattning

Trådlös teknik har traditionellt inte använts i tillämpningar inom kärnkraftsindustrin främst på grund av säkerhetsorsaker. Utvecklingen av trådlösa tillämpningar har emellertid varit mycket snabb under de senaste åren och används allmänt inom annan industri.

Under den senaste tiden har trådlös teknik förekommit i viss utsträckning också tillfälligt i kärnkraftverk såsom vid installeringar och driftavbrott. På grund av detta har styrgruppen vid Energiforsks forskningsprogram ENSRIC inlett en genomförbarhetsstudie för att närmare utreda hur trådlös teknik används inom nordisk och internationell kärnkraftsindustri samt inom annan säkerhetskritisk industri.

Som en del av detta kartläggningsprojekt beslöt man att anordna ett seminarium för att få mer kunskap om möjligheter och utmaningar med trådlös teknik i kärnkraftstillämpningar. Seminariet ”Wireless in nuclear applications” hölls den 8 mars 2018 hos Strålsäkerhetsmyndigheten i Solna, Stockholm.

Vid seminariet presenterades resultaten från Energiforsks projekt “Wireless in nuclear - feasibility study” [1] av Teknologiska forskningscentralen VTT tillsammans med inbjudna talare från kärnkraftsindustrin, leverantörer, rådgivare och forskningssamfundet.

Denna rapport är en sammanfattning av alla föredrag som hölls under seminariet.

Summary

Wireless technology has traditionally not been used in nuclear applications, mainly due to restrictions in safety and security. The development of wireless applications has however been very strong during the last years, and the technology is widely used in other industries.

Lately, wireless has also been used to some extent in the nuclear power plants (NPPs), in non-safety applications, and mainly in temporary installations e.g. during outages. Because of this, Energiforsk's R&D program ENSRIC steering group launched a feasibility study to map how wireless technology is used in Nordic and international NPPs and in other safety critical industries.

As part of the mapping project a seminar to learn more about the opportunities and challenges with using wireless in nuclear applications was decided to be organized.

The "wireless in nuclear applications"-seminar, was held on the 8th of March 2018 in Solna, Stockholm in the Swedish Radiation Safety Authority (SSM) conference premises.

In the seminar, the results of the Energiforsk's study "Wireless in nuclear - feasibility study" [1], mapped by the VTT Technical Research Centre of Finland Ltd., together with the invited speakers from power plants, vendors, consultants and research community were presented.

This report summarises all the presentations held at the seminar.

Abbreviations

AI - Artificial Intelligence

BWR - Boiling Water Reactor

DAS - Distributed Antenna System

DECT - Digital Enchanced Cordless Telecommunications

DOE - US Department of Energy

EMC - ElectroMagnetic Compatibility

EMI - ElectroMagnetic Interference

ENSRIC - Energiforsk Nuclear Safety related I&C research program

IAEA - International Atomic Energy Agency

I&C - Instrumentation and Control

IEC - International Electrotechnical Commission

IoT - Internet of Things

IR - Infrared

LPWAN - Low Power Wide Area Network

LTE - Long Term Evolution

LTO - Long Term Operation

NB-IoT - Narrow Band IoT

OLM - On-Line Monitoring

PWR - Pressurized Water Reactor

RFID - Radio Frequency IDentification

SSM - Swedish Radiation Safety Authority

NPP - Nuclear Power Plant

ONR - Office for Nuclear Regulation

RWM - Radioactive Waste Management

SSR - Stable Salt Reactor

TETRA - Terrestrial Trunked Radio

VOIP - Voice over IP

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1 Introduction

On March 8th, 2018 Energiforsk R&D program ENSRIC organized a seminar with the title of "Wireless in nuclear applications". The seminar was organized in the Swedish Radiation Safety Authority (SSM) conference premises in Solna, Stockholm.

Purpose of the seminar was to present the results of the Energiforsk's study of the wireless applications in nuclear [1] together with the invited speakers from power plants, vendors, consultants and research community.

Seminar had two main themes, which were the "wireless technologies, opportunities and challenges" and "wireless in nuclear". Purpose of the first theme was to present the opportunities of wireless technologies and its applications in general, but remembering also the challenges of the wireless technologies. The second theme presented the current state of the wireless technology usage in the Nordic NPPs as well as internationally, especially in U.S. and UK.

Seminar language was English. Seminar program and most of the presentations are available from the Energiforsk's seminar page:

https://www.energiforsk.se/konferenser/genomforda/wireless-in-nuclear-applications/

This report summarises the main discussions from the presentations.

2 Seminar

Seminar had two main themes, which were "wireless technologies, opportunities and challenges" and "wireless in nuclear". In this section, we present the seminar program and summary of all the presentations.

2.1 SEMINAR PROGRAM

Date: 8th of Mar. 2018

Location: Swedish Radiation Safety Authority (SSM), Solna, Stockholm.

Wireless in nuclear applications, program

Time	Presentation and presenter
9:00	Registration and coffee
09:30	Welcome [2], *Niclas Larsson, SSM and Monika Adsten, Energiforsk (Sweden)*
	Wireless technologies, opportunities and challenges
09:45	Wireless - an enabler for effective implementation of NPP digitalization [3], *Anders Johansson, Vattenfall (Sweden)*
10:00	EU project Modern2020 – wireless technology for repository monitoring programme [4], *José Luis García-Siñeriz M., Amberg infrastrucuras (Spain)*
10:30	ICON - Control & Wireless in Nuclear and other activities at the South West Nuclear Hub, Bristol, UK [5], *Guido Herrmann, University of Bristol (UK)*
11:00	Wireless Cyber security [6], *Reijo Savola, VTT Technical Research Centre of Finland Ltd. (Finland)*
11:30	Lunch
12:30	Operator's view on Low Power Wide Area Network (LPWAN) [7], *David Trotter, Telia (Sweden)*

	Wireless in nuclear
13:00	Wireless in Nordic NPPs Wireless at Loviisa Nuclear Power Plant [8], *Niklas Hurmerinta, Fortum (Finland)* Current situation and Future expectations for wireless in NPP [9], *Emil Ohlson, Forsmark NPP (Sweden)*
13:30	Wireless in Nuclear – Nuclear Radiation-Tolerant Wireless Transmitters [10], *Eva Gustavsson, Westinghouse Electric Sweden (Sweden)*
14:00	Coffee break and networking
14:30	Implementation experience and international guidance for wireless technology in nuclear [11], *Chad Kiger, AMS Corporation (USA, remote presentation)*
15:00	Wireless in Nuclear @Exelon [12], *William Ansley, Exelon (USA, remote presentation)*
15:30	Wireless in Nuclear feasibility study [13], *Arto Laikari, VTT Technical Research Centre of Finland ltd (Finland)*
16:00	Conclusions
16:30	End of seminar

2.2 PRESENTATIONS

Seminar program and most of the presentations are available from the Energiforsk's seminar page:

https://www.energiforsk.se/konferenser/genomforda/wireless-in-nuclear-applications/

This section provides short summaries of each presentation.

