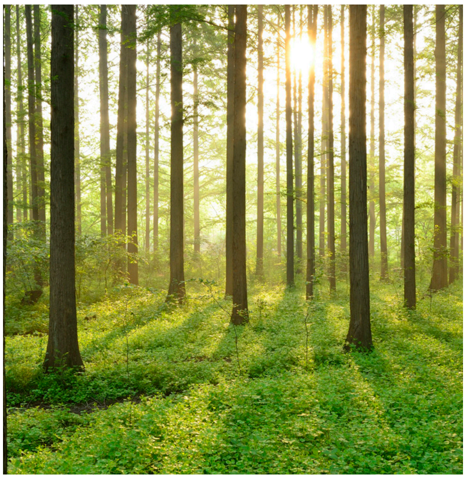
INDUSTRIAL INTERNET OF THINGS (IIOT) IN NUCLEAR SEMINAR REPORT

REPORT 2022:857



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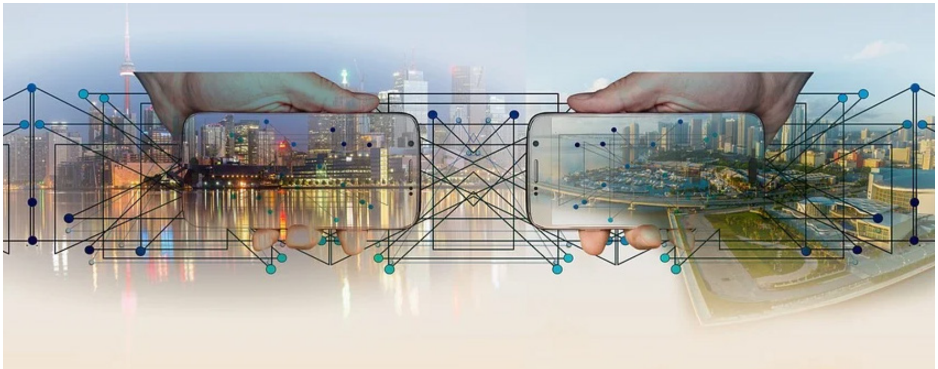

Energiforsk

Industrial Internet of Things (IIoT) in nuclear

Seminar report

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Foreword

Industrial Internet of Things, IIoT is a rapidly growing phenomenon across industries. These technologies provide the opportunity to add instrumentation and enhance monitoring options of the nuclear power plant equipment.

Energiforsk R&D program Digitalization in nuclear applications arranged an online seminar with the topic of Industrial Internet of Things (IIoT) in nuclear applications on the 18th of November 2021.

Arto Laikaro Arto, VTT Finland has written this seminar report which provides summaries from the presentations.

These are the results and conclusions of a project, which is part of a research programme run by Energiforsk. The author/authors are responsible for the content.

Sammanfattning

Industrial Internet of Things, IIoT är en teknik som utvecklas snabbt. Tekniken gör det möjligt att lägga till instrumentering och förbättra övervakningen av kärnkraftverksutrustning.

Energiforsks R&D-program Kärnkraftens digitalisering arrangerade den 18 november 2021 ett online-seminarium i ämnet Industrial Internet of Things (IIoT) i kärnkraftsapplikationer.

Syftet med seminariet var att presentera resultaten av Energiforsks studie av Industrial Internet of Things inom kärnkraft tillsammans med inbjudna talare från kraftverk, leverantörer, konsulter och forskarvärlden.

Seminarierapporten ger en sammanfattning av presentationerna som författarna har gett tillstånd att publicera på Energiforsks webbsidor. Innehållet i den här rapporten har tagits fram med hjälp av de publicerade presentationsbilderna och videorna från seminariet.

Summary

Industrial Internet of Things, IIoT is a rapidly growing phenomenon across industries. These technologies provide the opportunity to add instrumentation and enhance monitoring options of the nuclear power plant equipment.

Energiforsk R&D program Digitalization in nuclear applications arranged an online seminar with the topic of Industrial Internet of Things (IIoT) in nuclear applications on the 18th of November 2021.

Purpose of the seminar was to present the results of the Energiforsk's study of the Industrial Internet of Things in nuclear together with the invited speakers from power plants, vendors, consultants and research community.

This seminar report provides summaries from the presentations, which the authors have given permission to be published in the Energiforsk Internet pages. The content of this report has been created using the published presentation slides and videos.

Abbreviations

4G - 4th generation mobile networks / 4th generation wireless systems

5G - 5th generation mobile networks / 5th generation wireless systems

AI - Artificial Intelligence

APM - Asset Performance Management

AR - Augmented Reality

CBM - Condition-Based Maintenance

CIs - Critical Infrastructures

CM - Condition Monitoring

COTS - Commercial Off-The-Shelf

CRP - Coordinated Research Project

DOE - U.S. Department of Energy

EMC - ElectroMagnetic Compatibility

EMI - ElectroMagnetic Interference

EPRI - Electric Power Research Institute

ERS - Emergency Response System

ETSI - European Telecommunications Standards Institute

FSL – Few Shot Learning

GPS - Global Positioning System

IaaS - Infrastructure as a Service

IAEA - International Atomic Energy Agency

I&C - Instrumentation and Control

ICT - Information and Communication Technology

IEC - International Electrotechnical Commission

IEEE - Institute of Electrical and Electronics Engineers

IIC - Industrial Internet Consortium

IIoT - Industrial Internet of Things

IIRA - Industrial Internet Reference Architecture

IoT - Internet of Things

IP - Internet Protocol

IWLAN - Industrial Wireless Local Area Network

LPWA - Low Power Wide Area

LTE - Long Term Evolution

LTE-M - Long Term Evolution for Machines

LTO - Long Term Operation

MEC - Mobile Edge Computing

M2M - Machine to Machine

NB-IoT - Narrowband Internet of Things

NEA - Nuclear Energy Agency

NFC - Near-Field Communication

NPP - Nuclear Power Plant

NRC - U.S. Nuclear Regulatory Commission

OECD - Organization for Economic Co-operation and Development

PaaS - Platform as a Service

pLTE - Private Long Term Evolution

PRIS - Power Reactor Information System

RTLS - Real-time locating systems

SaaS - Software as a Service

SCADA - Supervisory Control And Data Acquisition

SKB - Svensk Kärnbränslehantering AB

SMR – Small Modular Reactor

SSM - Swedish Radiation Safety Authority

STUK - Radiation and Nuclear Safety Authority of Finland

TETRA - Terrestrial Trunked Radio

URL - Underground Research Laboratory

VR - Virtual Reality

WLAN - Wireless Local Area Network

WMAN - Wireless Metropolitan Area Network

WPAN - Wireless Personal Area Network

WSN - Wireless Sensor Network

List of content

1 Introduction

On the 18th of November 2021, Energiforsk R&D program Digitalization in nuclear applications arranged this seminar as a webinar on Industrial Internet of Things (IIoT) in nuclear applications. The seminar was organised online via MS Teams due to the COVID-19 restrictions.

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

Seminar had three main themes, where the first part presented Industrial Internet of Things (IIoT) and security aspects. Second theme handled the IIoT examples and wishes in the Nuclear Power Plants (NPP). The third theme was covering the IIoT from international point of view providing aspects from a nuclear service provider and nuclear consultant.

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

https://energiforsk.se/konferenser/genomforda/industrial-internet-of-things-in-nuclear/

This page collecting the presentations, includes also the links to the Youtube videos of the shared presentations.

This report summaries the main topics from the presentations and provides a one document synopsis from the day. In case the reader is interested to learn more either from the individual presentations or from IIoT, we encourage you to visit the presentations and the Energiforsk's study of the Industrial Internet of Things in nuclear [1].

2 Seminar

Seminar had three main themes, which were the Industrial Internet of Things IIoT in general, Industrial Internet of Things in NPPs and vendor and consultant aspects on IIoT in nuclear.

In this section, we present the seminar program followed by the summary of all the presentations, to which we have the permission to publish. Due to the ongoing COVID-19 restrictions, the seminar was organized fully online. Although physical face-to-face interactions were not possible, the audience and speakers were offered the opportunity to enter discussion breakout rooms during the breaks of the seminar and several participants utilized this opportunity.