2.2.1 Opening and welcome

As the hostess of the seminar, Mrs. Monika Adsten, Research Area Director from Energiforsk welcomed the audience to the seminar. Mr. Niclas Larsson Analyst, System Assessment from the Swedish Radiation Safety Authority (SSM) welcomed the audience on behalf of SSM, which had provided the seminar facilities and presented the practicalities of the day. Mr. Arto Laikari, Senior Scientist from VTT Technical Research Centre of Finland Ltd., Finland acted as the moderator of the seminar.

After the welcoming and practicalities, Mrs. Adsten presented the Energiforsk's operation and nuclear portfolio programs for 2018 with its stakeholders. The latter part of her presentation described the ENSRIC – Energiforsk Nuclear Safety Related I&C program, its activities and goals. Vision of the program is to support the decision making process in modernization of I&C systems and main focus areas in the year 2018 are long term operation (LTO) of existing platforms and systems, safety demonstration and licensing and emerging technologies. The topics of this seminar belong to the emerging technologies subprogram. [2]

2.2.2 Wireless - an Enabler for Effective Implementation of NPP Digitalization

Mr. Anders Johansson, Senior Nuclear Technology Advisor from Vattenfall, Sweden, who is also acting as the chairman of the ENSRIC program opened the seminar with his presentation "Wireless - an enabler for effective implementation of NPP digitalization".

Mr. Johansson has 15 years of background in the modernization of Ringhals Nuclear Power Plant (NPP) in Sweden and being the chairman of the ENSRIC program, he presented business drivers for digitalization and wireless usage in the NPPs as the motivation for the seminar. These include the increased safety, rationalized production, lower costs and higher attractiveness.

As examples he presented how wireless could make it possible to increase cost efficiently monitoring of equipment, e.g. pumps with higher amount of sensors providing better information and more signals for condition monitoring. Another example concerned replacing the current communications in NPPs using papers with electronic documents using wireless carry on equipment, which could intensify and speed up many working processes.

Mr. Johansson concluded his presentation giving an example how wireless is gaining space everywhere. When Vattenfall released a trainee recruitment video in YouTube, they received approximately 500.000 views for their video and most of

the views were done with wireless terminals. He ended his presentation welcoming the wireless in to the NPPs. [3]

2.2.3 EU project Modern2020 – wireless technology for repository monitoring programme

Mr. José Luis García-Siñeriz M., Head of New Developments from Amberg infrastrucuras, Spain presented wireless technologies researched and developed for the nuclear repository monitoring programme in the Modern2020 project, which has received funding from the Euratom research and training programme 2014-2018. This research project's main research topic is researching monitoring the geological disposal in Radioactive Waste Management (RWM).

In the beginning of his presentation Mr. García-Siñeriz, presented the project facts and outlined the Geological disposal in RWM and why disposal site should be monitored. He also brought out the challenges and requirements for monitoring the repository. Requirements that he mentioned were:

- Buried operation with no access
- Avoid cables and minimize intrusion
- Power supply and data collect from more than one parameter (standard sensors)
- Lifetime >10 years and 100 years desirable
- Minimize power consumption (low reading frequencies)
- Move from batteries to other alternatives
- Withstand the expected conditions (T+H+M) + Radiation
- Transmission distance 300 - 500 m (deposition galleries – surface)
- Host rock: Clay, crystalline rock or salt

After the requirements, he was presenting the state of the art of wireless communications in mine communication, military communication (submarines and rock phones), and communication in repositories. In the hard underground environment, low frequencies and bigger sized antennas can provide significant communication distances through the rock and other blocking materials.

In the MoDeRn and the following Modern2020 projects, research and development was done with improving short range wireless system, wireless energy transmission with communication add-on, developing a multi-hopping protocol and long distance data transmission, which were presented.

Next Mr. García-Siñeriz presented the long distance demonstrators in Belgium and France, which were using the low frequency radio communication.

Last part of his presentation described a short overview of the alternative power supply sources, which was followed by the comparison of energy consumption distribution using batteries and thermal energy harvesting.

He concluded his presentation showing the repository tunnel layout with radio communication scheme shown in Figure 1. [4]

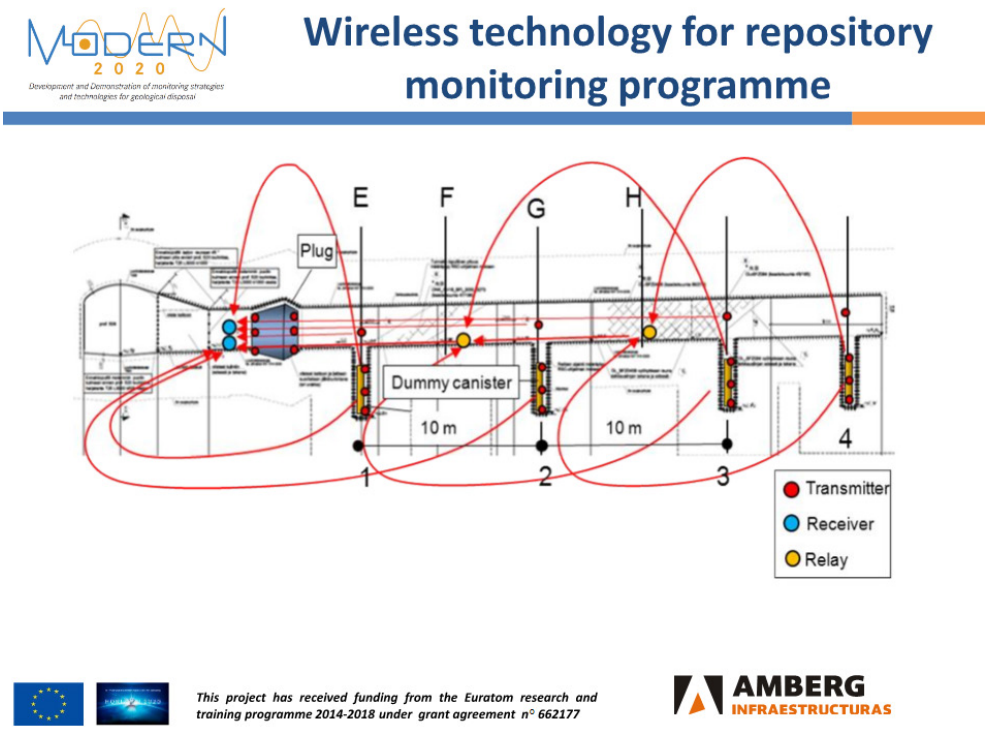

Figure 1 Modern2020 project repository tunnel and its communication scheme.