2.1 SEMINAR PROGRAM

Seminar was held as a half day online webinar on the 18th of November 2021 using MS Teams. Seminar was moderated by Monika Adsten from Energiforsk and assisted and co-moderated by Arto Laikari from VTT Technical Research Centre of Finland Ltd. Seminar program is presented in the following Table 1.

Table 1 Seminar program

Time	**Presentation title and presenter**
12:30	Welcome, *Monika Adsten, Energiforsk*
	Theme 1: Industrial Internet of Things (IIoT)
12:40	Industrial IIoT in nuclear - feasibility study, *Arto Laikari, VTT*
13:10	Computer Security Applications of IIoT Digital Twins for the Nuclear Sector, *Paul Smith, Austrian Institute of Technology*
13:40	Break/Join the discussion session
	Theme 2: Industrial Internet of Things in NPPs
13:55	IoT and wireless at Ringhals NPP, *Andreas Björklund, Ringhals NPP*
14:15	IIoT and wireless at Loviisa NPP, *Tomas Nyström, Fortum*
14:35	EDF activities in IIoT, *Eric Perrier, EDF*
15:05	Break/Join the discussion session
	Theme 3: Vendor and consultant aspects on IIoT
15:20	GE activities in IIoT, *Nathan B Askwith and Abhinav Saxena, GE Power*
15:50	Implementation of IIoT and Wireless Technologies in US NPPs, *Chad Kiger, AMS Corporation*
16:20	Concluding remarks, *Arto Laikari, VTT*
16:30	End of webinar/join the discussion session

2.2 PRESENTATIONS

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

https://energiforsk.se/konferenser/genomforda/industrial-internet-of-things-in-nuclear/

Following sub-section provide summaries of each presentation. These summaries have been created using the published presentation slides and videos.

2.2.1 Opening and welcome

Presenter:

- Monika Adsten, Energiforsk

Link to the slide set:

- https://energiforsk.se/media/30576/0_energiforsk_iiot_2021.pdf

Link to the Youtube video:

- https://youtu.be/Rii8nRidw1s

Synopsis of the presentation:

As the hostess and main organiser of the seminar, Mrs. Monika Adsten, Research Area Director from Energiforsk, welcomed the audience to the seminar and outlined the program of the day.

After the welcoming and practicalities, Mrs. Adsten presented the Energiforsk's operation and various ongoing portfolio programs. This was followed by the outline of the current digitalization in nuclear program, which has the vision of "Reducing maintenance and operation costs, increase availability and make nuclear an attractive industry". As one of the dissemination channels, the digitalization program publishes a newsletter 10 times a year. This program has several ongoing and finalised activities, which were briefly presented. One of these activities included also the feasibility study of IIoT in nuclear applications [1], which was presented in this seminar (See next subchapter 2.2.2).

As an outline of ongoing activities in the digitalization program, following topics were mentioned:

- Digital worker –supporting the worker on-site
- Study on suitable artificial intelligence (AI) solutions for nuclear power plants
- Newsletter on digitalization in nuclear 10 times a year

Finalised activities in the digitalization program included:

- Feasibility study IIoTin nuclear applications
- Mapping of robotics and drones in nuclear applications
- Webinar on M&D centres
- Webinar on Metal additive manufacturing
- Field trip to UK

Mrs. Adsten concluded her presentation with the recap of the day's agenda and the practicalities and house rules of the webinar.

2.2.2 Industrial IIoT in nuclear - feasibility study

Presenter:

- Arto Laikari, VTT Technical Research Centre of Finland Ltd.

Link to the slide set:

- https://energiforsk.se/media/30577/1_2021-11-18-iiot-in-nuclear-arto-laikari.pdf

Link to the Youtube video:

- https://youtu.be/Rii8nRidw1s?t=507

Synopsis of the presentation:

Mr. Arto Laikari, senior scientist from the VTT Technical Research Centre of Finland Ltd. presented the Energiforsk report 2021-726, Industrial Internet of Things in Nuclear and its findings. [1][3] Additionally this first presentation acted as the introduction to the IoT technologies and other presentations during this seminar.

As principle backgrounds for this report are the digitalisation being one of the mainstream driving themes across industries and society and the fact that the Nordic NPPs have been designed and constructed before the digitalisation era. This report is based on literature reviews from various sources, experience gained from other projects and on-line surveys with selected experts from the Nordic NPPs. It was also mentioned that as being a public report, there was the need to balance with the confidentiality, IPRs and openness, when writing the report.

After the introduction the four main sections of the report were listed, which were the general IIoT technologies in brief, IIoT applications in nuclear, IIoT applications in other industries followed by the final considerations. Next Mr. Laikari presented briefly each of these sections.

First of these main sections discussed about the IIoT technologies in brief. The five sub-topics in this section were the wireless technologies, data management, cyber security, IoT platforms and IoT forecasts.

Wireless technologies are mentioned to be an important building block in most of the IoT environments. It was said that this topic has been more deeply handled in the earlier Energiforsk report "Wireless in Nuclear Feasibility Study" [4]. In this currently presented IIoT report, there is collected a brief updated summary to make the report a standalone document. Although the wireless technologies have traditionally been considered as a technology to be avoided because of interference with the existing legacy equipment, rising interest to adopt wireless technologies in the Nordic NPPs can be seen. Mr. Laikari mentioned that the audience will hear later during the day examples from pilots both from Ringhals and Loviisa plants. Additionally, he mentioned the recent press release of Fennovoima from November 2021. Fennovoima company is designing to build a new NPP in Finland. In this press release it was mentioned that there will be planned and taken the authority network Virve 2.0 in to use in the support and auxiliary buildings of the plant. Virve 2.0 services will operate on 4G and 5G networks.

Next important IoT subtopic was the data management. IoT creates a lot of data, which need to be processed and interpreted, because otherwise these masses of data wouldn't be useful for humans. In the data management section, the concepts of cloud and edge computing were described and brought out that there exist several big data analytics platforms, which are connected also the IoT systems. When talking about big data, artificial intelligence and deep learning are also concepts, which come up to handle the massive amounts of data.

In nuclear sector, all operations are safety critical. Connectivity, accessibility and new features of IoT solutions bring new technological opportunities but on the other hand bring also new risks and threats, which makes cyber security as one of the important corner stones for these systems. Vast group of malicious actors are active with different agendas for their cyber-attack, cyber sabotage and cyber espionage campaigns in mind. It was also mentioned that many news has shown that these groups are well financed and resourced. Because of these facts, security issues need to be taken into account already from the beginning of the planning. More issues concerning cyber security was mentioned to follow in the next presentation of Mr. Smith from AIT (see section 2.2.3).

As the IIoT area us very complex, Mr. Laikari mentioned that without an IoT platform, the challenges for building an IoT application are significant. These include developing the application logic, user interface and database and developing data analytics. He mentioned that several IoT platforms exist as well as service providers for them and in the conclusion section more discussion about the platforms has been presented. As an important key issue, he mentioned that understanding what each provider offers is required when IoT platforms are evaluated. Selection of the underlying platform can also be a critical decision for an IoT-based service developer.

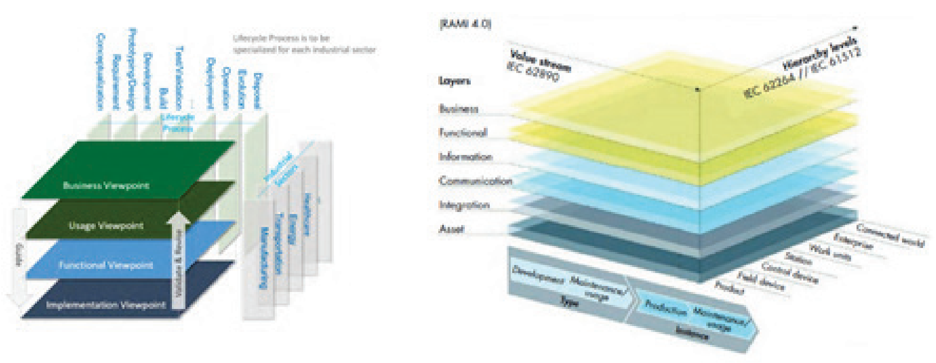

Figure 1 Examples of IoT architectures: Industrial Internet Consortium's (IIC) Industrial Internet Reference Architecture (IIRA) on the left side and the Reference architectural model Industry 4.0 (RAMI 4.0) by ZVEI (© Platform Industrie 4.0) on the right side.

As the last topic in the IoT section, it was told that many companies and institutions are making forecasts about IIoT technology evolution and expansion both technology as well as market wise. Unfortunately, these market and technology research reports are often subject to a charge, so they cannot be used or referred in a public report. But as a general message from these, they all forecast increasing amount of IoT and wireless adoption and usage in all industrial sectors.

Second main section of the report handled IIoT applications and issues in nuclear field. Sub-topics in this section were the regulatory requirements and restrictions, standardisation, IIoT applications in the Nordic NPPs and finally also IIoT applications in international NPPs.

In the regulatory section Mr. Laikari told that several countries (in Europe) use the IAEA Safety Standards (Figure 2) as a basis for formulating national regulations and that there are other international forums also involved, like the OECD Nuclear Energy Agency (NEA) and Western European Nuclear Regulators Association (WENRA) with whom the local regulators interact. In the Nordic countries, STUK in Finland and SSM in Sweden are the national regulators and authorities applying these regulatory issues into local use.

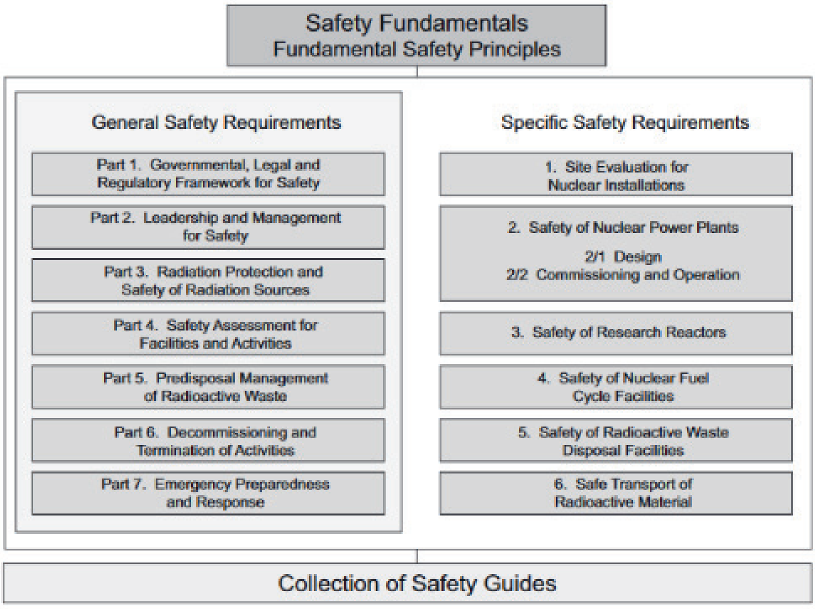

Figure 2 Example, the long-term structure of the IAEA Safety Standards series.

In IIoT, many technologies are involved, both from Nuclear field & ICT field. This results to the fact that there are very many standardization bodies working in this area, like IAEA, EPRI, IEEE, ISO, ETSI and many others. In the report, several standardization links have been listed for the reader.

Mr. Laikari brought out that as the Nordic NPPs (Figure 3) have been designed and constructed before the era of digitalisation, IoT and wireless usage is still quite modest in them. He mentioned that one main driver for new technology adoption in the Nordic NPPs could be the modernization of old NPPs in the Long-Term Operation (LTO) programs. Additional examples from the Nordic nuclear field are the nuclear waste organizations Posiva and SKB, which are using modern technologies for their nuclear repository site testing projects, which the plants could also follow.

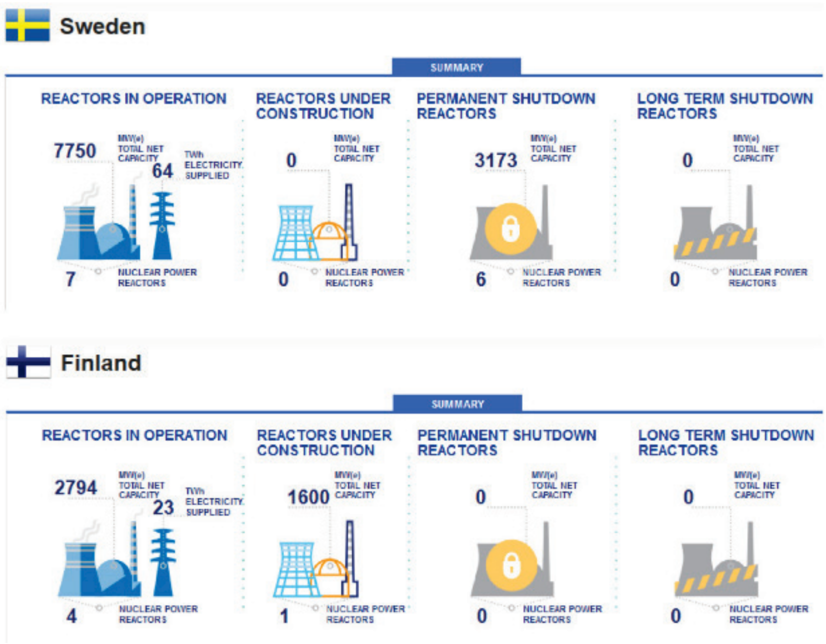

Figure 3 15 reactors in the Nordic countries, source IAEA Power Reactor Information System (PRIS).

He mentioned also that one big challenge to report the current state of the Nordic NPP IoT usage is that most of the NPP information is classified or at least restricted and not publicly available. Some general examples have been collected into the report, which include among other:

- Local (temporary) measurements have been implemented e.g. wireless vibration monitoring
- Safeguards surveillance technologies (Seals and Cameras) are in use
- Fire alarm using TETRA SDS messages
- Short range RFID identification
- Perimeter radiation control

He also mentioned that later during the seminar, insights from Ringhals (see section 2.2.4) and Loviisa (see section 2.2.5) plants will be heard.

Next topic of the presentation was the IIoT applications in international NPPs, which contains a non-comprehensive list of examples of various (I)IoT projects and pilots within international NPPs with short descriptions across the world. These include both pilot projects and research approaches with brief descriptions. He mentioned that there was partly the same challenge information being classified and not publicly available, when searching information. But as the world is big, there are also several open examples, which have been collected in the report, like:

- Equipment monitoring of various devices like valves, pumps, motors, leaks, vibration, temperature
- Various radiation monitoring system, some even with drones
- Wireless applications in nuclear decommissioning and robotics in NPPs
- IoT and data platforms

- Even blockchain pilots/proposals both for IoT device support and nuclear material tracking

He mentioned that during the seminar, more insights from the international speakers from EDF (see section 2.2.6), GE Hitachi (see section 2.2.7) and AMS Corp. (see section 2.2.8) will be heard.

The third main section of the report presented some brief examples from other industry IIoT usage from the fields of electric power and energy systems; environment, health and safety; and maintenance. From the Nordic telecom operator, a listing of example IoT projects has been presented in the report as the Nordic telecom operators might already be partners for the NPPs and also provide future services to them.

Next Mr. Laikari presented the last chapter of the report, which contains the summary and final considerations. He told that there does not exist one single correct way for successful IIoT adoption. This big change in the NPPs is a long journey with many traps and obstacles on the way. He repeated that one probable reason for the change can be the LTO-programs of the NPPs, which can create the need for IIoT adoption, as the replacement of the old I&C technologies will most likely turn more difficult in the future.

Important part of the conclusion section are the guidelines and starting points for IIoT adoption process. New options bring also new threats. Main gaps to fill were mentioned to be:

- Integrating IoT solutions into existing business workflows
- Managing data
- Identifying use cases and applications

He mentioned that the advice is to keep the big picture in mind, even with small experiments, because businesses tend to focus too narrowly when thinking about how to use IoT. But on the other hand, sometimes small isolated experiments are first needed to start the change. In the discussions with the NPP representatives it has been often said that business cases are needed to support the project creation. This implies that business case and strategy planning should be done parallel in an iterative way and often the "missing infrastructure" can hinder or slow the IoT projects. As twelve potential starting points for IIoT business case in NPPs he presented the following:

1. Improve internal processes with enhanced monitoring
2. Bring cost savings with predictive maintenance and analytics
3. Improve security
4. Improve safety
5. Improve resilience
6. Improve data collection, management, and analytics
7. Increase automation
8. Track assets
9. Improve logistics
10. Replace existing legacy I&C systems in small scale
11. Replace existing legacy I&C systems in large scale
12. Create digital twins

Strategy planning is also important. The NPPs are in operation and processes are already defined and working. Changes to the original business processes and IT-strategies need to be carefully evaluated, because IIoT adoption can and will impact to the work processes and require changes to them. In some sources it is said that implementing greater number of IoT use cases often correlates with financial success. One important strategical issue is also the service model selection for the IIoT, how much own effort can be invested in the process. Is it implemented using Infrastructure as a Service (IaaS), Platform as a Service (PaaS) or Software as a Service (SaaS) service model?