2.2.4 ICON - Control & Wireless in Nuclear and other activities at the South West Nuclear Hub, Bristol, UK

Mr. Guido Herrmann, Reader in Control and Dynamics from University of Bristol, UK had three themes in his presentation: emerging ICON -project, outlook of wireless future in nuclear and South West Nuclear Hub at the University of Bristol.

In the first part of his presentation, Mr. Herrmann told about the emerging ICON project. ICON project has recently got UK funding and it has 3 project partners, which were presented. Altran is leading the project and University of Bristol and Moltex energy are the other project partners, which all were presented including the key personnel from the University of Bristol.

ICON project aims to the feasibility of using wireless technology in Nuclear Control Systems. Project has received funding but the finalization of the detailed project plan is still under work. ICON key objectives were listed as:

- Control Concept with architectures for wireless communication and wireless asset monitoring and security, (generic and) applicable for the Moltex Stable Salt Reactor (SSR) application
- Development of interruption-tolerant signal and self-powering hardware architecture proposal, to be peer reviewed by Office for Nuclear Regulation (ONR).
- Safety assessment to substantiate claims that wireless C&I in Stable Salt Reactor (SSR) is a viable first-of-a-kind deployment for the technology.

After the objectives he was presenting the Moltex' Stable Salt Reactor structure and some characteristics of it. This was followed by the plans of architectures for ICON control and comparison of some wireless technologies for sensors ending to the selected wireless technology for the ICON project wireless structure. Some consideration of radiation effect to the radio signals was shown and the process of failure analysis for the communication scheme was presented. Project aim is to have a review of the results by the office for nuclear regulation (ONR).

Second part of Mr. Herrman's presentation consisted of the outlook of the wireless technology advantages over wired communication taking account the wireless sensor & control network considerations for nuclear. These are show in Figure 2. This was followed by the discussion about networked control system requirements, limitations and issues like topology, protocols etc.

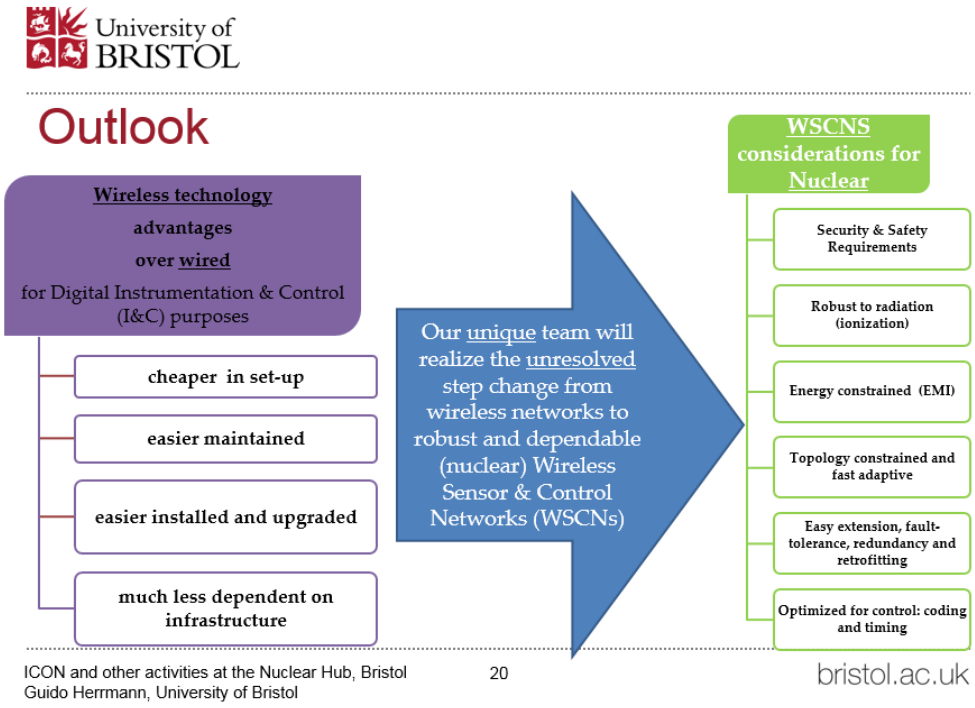

Figure 2 Wireless technology advances over wired.

In the final part of Mr. Herrman's presentation, he gave an overview of the South West Nuclear Hub in UK. After the project portfolio, the players in the area were presented with the hub objectives. [5]

2.2.5 Wireless Cyber security

Mr. Reijo Savola, Principal Scientist from VTT Technical Research Centre of Finland Ltd., Finland brought out the Cyber security issues of wireless communication in nuclear applications. In his presentation, he covered the trends, which are relevant to cybersecurity, cybersecurity considerations in nuclear power

plants, wireless cybersecurity in nuclear applications and cybersecurity risk analysis and measurement.

Mr. Savola started his presentation discussing about the current new technologies and concepts like 5G, IoT, Big data and data in the clouds. According to him these are shaping our society and providing efficient ways to work but they will also create new dependencies and create a more dynamic threat landscape, which require efficient and effective cybersecurity solutions to be developed and taken in to use. Malware will continue to evolve and the complexity and combination of these lead to new security issues. Applying artificial intelligence (AI) and machine learning can help to provide better solutions for the cybersecurity systems.

This was followed by presentation of different levels of nuclear power plant cybersecurity defined by the US Nuclear Regulatory Commission, main cyber risk scenarios by IAEA and vulnerability categories and associated threats in NPPs as listed in a document released by U.S. Department of Homeland Security.

Next Mr. Savola was discussing about some typical wireless vulnerabilities, like configuration problems, rogue access points or device impersonation and encryption problems.

To mitigate the cybersecurity threats, he presented the processes for cybersecurity risk analysis and measurement. Cybersecurity risks often include lot of interdependencies. In order successfully to manage the metrics, hierarchical approach and visualisation is needed. Part of the analysing process is shown in Figure 3.