As his final concluding guidelines to start planning the IIoT system, Mr. Laikari told that the technology and service providers, involved in the design and implementation process, will offer guidelines and tools to help the planning, but the buyer should self be aware of possibilities and pitfalls. Providers will sell the concept, which is familiar to them. There exist lot of offerings for products, devices and services, like IBM's Watson, Microsoft Azure, GEH's Predix, Schneider's EcoStruxure, Honeywell's Sentience, Telecom operator's IoT, Amazon Web Services (AWS), Cloud IoT Core. In the report, some toolkits and guidebooks are listed, which can be used as starting process, when beginning the work and learning. There is a lot of material available, which can be challenging, as the time is often the most valuable resource.

2.2.3 Computer Security Applications of IIoT Digital Twins for the Nuclear Sector

Presenter:

- Paul Smith, Austrian Institute of Technology (AIT)

Link to the slide set:

- https://energiforsk.se/media/30581/2_smith_digital_twins_computer_security.pdf

Link to the Youtube video:

- https://youtu.be/Rii8nRidw1s?t=2214

Synopsis of the presentation:

The second presentation [5] of the day was held by Mr. Paul Smith, senior scientist from the Austrian Institute of Technology's (AIT) Centre for Digital Safety and Security. His presentation title was "computer security applications of IIoT digital twins for the nuclear sector, which he had composed together with his colleague David Allison. They have been supporting in the recent years the IAEA with its security initiatives including research and training.

As a start, Mr. Smith presented briefly the Austrian Institute of Technology's (AIT), which is the largest applied research centre in Austria based in Vienna and some of its main research topics. This was followed by the outline of the presentation, which consisted of following three main topics:

- What is a digital twin, including common applications?

- A word on the computer security of digital twins
- Applications of digital twins to computer security activities

As the first topic, Mr. Smith mentioned that the definition of a digital twin has not yet been standardised. There is talk ongoing in standardisation organisations, like IETF, about the definition. Generally speaking, a digital twin is a virtual representation of a real-world system that uses real data for analysis and improvements (Figure 4).

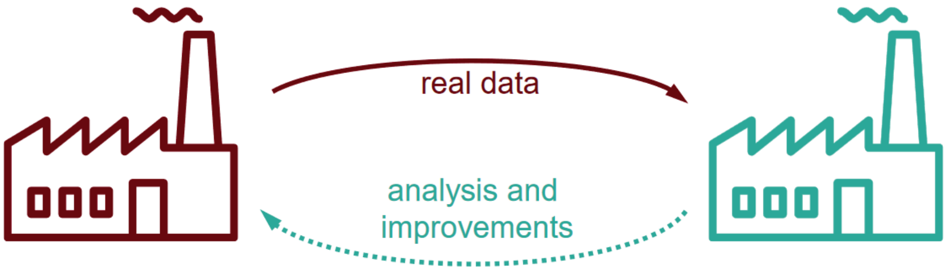

Figure 4 What is a digital twin?

Next, he presented some of the common applications of digital twins. These examples included:

- Predictive maintenance
- Product design
- State estimation
- Increasing process efficiency

He mentioned that as additional value for using these digital twins, the interesting research question is, could they be used also for computer security applications? One part being the usage of digital twins for security and the computer security of the digital twins themselves.

He continued that ensuring the computer security of digital twins is a concern, as in the nuclear domain, theft of sensitive nuclear information could be a concern. He mentioned that one can think of a digital twin as a potentially highly distributed control loop; therefore, they are potentially susceptible to the same cyber-attacks as control systems. These include (stealthy) false data injection attacks, control command manipulation and model as well as data integrity manipulation. He also mentioned that there are several computer security solutions that can be applied to address these risks.

Next Mr. Smith presented, how the digital twins can be used to for computer security risk assessment. As the risk is typically calculated as risk = likelihood x impact, the digital twin can be used both to provide quantitative estimates for the likelihood as well as for the impact. According to Mr. Smith, the digital twins can be used to make the estimates of likelihood and impact less subjective (Figure 5).

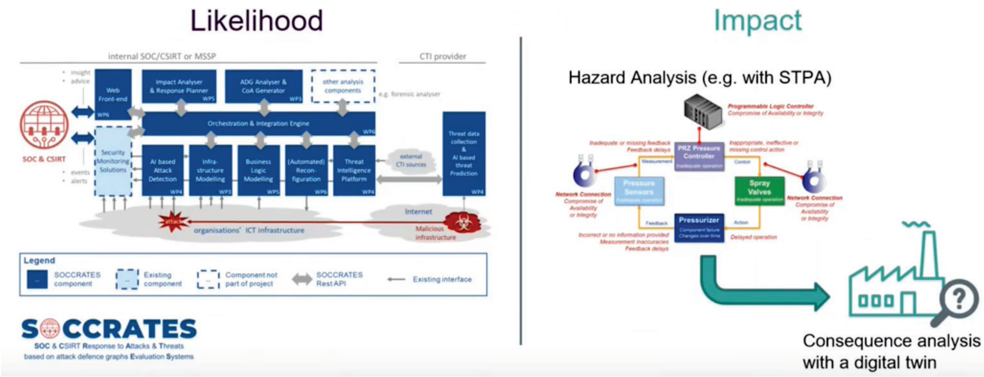

Figure 5 Analyzing likelihood and impact of risks (Source: EU project SOCCRATES)

Next Mr. Smith presented another usage of digital twins for the decision support for incident response. Here digital twins can be used to support cyber physical incident response workflows for anomaly detection, root cause analysis and state estimation (Figure 6).

Level	Example Questions
1. Association	What is the root cause of this event?
2. Intervention	What if I change my firewall?
3. Counterfactuals	Was it the new policy that caused the security breach?

Source: Judea Pearl

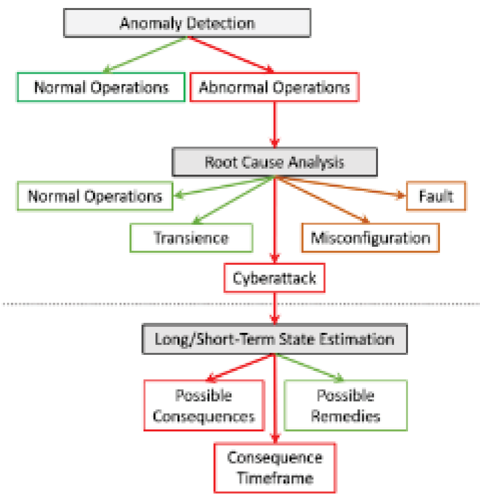

Figure 6 Anomaly detection, root cause analysis, state estimation

Digital twins can also be used to train machine learning models (Figure 7). It may be desirable to use machine learning models to classify the observed behavior of a target system, for example, classifying attack types, abnormal system states and so on. But he mentioned that the challenge can be that there is not an abundance of data that can be used to train models that classify rare behavior.

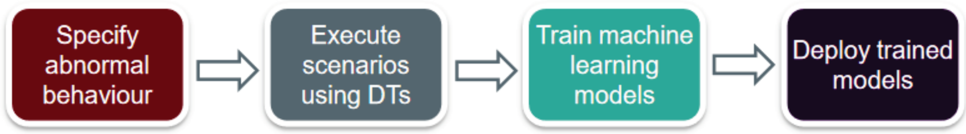

Figure 7 Training machine learning model

As another challenge, he mentioned that the model is not a 100% replication of the actual real-life situation, but the model can be gradually updated using machine learning techniques, such as transfer learning Few Shot Learning (FSL).