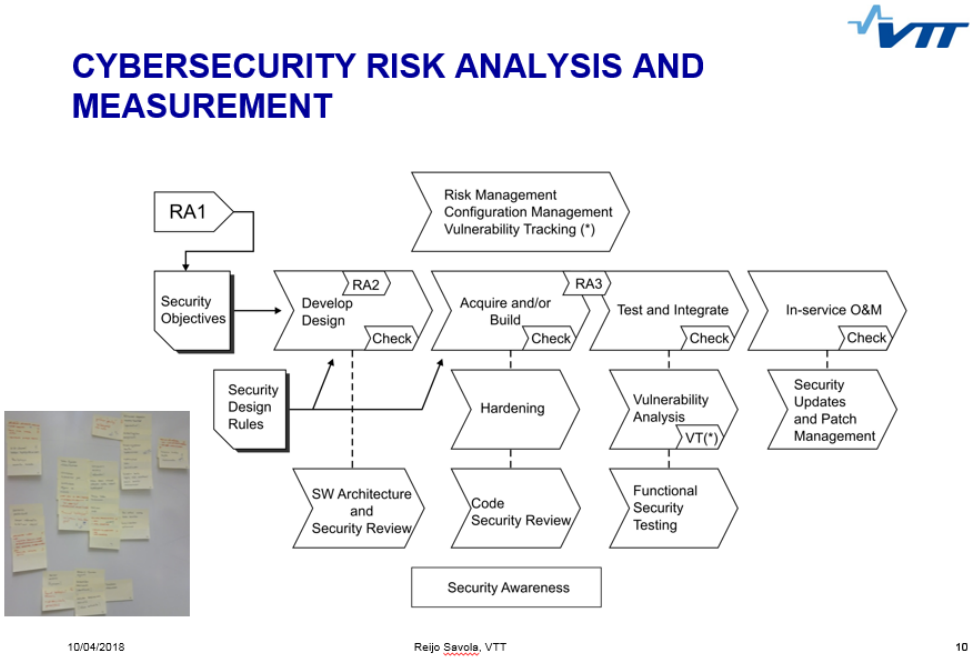

Figure 3 Cybersecurity risk analysis and measurement processes.

At the end of his presentation he showed the concept of the "war room", which is also used at VTT to analyse and simulate attacks, countermeasures and defence in an isolated and safe environment.

Mr. Savola concluded his presentation stating that cybersecurity risk analysis is not yet developed as a widely understood activity. This requires iterative RA and metrics enable implementation of effective and efficient risk-driven security controls. Also systematic security assurance is needed. [6]

2.2.6 Operator's view on Low Power Wide Area Network (LPWAN)

After the lunch break, Mr. David Trotter, Head of IoT Sweden | Divison X from Telia, Sweden had a presentation of operator's view on Low Power Wide Area Network (LPWAN). He presented that the smart societies are built on digital infrastructure, like various wireless and wired technologies, communication, identity services and data analysis enable among others smart transport, infrastructure, eHealth as well as smart homes and building.

Mr. Trotter presented the Telia IoT platform and different wireless technologies offered for various purposes, as one solutions does not fit everywhere. Different systems have different requirements concerning the data amounts, energy consumption and communication speed. He also presented the comparison of narrow band IoT (NB-IoT) and LTE-M and technical specifications of them. He told how NB IoT answers to the need of coverage, 4G/5G to need of capacity and the emerging 5G to the need of low latency. NB-IoT and LTE-M use cases shown in Figure 4 present the various usage possibilities of wireless solutions with analyses of the key issues, like cost, performance, battery life etc.

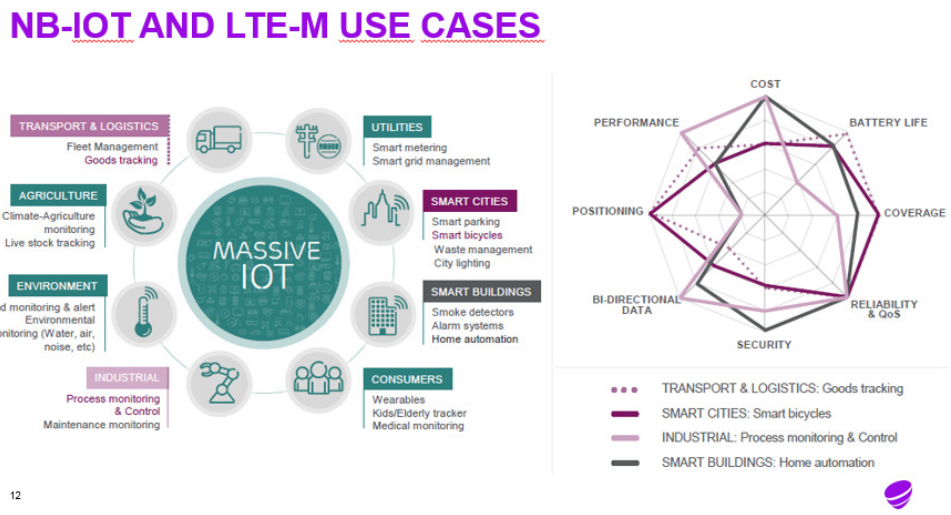

Figure 4 NB-IoT and LTE-M use cases.

After the use cases he was presenting some service examples of Telia customers. These were the Swedish mining company dashboard collecting many IoT sensor data with various technologies and Landvetter airport water tap monitoring

system in the public toilets. He also promoted that an operator has the access to information like where people have moved, when they have moved and how they have moved and what equipment they have used as well as how they behave. All this data opens options for many kinds of novel services. He told that Telia can provide end-to-end services with the orchestration, integration, billing and support needed for successful IoT implementation. He concluded his presentation to the end-to-end security for the IoT communication shown in Figure 5 and promoted that as an operator Telia wants to have active dialogue with their customers and partners. [7]

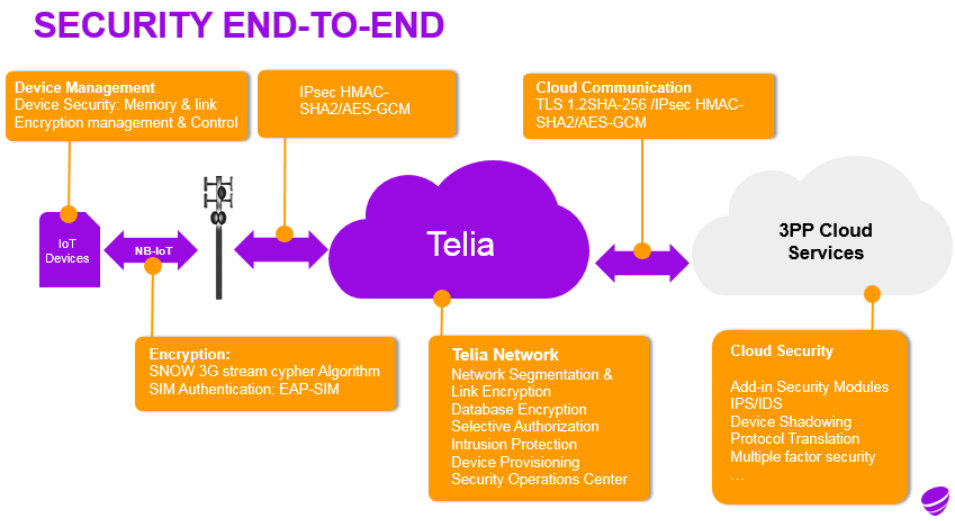

Figure 5 Security end to end in an IoT system.

2.2.7 Wireless at Loviisa Nuclear Power Plant

Mr. Niklas Hurmerinta, Digitalisation coordinator from Fortum, Finland supported by Tomas Nyström, IT Manager started the Wireless in Nordic NPPs part of the seminar with the presentation of wireless wishes at Loviisa NPP, which is a nuclear power plant in South-eastern Finland.