As the last topic of digital twin usage examples, Mr. Smith presented the computer security training. Digital twin enables computer security training and exercises on representative systems without operational risks. As an example, he mentioned the Asherah Nuclear Simulator (ANS) developed as part of IAEA CRP J02008, which has been used for several exercises. He also mentioned that a major challenge is developing models that are robust to simulated cyber-attacks and integrating models with representative hardware.

In his conclusion of the presentation, Mr. Smith presented that the digital twins are becoming an increasingly significant technology for non-security applications. Benefit could be enhanced by applying them also to computer security. In many cases, these applications relate to decision support for various computer security processes, like secure design, risk assessment and management, incident response and training. Digital twins can potentially provide more accurate and quantitative insights for the decision support and allow the execution of scenarios that would not be permitted or possible on real systems (e.g. to support model training and exercises).

Value of the digital twins could be added by considering the relationship between digital twins and other emerging technologies (in the nuclear sector), such as Cloud, Industrial IoT, AI and Machine Learning.

2.2.4 IoT and wireless at Ringhals NPP

Presenter:

- Andreas Björklund, Ringhals NPP

Link to the slide set:

- https://energiforsk.se/media/30578/3_vattenfall-ringhals-energiforsk-wireless-and-iiot-211118.pdf

Link to the Youtube video:

- https://youtu.be/Rii8nRidw1s?t=5115

Synopsis of the presentation:

After the first break in the seminar, Mr. Andreas Björklund, who works as a manager of the plant strategy and investment portfolio at Vattenfall in the Ringhals NPP gave a presentation with the title of "Ringhals and Forsmark, digitalization – wireless and IIoT" [7].

He works also at the Forsmark NPP. For the background, he presented the nuclear plants operated in Sweden, which consist of 2 PWR reactor in Ringhals at the west coast of Sweden and 3 BWR reactors in Forsmark on the east coast of Sweden. The main content of the presentation handled Ringhals NPP, but the presentation contains some connections also to Forsmark site.

In the first part of Mr. Björklund's presentation, he discussed about the foundation and asset management. Digitalization is in general a part of Vattenfall's Asset Management, including also wireless and IIoT technologies. He mentioned that monitoring, diagnostic and prognostic are in particular a part of performance monitoring based on WANO Performance, objectives and criteria. Data and information are used within the Scram reduction program and reliability centred maintenance and the focus areas are the systems and components classified as single point vulnerability and/or critical. The target group for these are the system engineers and maintenance network in the MDP centre.

Next, he presented, how the mapping of the digital eco-system has been planned at the site. Categorisation was presented to be from the operational personnel and ways of working and from the other side from the plants and assets side and is shown in Figure 8.

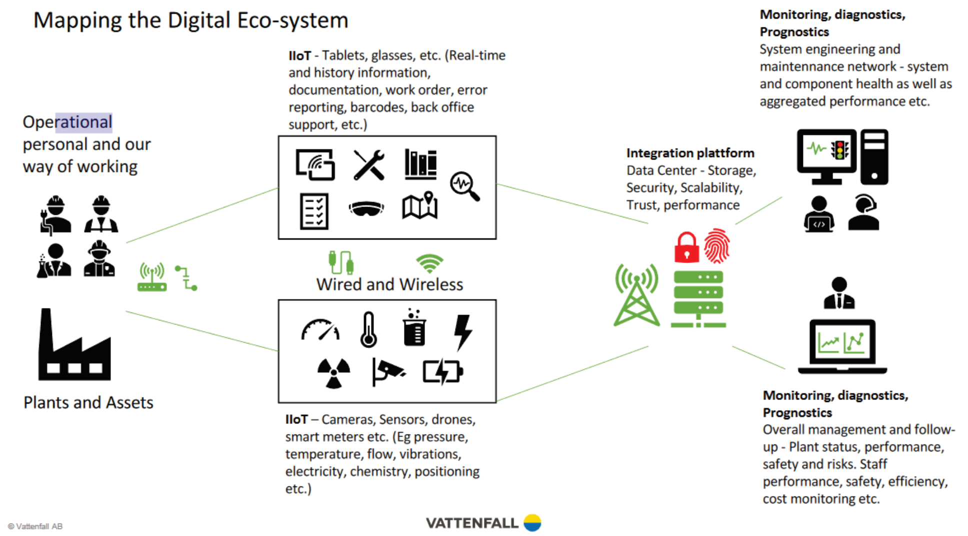

Figure 8 Mapping the digital eco-system.

In order to achieve the working digital eco-system, he presented several prerequisites, which are needed. These included:

- IT –Safety and Security (Plant network and administratively network including categorization of sensitive data)
- IT Infrastructure – Wired and wireless (Safe, secure and available with full coverage within the plants)
- IT Architecture–Storage and servers including data management through data warehousing and data catalogue
- Standards and regulations–Over all alignment to maintain the construction basis
- Partners and stakeholders–Experience coverage and good practices

The prerequisites were followed by the missing pieces, which are the wireless and IIoT platform. Wireless installations are planned to be started in Ringhals in 2022 with successive implementation facility by facility. The network should cover the plant facilities and it will be used only for informative data, not for controlling equipment. Selected technology for wireless is WiFi, with future compatibility for ISA.100, Wireless Hart etc. which are classified for industrial use. Backbone of the network will consist of wired copper and optical fibre to ensure robust solution.

Mr. Björklund mentioned as challenges for the wireless network to be:

- Cyber Security
- Separation and shielding to avoid disturbance of existing equipment
- Short equipment lifecycle of 7-10 years
- New extensive preventive maintenance of batteries related to IIoT equipment
- Extensive cabling to achieve a backbone
- Technical standardization and rules for IIoT equipment
- Constantly new, upcoming technologies and protocols such as for example 5G

In the near future the aim at Ringhals is the plan for monitoring, diagnostics and prognostics to start implementation of a MDP-center for Ringhals 3 and 4 and create user interface with dashboards. Indicators for system and component health assessment including alarms and notifications will also be created with applied analytics for pattern recognition and prediction. Governing the condition-based maintenance and predictive system health is also seen an important topic.

Next Mr. Björklund gave the purpose and requirements for the MDP centre development. These are the reduced maintenance cost and a better component and system availability as well as reliability. MDP centre can provide early indications of possible/potential fault to avoid failures and breakdowns, avoid corrective maintenance and finally also avoid unnecessary change of components. Other benefits are foreseen to be the reduction of manual plant inspections, optimisation of maintenance and adoption of predictive maintenance principles, which will lead to life-time extension of components through stronger real time monitoring of leading health indicators.

The prerequisites of the MDP centre were presented next and these should be defined, gathered and cooperated in close contact with internal and external actors. These prerequisites included:

- Define objects due to single point of vulnerability and/or criticality
- Define target areas well as standards and best practices for IIoT, monitoring and prediction (e.g. vibrations, temperature, flow, pressure, position etc.)
- Define data and information sources and gather relevant input
- Define the digital and integration platform including:
  - × Tools (Hardware and software)
  - × Datamodels and algorithms
  - × Visualization and user experience

As a conclusion, Mr. Björklund was listing the foreseen challenges to achieve these goals. These were the data/information management and governance as well as understanding and confidence. Gaps in competence skills (e.g. IIoT, Data science and UX) and the search of the best suitable data model for the object to fulfil the purpose were also seen difficult. In the working ways the inclusion of predictive and condition-based maintenance in today's working methods and processes can also create problems and finally the priority and business case (workload and effort) were mentioned.

2.2.5 IIoT and wireless at Loviisa NPP

Presenter:

- Tomas Nyström, Fortum

Link to the slide set:

- NA

Link to the Youtube video:

- NA

Synopsis of the presentation:

Mr. Tomas Nyström from Fortum had a presentation about insights of the private LTE architecture and its planning process taken into use at Fortum's Loviisa NPP, but due to the company policy restrictions, this presentation nor video cannot be published in an open forum.