He opened his presentation with the business needs for wireless connection, where the business would like to have wireless applications anywhere in the plant and the drivers for these are e.g. Digitalization, Mobile, handheld devices online, 360° videos, IoT and Data Cloud. Several wireless technologies exist to implement these.

After the business needs, he discussed about the questions of purpose for wireless connection, which are raised in the NPPs, when talking about the wireless. This was followed by the discussion of actual benefits and consideration: are the risks still higher than the benefits.

With the data security levels from "public" to security levels 5 to 1, where the security level 1 is the most demanding, each level consists of equipment and systems, which have the same security level and information security level

requirements. The data communication between Security levels (Security boundary) must be managed in-line with these requirements.

This was followed by the discussion of interference issues and evaluation process of the wireless use in NPPs.

Mr. Hurmerinta concluded his presentation with the wish list for the wireless connections at NPPs, where must haves are:

- secure
- protected
- restricted
- manageable
- safe

Ideally also wireless should be fast, reliable and it should ease work. [8]

Figure 6 Loviisa NPP, Finland

2.2.8 Current situation and Future expectations for wireless in NPP

Mr. Emil Ohlson, Manager - Automation, from Forsmark Kraftgrupp AB Forsmark NPP, Sweden continued the nordic NPP presentations with the current situation and future expectations for wireless in NPP.

Mr. Ohlsson opened his presentation presenting the facts of the Forsmark nuclear power plant in central Sweden, which has 3 boiling water reactors built between years 1980-1985. He noted that there are still a lot of analogue I&C systems in use from the plant start-up.

After the plant presentation, he discussed about the current limited use of wireless at Forsmark. As the plant is very old, like all other Nordic NPPs, there are only few wireless systems in use:

- Communication – DECT, Tetra
- Wireless (radio) control for cranes/traverse (e.g. refueling floors, turbine hall, etc.)
- Card readers for access system (RFID), e.g. access to refueling floors
- Some use in Physical Protection System
- Internet access by WiFi in the administration areas

Next Mr. Ohlsson discussed about the challenges with wireless, which include cyber security issues, electromagnetic compatibility (EMC) issues, as existing

equipment were installed prior to most currently existing EMC standards, challenging building/room layout for wireless and radiation sensitivity of modern equipment. He also mentioned that use of wireless would require an infrastructure and a good business case would be a prerequisite for such an investment.

He concluded his presentation stating that there are no current plans for additional wireless applications at the moment at Forsmark NPP, but the wish list for possible future wireless applications could be:

- Use existing wired infrastructure to create a (temporary) wireless access point in a room to move around with e.g. wireless cameras, measurements Equipment Status Data could be collected by wireless
- Temporary measurements, e.g. during outage
- Measurements with needs/use for flexibility (location/duration/etc.)
- Some Radiation Measurement Systems:
  - × Measurements in refueling floors during outage/fuel handling
  - × Tele dosimetry for certain work tasks

[9]

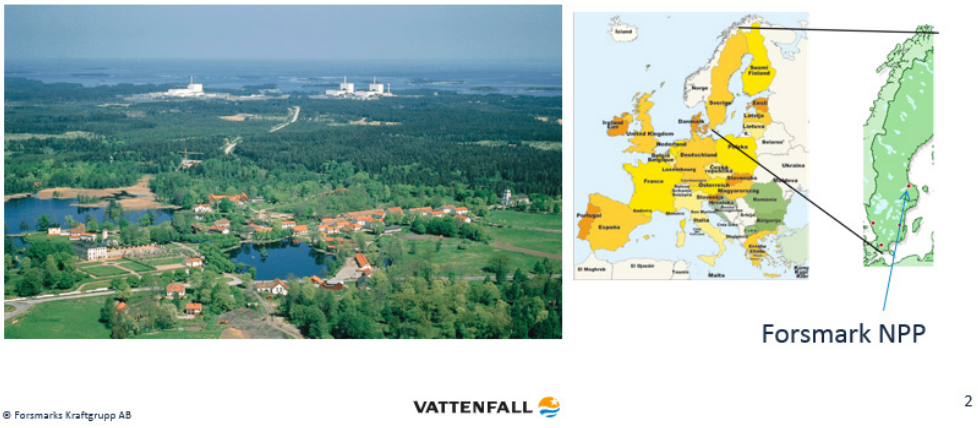

Figure 7 Forsmark NPP, Sweden

2.2.9 Wireless in Nuclear – Nuclear Radiation-Tolerant Wireless Transmitters

Mrs. Eva Gustavsson, Fellow Engineer & Marketing Manager, Global I&C from the Westinghouse Electric Sweden had a presentation with a title of "Wireless in Nuclear – Nuclear Radiation-Tolerant Wireless Transmitters". She opened her presentation with the vision and values of Westinghouse.

In the introduction part of her presentation, she outlined the radiation and temperature tolerant wireless transmitter characteristics. The transmitter is operating inside a fuel assembly top nozzle and it is capable of continuously transmitting neutron flux data during plant operation. Device itself can be powered by harvesting radiation from the core. The transmitter serves also as an enabling technology for other applications such as In-pile sensors and in-containment applications.

As benefits for the technology, Mrs. Gustavsson presented that it can be applied both in to PWR and BWR reactors. As all fuel assemblies could be instrumented, the reactor operating margin could be increased compared to the traditional situation, where only part (33%) of the fuel assemblies would be instrumented.

Next part of her presentation contained information of the proof-of-principle test configuration from year 2015, where the objective was to assess radiation effects on continuously transmitting oscillator. The results were published in the American Nuclear Society February 2017 Nuclear technology journal. This was followed by the proof-of-principle test results from the same year, where the system was tested at the Penn State Breazeale Reactor. Tests were reported to be successful and the wireless transmitter system functioned as expected even with order of magnitude higher radiation tolerance than other discrete components.

After successful tests, Westinghouse was awarded 2016 a research grant for a 3 year project from the US Department of Energy (DOE). Scope of the project was to develop and irradiate amplitude modulated (AM) wireless transmitter based on the previously mentioned tests. The system should be capable of processing a real self-powered Rhodium neutron detector signal. Additionally the project should also develop an in-core neutron flux and gamma harvesting power supply. The test configuration is described in the Figure 8. Both wireless and a wired detector as a reference were installed.