Reader can visit the press release from the Finnish transport and communication agency Traficom, with the title of "New leaf turns in the history of telecommunications - Fortum's Loviisa Power Plant gets its own mobile network" published on 7th of July 2020. [7]

2.2.6 EDF activities in IIoT

Presenter:

- Eric Perrier, EDF

Link to the slide set:

- https://energiforsk.se/media/30645/5_edf-activities-in-iiot.pdf

Link to the Youtube video:

- https://youtu.be/3ttWrQ24lrM

Synopsis of the presentation:

The third NPP presentation was held by Mr. Eric Perrier de La Bâthie from EDF R&D and he is working with projects in nuclear sector, but also in hydro power plants and windmills. His presentation title was "EDF activities in IIoT". [8]

As the first topic, Mr. Perrier presented the roadmap and time line for the EDF connect-project, which is dealing with the deployment of private networks in EDF NPP sites and where the long term plan is to make a roll-out of the private wireless networks to all of their NPPs. This roadmap, including the selected wireless technologies and frequencies (4/5G, NB-IoT, LoRaWAN, Wireless HART, Tetra etc.) is presented in the following Figure 9.

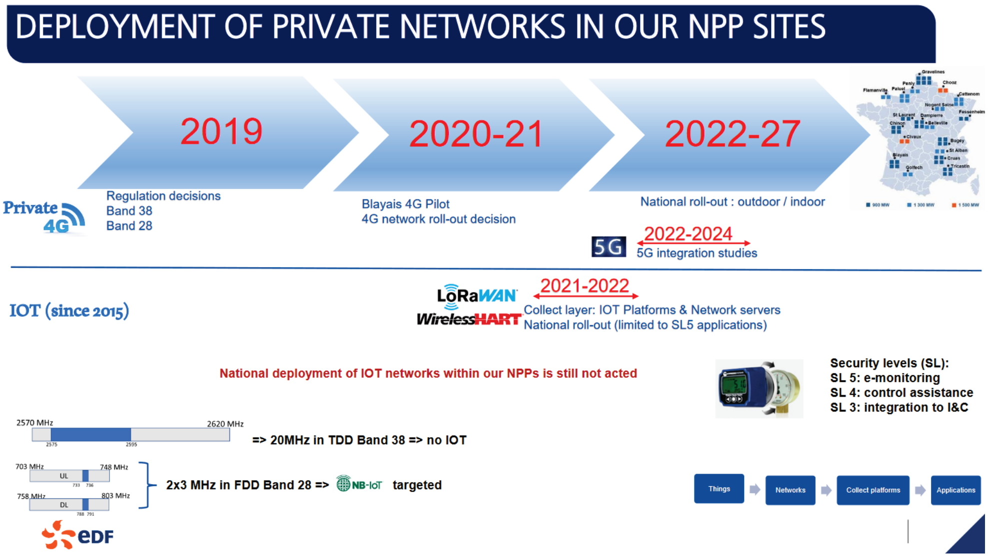

Figure 9 EDF deployment of private wireless networks in EDF NPP sites.

One of the motivations to start planning and using of the new private wireless networks at EDF was that the service life of the old DECT communication network was approaching its end. For the IoT networks, it was said that currently the security level SL 5, which are just for monitoring purposes and not connected to the I&C systems, are easier to be replaced and connected to the IoT systems, but the ones connected to control systems are still under discussions.

Next Mr. Perrier was presenting the IIoT & telecom integration building blocks of EDF (shown in Figure 10), where the IIoT infrastructure deployment strategy is to be linked with the strategies on the different verticals and critical infrastructures of security levels SL 4 / 3, where SL 4 is the control assistance and SL 3 is the integration to I&C. The integration to these higher security levels is still under discussion, like he mentioned earlier.

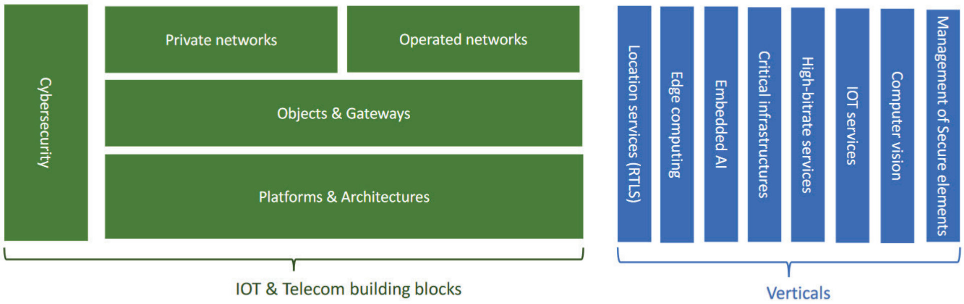

Figure 10 IIoT and Telecom integration in EDF.

As a summary of use case amounts, he told that on the definition level there are 47 use cases, 10 are in pre-study phase and 3 are in the technical integration phase. In the piloting phase there are 4 cases, and these are already validated cases almost ready to be catalogued. However, there are not yet any catalog integration ready use cases. This is because there are not yet massively ready wireless networks available in the NPP. The examples presented, were for one NPP and there is not yet any national view, how to spread them to other plants, although this is the long term plan. Some listed use cases were:

- Thermic monitoring of transformers (pre-study phase)
- Valve leakage quantification (technical integration phase)
- Max time of exposure in the machine hall (technical integration phase)
- Frazil protection removal (pilot phase)
- Valve leakage detection (pilot phase)
- Air quality monitoring (pilot phase)

Some of these use cases were further presented in their own slides. First one was the valve leakage detection in the pilot phase, where the need was to analyse the temperature evolution of important calves of the secondary circuit to locate yield-losses and optimise unit shutdown maintenance by targeting the right valves. The motivation for this was that 1 MWh over 1 year causes 350 kEUR costs. The data flow in this use case is presented in Figure 11.

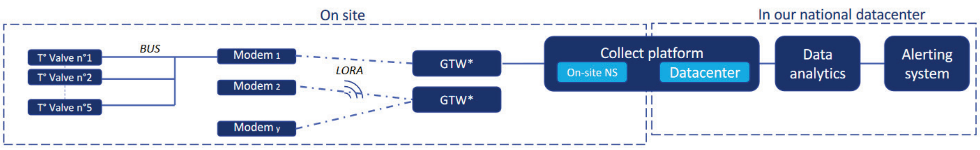

Figure 11 Data flow of the EDF valve leakage detection

Next presented use case was about the by-pass condenser valves leakage quantification. Here the leakage detection is not enough to decide adequate maintenance of the internal parts of these valves, but also digital twin model is involved, but this part is still under development. Leakage quantification is needed to determine the right actions, at the right period. The cost motivation for this use case is that the average yield-losses due to these valves is estimated to be 1MW - 2MW per nuclear unit. Concept of this use case is presented in the following Figure 12.

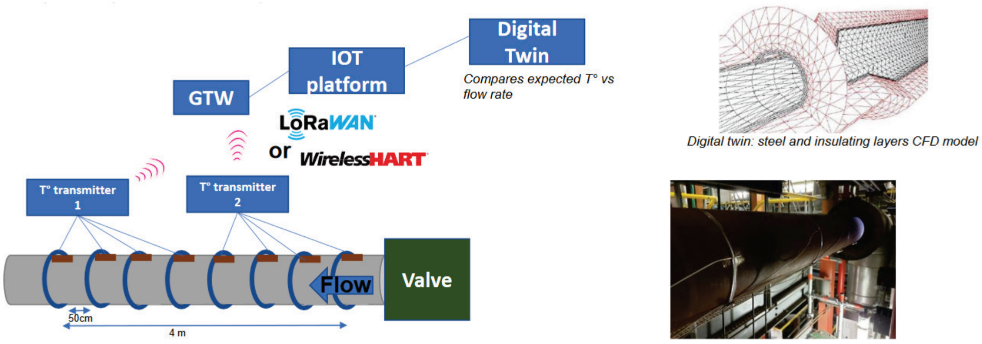

Figure 12 EDF by-pass condenser valves leakage quantification

Next presented use case was the freezing protection removal assistance, where the pumping station freezing is prevented. This concept is presented in the following Figure 13.