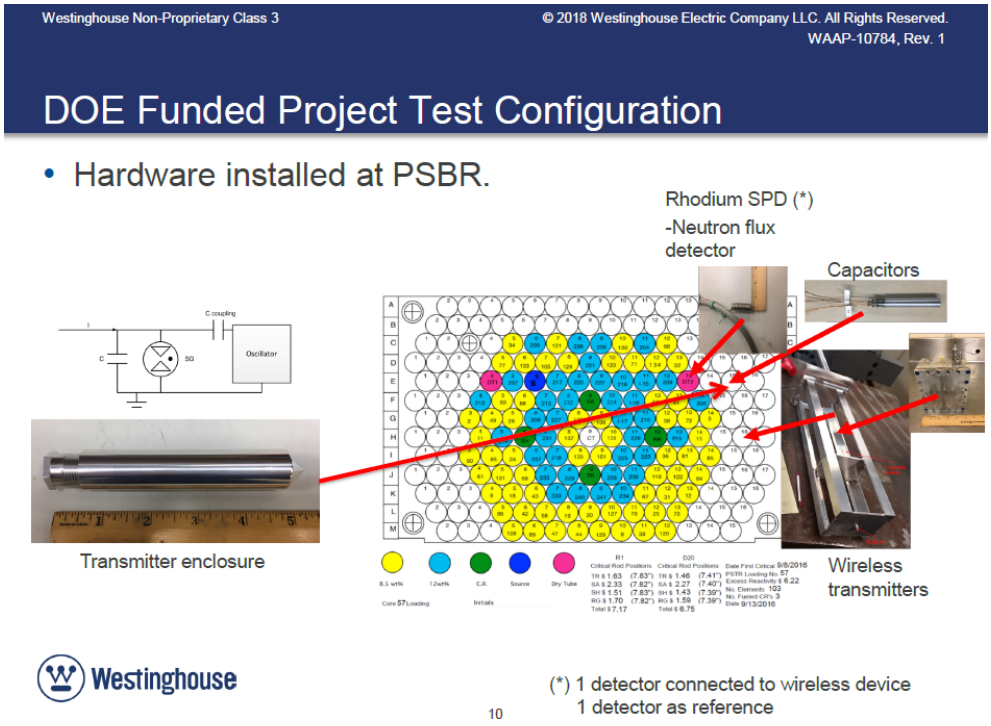

Figure 8 DOE funded project test configuration of Westinghouse.

Presented project results up to date showed promising results that the system is working, as expected. Wireless transmitter was capable of processing the small DC current from the Rh self-powered detector (SPD). Transmitter also outputs a

repeatable and accurate signal proportional to the Rh SPD current in the presence of neutron and gamma radiation.

Mrs Gustavsson concluded her presentation with other wireless transmitter applications of Westinghouse, which included the integral fuel rod real-time wireless sensor, where the sensor is located inside a fuel rod and it provides real time data such as centerline fuel temperature, fuel pellet elongation and rod internal pressure. This wireless sensor has been tested at the Massachusetts Institute of Technology Test Reactor. Other discussed system was the gas void monitoring system, which allows the ultrasonic interface box to be adjacent to the pipe being monitored which significantly reduces cable length. [10]

2.2.10 Implementation experience and international guidance for wireless technology in nuclear

Mr. Chad Kiger, EMC Engineering Manager from Analysis and Measurement Services Corporation (AMS), USA, had a remote presentation with a recorded audio along with his presentation slides and he participated the seminar over a Skype link.

He started his presentation with a summary of AMS activities related to wireless. AMS has a long history with the wireless and they have had numerous funded R&D Projects related to nuclear and wireless with the United States Department of Energy. Mr. Kiger is also active in the standardization and IAEA work.

After the company introduction he presented some of the wireless sensor projects, where AMS has been involved. The first one was the Comanche Peak Nuclear Plant, which he said was the first plant to implement large Scale Wireless Sensor Network (WSN) in USA. In this plant, an industrial implementation of a Wi-Fi Network with over 400 Access Points was installed and wireless sensors for monitoring 42 generation-critical plant assets were used. A power optimization center to monitor process and equipment health data was also installed and AMS demonstrated a wireless vibration monitoring system on an Auxiliary Feedwater pump and motor.

Next part of his presentation was the wireless monitoring of Arkansas Nuclear One (ANO) containment fans. In this R&D project over 100 Wi-Fi access points were deployed to collect sensor data from the sensors monitoring fans for predictive maintenance purposes, as earlier the data could be collected only once every 18 months during maintenance breaks.

Last presented example case was the Oak Ridge National Laboratory High Flux Isotope reactor (HFIR) Equipment Health Monitoring case. In Oak Ridge National Laboratory a system was developed, which can routinely collect vibration and ultrasonic data from the four fan motors as well as the gearboxes. These were earlier not monitored.

Mr. Kiger discussed after these examples about the exclusion zones that are defined in US to Prevent EMI/RFI and which they had to deal in each of these cases. In AMS experience, these exclusion distances are overly conservative and portable wireless devices will typically not cause interference with plant systems.

He presented also some test results of the vulnerabilities identified in a pressure transmitter, which are frequency dependent. When the frequencies reached 2 GHz and above, there was almost no impact from the RF field on the transmitter output. With lower frequencies transmitter's output deviated significantly.

He continued with the EMI/RFI issues presenting the AMS method for reducing exclusion distances while verifying immunity of plant equipment. The process includes walkdowns to identify equipment that may be susceptible to EMI/RFI and mapping of nuclear power plants to characterize the EMI / RFI environment. Going further, the performance of an in-situ immunity testing is executed to verify that nuclear power plant equipment are able to withstand the signals from wireless devices. A test setup shown in Figure 9.

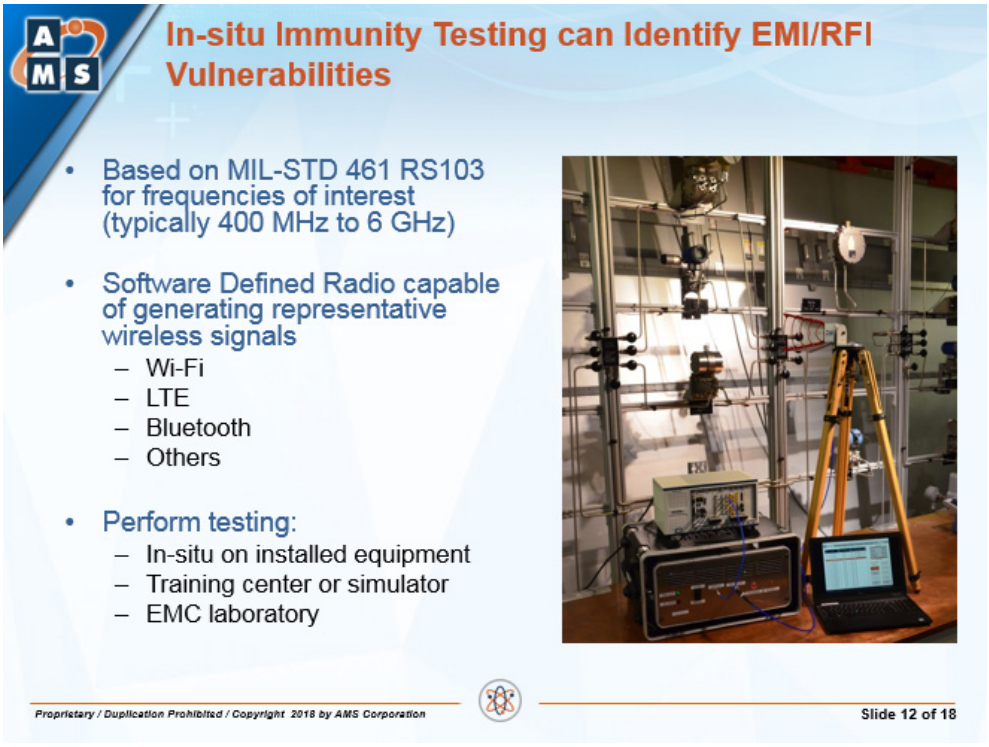

Figure 9 In-situ immunity testing to identify EMI/RFI vulnerabilities.

As a project example he presented how this process was used to allow wireless devices in the power block at Diablo Canyon Power Plant and what vulnerable plant equipment were found and which was the vulnerability ranges of them. All vulnerabilities were mitigated through the use of metallic fabric shielding.

In the final part of his presentation, Mr. Kiger discussed about the IAEA wireless guidance, where he has been working. In 2015, the IAEA initiated a coordinated research project titled Application of Wireless Technologies in Nuclear Power Plant Instrumentation and Control System. Project has been completed and the technical review of the final document is ongoing and it is expected to be published in 2019. Mr. Kiger is also working with the standardization in the

International Electrotechnical Commission (IEC) Standards committee, where he is acting as the chair of the IEC 62003 standard, which provides requirements for the EMC of equipment to be installed into nuclear power plants. He is also acting as a co-chair of the IEC 62988 standard, which covers the selection and use of wireless devices in Nuclear power plants. IEC 62988 Wireless Standard is expected to be published in 2018/2019.

Mr. Kiger concluded his presentation stating that nuclear power plants are implementing wireless technology. There are numerous applications and benefits for wireless technology, which are applicable. The guidance and standards are also changing with the evolving technology and operating experience. Plants need to have confidence that wireless technology will not impact sensitive plant equipment. [11]

2.2.11 Wireless in Nuclear @Exelon

Mr. William Ansley, Innovation Specialist from Exelon Corporation, USA, had also a remote presentation and presented his presentation slides over a Skype link. His topic was the wireless in nuclear at Exelon.

He opened his presentation with an overview of the Exelon corporation, which he told to be the largest competitive integrated energy company in the U.S. and it consists of Exelon Generation and Exelon Utilities.

As an introduction, he discussed about the possibilities, like advanced computer applications with analytics, organizational performance increase and state of the art communications infrastructure and wireless IoT.

After the introduction, Mr. Ansley discussed about the predix asset performance management (APM), which works as a unified platform across all of Exelon Generation. Platform contains several core products and it provides tools e.g. for fault diagnostic, thermal performance, load following and startup & shutdown monitoring. Platform development is ongoing with some parts already implemented and many still being further developed. As an example for value of additional sensors, he presented the “condensate booster pump” example with the current state of limited focus today and how it can be enhanced with wireless sensors to cover wide visibility to the motor/pump failure modes.

He continued his presentation comparing the current state of wireless usage at Exelon and the plans for the future state. Currently in use are the wireless radios, mobile worker with electronic work packages, temperature sensors and limited vibration sensors. In the future state additionally there would be also more vibration sensors, dosimetry, gauge readers, valve position sensors, RFID tags and structural health monitoring using wireless. This way Exelon could add over 1000 sensors per unit. The motivation to have focus on wireless is the cost savings.

As an attractive alternative for boosting the wireless communication he discussed about the distributed antenna systems (DAS), which can bring signals into areas that have poor coverage. The principle of the DAS was presented with the options of antenna or leaky coax cable to distribute the RF into plant. In an ideal configuration for power plant system, it contains several radio modules, which

operate on different channels providing e.g. 433 MHz sensor communication, 450 MHz radio communications, 700 MHz LTE channel for tablets/cellular and 900 MHz sensor communications. He also reminded that there is also a place needed for the Wi-Fi, which is used for the corporate network, dosimetry VOIP phones etc.

Next part of his presentation, Mr. Ansley discussed about the industrial IoT (IIoT) requirements for voice, video, data and sensors. There exists many wireless technologies, but they all are needed to fill up the technology gaps, as various systems have different requirements for power consumption, range, latency and data amount etc. Frequency hopping spread spectrum and lower frequencies have bigger range, but higher frequencies bounces easier.

In the latter part of his presentation, he presented some novel wireless sensors that they have been using at Exelon. First one was the wireless sensor of Petasense inc. which is a self-contained battery powered wireless devices to monitor rotational machinery. Using various on-board sensors, the devices collect raw data, process the data and feed it in to the cloud services for examination, where it can be analysed with machine learning. Next presented sensor was the Cypress Gauge readers using Leaky Wire/Distributed Antenna System (DAS) 900 MHz Network. He told that they have also the wireless gauge, pressure & temperatures sensors and other innovative monitoring technologies, which are good in their opinion for one-way communication. Next of the presented sensors was the Innovative Technologies non-contact vibration sensor (IRIS-M), which uses a video camera to take the measurement without contact. Custom image processing software generates vibragrams or waveforms. The other Innovative Technologies sensor discussed was the on-line thermography, which provides 24/7 thermography and remote fault detection and alarm generation. Sensor technology presentation continued with the used new sensor technologies for on-line monitoring (OLM) using IR cameras, EMSA, DGA and core & winding temperature and cycle isolation sensors.

He concluded his presentation discussing about the Exelon monitoring system architecture shown in Figure 10. [12]

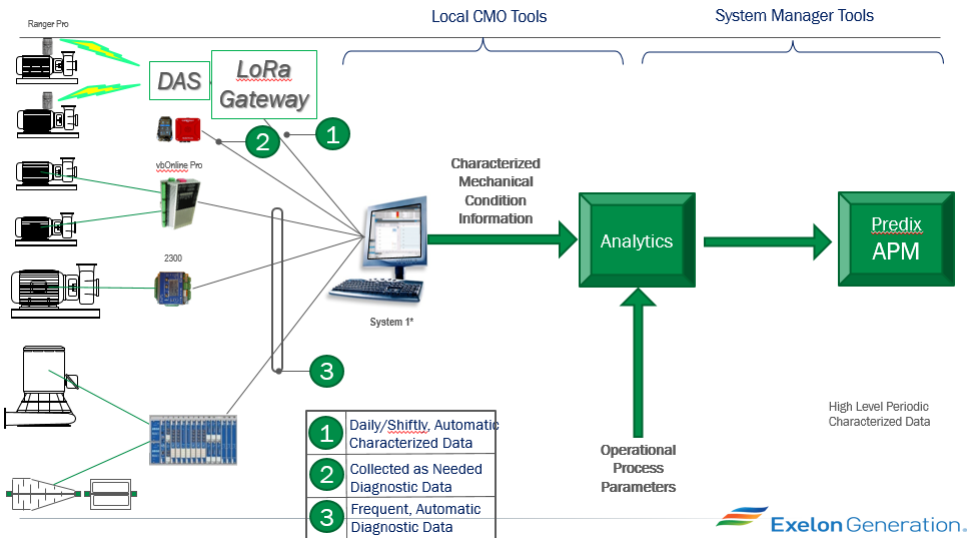

Figure 10 Exelon monitoring system architecture.