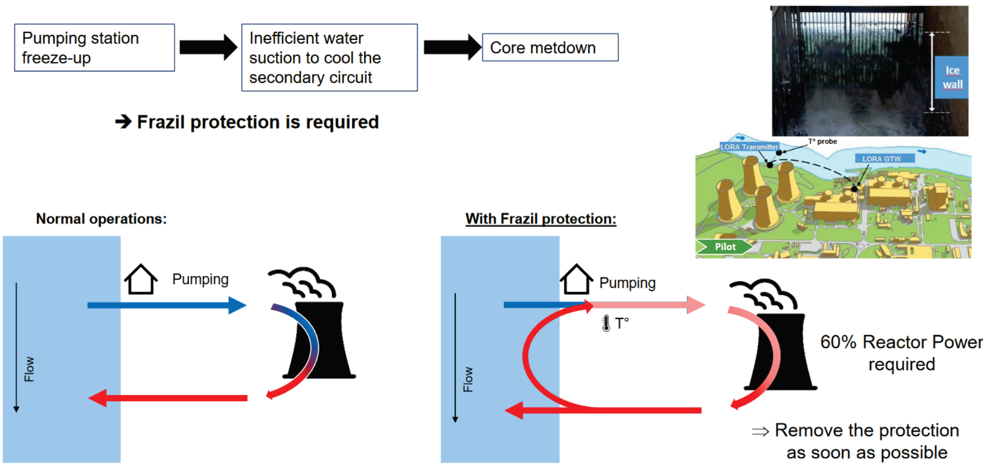

Figure 13 EDF frazil protection removal assistance

Two following pre-study phase use cases, which Mr. Perrier presented, were the visual positioning and alerting workers of lifting dangers.

In the visual positioning use case, 3D scans & panoramic photos are used to enable localisation services. These can be used either as a static service: by taking a picture with a smartphone and get the geo-reference in the map. The other choice is to use it as a dynamic service with location tracking with the aid of a camera on the helmet. Motivation for inspecting the visual positioning is that currently the Real-time locating systems (RTLS) are still considered expensive to deploy.

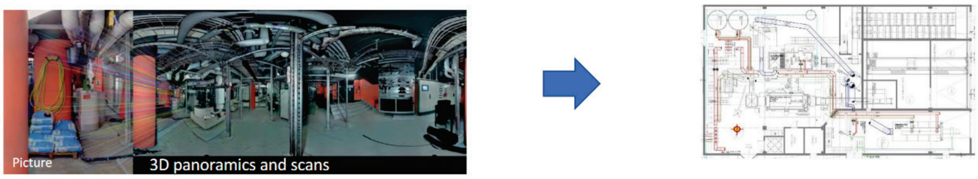

Figure 14 Visual positioning based on 3D scans and panoramic photos

In the alerting workers of lifting dangers use case, dynamic geofencing is used and workers are not using any specific active tags. Instead stereoscopic imaging and lidars are used to track the workers and objects. These include hook elevation, ground footprint load, authorised and unauthorised workers.

In his concluding slide, Mr. Perrier discussed about the challenges and R&D investigations concerning the IIoT. These challenge areas included private cellular networks, embedded AI and edge computing, cyber security, territorial IoT and massive IIoT standardisation. These challenges are presented more detailed in the following Figure 15.

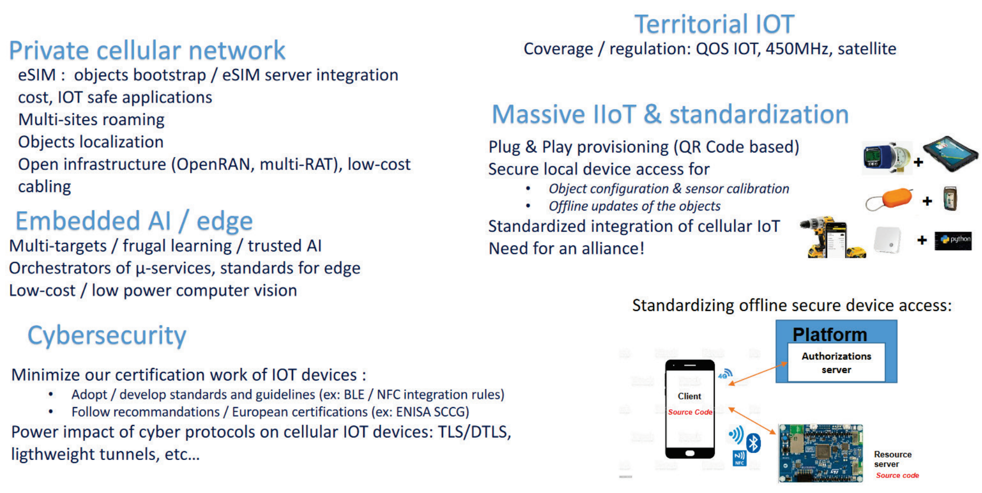

Figure 15 EDF IIoT challenges

2.2.7 GE activities in IIoT

Presenters:

- Nathan B Askwith and Abhinav Saxena, GE Power

Link to the slide set:

- https://energiforsk.se/media/30579/6_geh_digital_solutions_for_nuclear_plants_final.pdf

Link to the Youtube video:

- NA

Synopsis of the presentation:

Mr. Nathan Askwith, senior product manager at GE Hitachi Nuclear Energy (GEH) and Mr. Abhinav Saxena, principal scientist, machine learning, at GE Research, presented the GEH digital solutions for nuclear power plants. [9]

Mr. Askwith started the presentation with on outline of GEH units and their upcoming division, which are the aviation, healthcare and renewable energy and power. It was followed by the sections of GE Hitachi nuclear energy unit, where GE digital and GE research provide the services like computing, algorithms, fleet data and domain expertise for advanced nuclear services.

Mr. Askwith presented the decarbonization is in front and centre in GE's strategy for energy transition and in combatting climate change in the near term. Medium for this are e.g. coal to gas switching, natural gas to H_2, wind power, small modular reactors (SMR), nuclear for H_2, extending life of existing nuclear.

Next, he presented the journey to digital transformation, where today's proactive time-based maintenance will evolve during time to new autonomous operation in the future fleet. This roadmap is outlined in the following Figure 16.

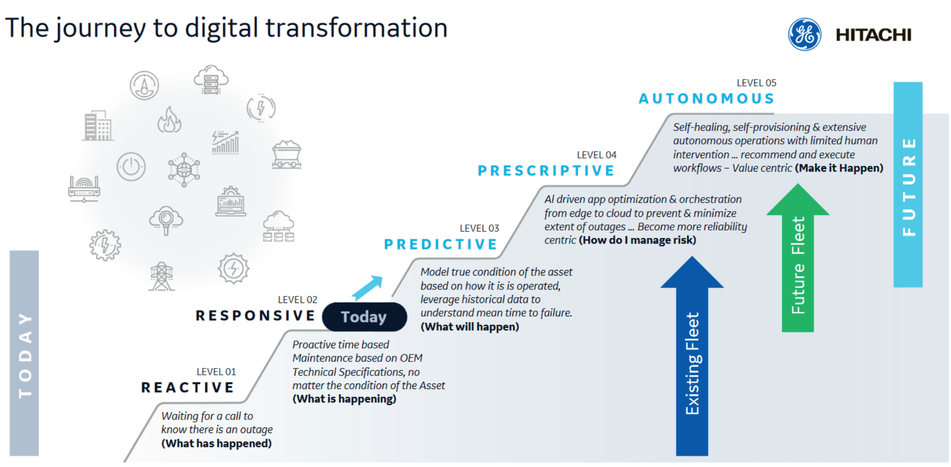

Figure 16 GEH journey to digital transformation.

Discussion about digital solutions for existing fleet was opened with some general customer concerns, like reducing operation costs, data reliability, historical information interpretation, aging workforce, etc. The answer to these concerns with existing fleet was given to be the asset performance management with connecting relevant data sources, assessment of data quality, automated reporting and monitoring and diagnostics. Each of these topics were then further elaborated.

Connecting relevant data sources brings to the asset performance management existing sensor data (time series), rounds, logs, work order management, equipment hierarchy, equipment criticality, corrective actions and preventive actions.

Assessment of data quality was presented as a flow chart in the following Figure 17.