2.2.12 Wireless in Nuclear feasibility study

Mr. Arto Laikari,Senior Scientist from VTT Technical Research Centre of Finland ltd., Finland presented in the final presentation of the seminar the "wireless in nuclear feasibility study" report and its findings [1].

Mr. Laikari presented that the motivation for the study were among others the facts that wireless technologies have been developed very much in the recent years. Novel sensors and radio technologies provide the opportunity to create extensive wireless sensor networks to monitor and control complex systems without wires. Wireless also enables the mobility of personnel and applications creating new ways to rationalize the operations in all business sectors and this has already been adopted widely into use. Freedom from wires opens opportunities to develop systems into processes, where wired systems would not be possible to be implemented. Content of the study contains four main chapters, common wireless (radio) technologies, wireless applications in nuclear, wireless applications in other industries and final considerations: To use or not to use wireless in nuclear?

In the first part of the report, the various wireless technologies were briefly presented in the technology overview. For the Nordic NPP interviews, four categories have also been outlined. These are the audio-visual communication, surveillance, monitoring and control and large data transfers. However during the interviews it was found out that the last category was obsolete and the most interesting category is the monitoring and control, as expected.

Next he presented the second part of the study, which covers the wireless in nuclear. It starts from the regulatory and standardization issues, where regulation e.g. in Nordic countries, Finland and Sweden are very similar. Similar restrictions apply also in the US. IEC and IAEA are working actively on standardization and wireless use in NPPs, like was also discussed in the previous presentation.

After summary of NPPs globally the overview of Nordic NPPs was presented, from which it could be clearly seen that the Nordic reactors are very old and wireless technologies are almost not at all used in them. This information came up from the interviews with the Nordic NPP representatives. Main concerns in the Nordic NPPs, like in other countries also, are reliability, security, electromagnetic compatibility (EMC) / - interference (EMI), spectrum management, heavy structures and radiation effects.

Last part of the wireless in nuclear section listed several research and other projects, which have already been implemented in the NPPs globally. Short descriptions of these, can be found from the report.

Wireless in nuclear was followed by the third section presentation about the wireless in other non-nuclear industry. It contained listing of various domains and wireless examples cases, which can act as examples for the nuclear industry. After the domain discussion, he presented individual example-case descriptions from the non-nuclear industry. Section ended to the forecast of wireless industrial IoT growth predictions.

Next Mr. Laikari presented the last chapter, final considerations, which contains the subchapter of considerations of disadvantages using wireless. This chapter contains also the countermeasures to mitigate the disadvantages, as it is predicted that in the future, wireless applications could move in to the Nordic NPPs. After the disadvantages, the next subchapter discusses the advantages of using wireless.

Presentation ended to discussion of the different NPP phases / operation modes, like normal operation, annual outage, service operation before decommission, decommission and emergency. These were followed by the discussion about proposed first wireless steps in Nordic NPPs, as shown in Figure 11.

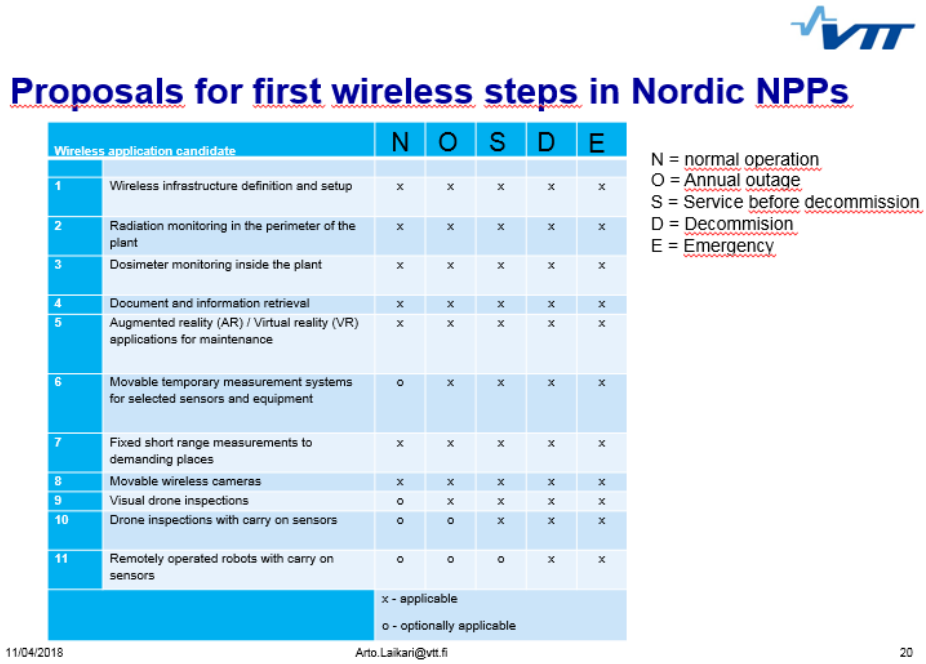

Figure 11 Proposal for the first wireless steps in Nordic NPPs.

Mr. Laikari concluded his presentation stating that wireless has been adopted into use in the other industries and wireless is also on the way in to the NPPs. [13]

3 Conclusions

Seminar presentations showed very well the maturity of various wireless technologies and that vendors and operators are already offering them to many industries, where they have been well adopted into use. Additionally vendors are creating and offering wireless solutions to the nuclear industry.

Nordic NPPs have still been conservative and wireless technologies are not yet used. This is mainly because of the high age of the Nordic reactors, electromagnetic compatibility issues and regulation. Internationally, especially in the U.S., wireless is already moving in to the nuclear plants and several projects have been implemented there.

When IEC standards and IAEA documents concerning wireless in nuclear will be published in 2019, as expected, it can increase the interest to adopt more wireless systems in the NPPs globally.

4 References

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WIRELESS IN NUCLEAR APPLICATIONS SEMINAR REPORT

A seminar was held in March 2018 featuring presentations on wireless installations in nuclear applications, research projects, coming wireless technologies and cyber security.

This report offers an overview of what was presented. Seminar presentations and discussions showed very well the maturity of various wireless technologies and that vendors and operators are already offering them to many industries, where they have been well adopted into use. Additionally vendors are creating and offering wireless solutions to the nuclear industry.

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