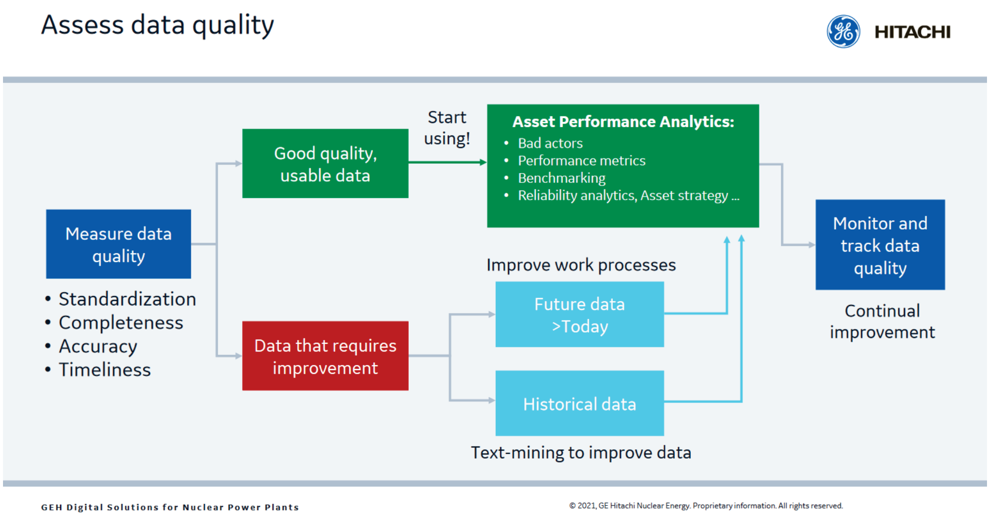

Figure 17 Assessment of data quality.

Automated reporting was presented with a unified example dashboard of O&M status and activities to review and plan daily priorities. Key summary of dashboards and drilldowns highlighted the asset health heat map by criticality, analytics from last 72 hours, round deviations, work orders by priority and time, key shift events, overdue actions and key operational KPIs. This was followed by an example equipment health monitoring workflow dashboard.

Mr. Askwith continued showing an example of existing analytics of a failed cooling fan detected on a condensate pump. In this case example, analytics had found that "The stator temperature on a condensate pump motor at a nuclear power plant increased from 222°F to 237°F (106°C to 114°C) ... the plant was not aware of the unusual temperature increase, as it was below the control room's alarm levels." As a result to this finding, the customer engineers were able to address a malfunctioning cooling fan, and they received confirmation that their maintenance action was successful when actual values returned to expected values. With the early warning, shut down of the pump was avoided.

Next, he presented the asset performance management (APM) operating model for the nuclear field. This model can be seen in the following Figure 18.

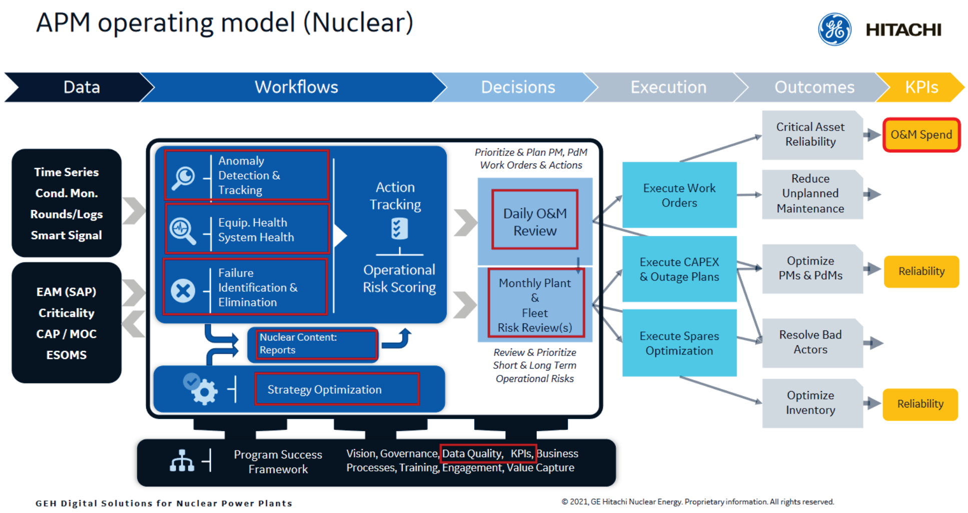

Figure 18 GEH Asset Performance Management (APM) operating model for nuclear.

This was followed by the specifications of the BWRX-300 small modular reactor (SMR), for which GEH has initiated licensing in the U.S. and Canada and they expect it to be operational by 2028. Operation and maintenance cost reduction is planned to be achieved with remote monitoring, predictive maintenance, automation and optimized scheduling and central crews using AI-enabled digital twins.

Mr. Abhinav Saxena continued the presentation with the topic of Humble AI. He told that “Humble AI is part of a new lexicon of AI terms emerging, as AI becomes integrated into critical industrial infrastructure where safety, reliability, and performance are paramount”. Decision making for automated or human-in-the-loop question was shown in the following Figure 19.

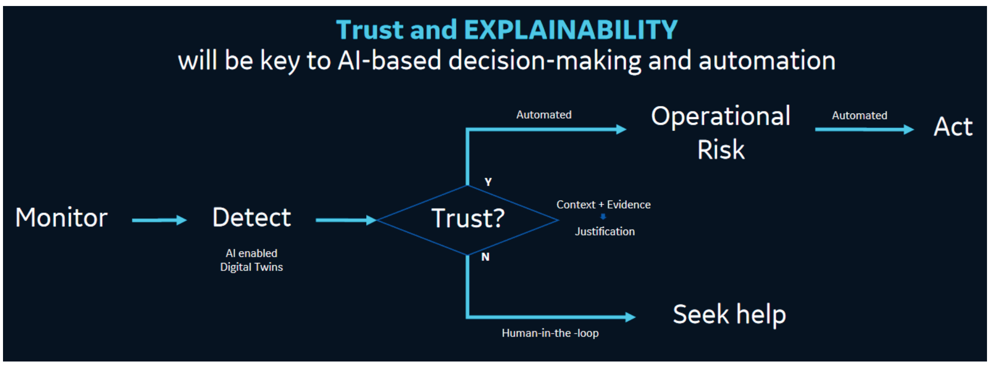

Figure 19 Humble AI, decision making automated or human-in-the-loop.

Humble AI was described to be an AI that is aware of its own competence and improves its competence via learning and it should maintain safety and reduce time to value. As a follow-up AI is applied for t digital twin and this was presented with the following Figure 20.

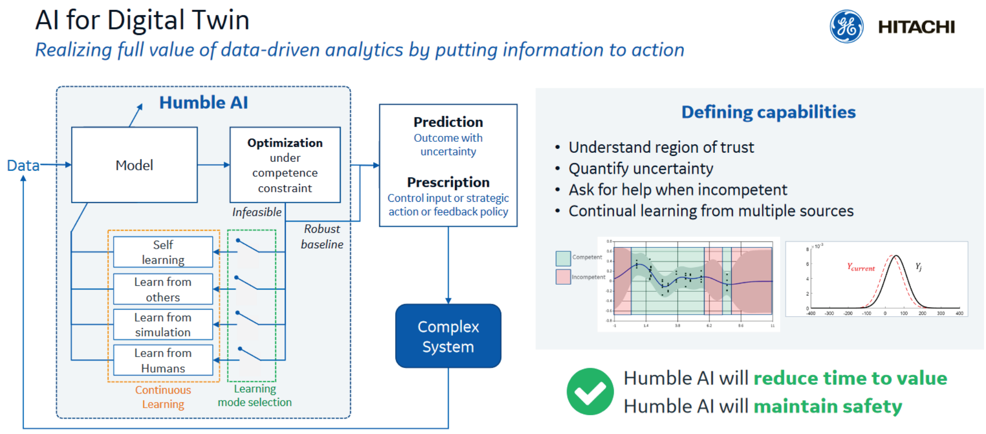

Figure 20 GEH AI for digital twin.

He continued the presentation with the AI-enable predictive maintenance digital twins project called GEMINA, where the team consists of GEH, the University of Tennessee Knoxville, Oak Ridge National Laboratory and Exelon Generation and is funded by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001290. Target of the project is to build an AI-enabled predictive maintenance for BWRX-300 Advanced Nuclear Reactor to lower the O&M labor costs. Targets of the program are use automation to lower labor costs, obtain seamless operation with predictive maintenance and move trust from humans to Humble AI. As a technology summary of the project, he listed following items:

- Reactor Operations
  - × Physics-informed machine learning, sensor optimization
- Reactor Health
  - × Causal, Humble & Explainable AI for predictive maintenance
- Decision Making
  - × Autonomous risk-informed decisions for reconfiguration & maintenance

In the conclusion, GEH digital journey was summarized to provide following benefits:

- The existing fleet can leverage its existing data using GE’s Asset Performance Management (APM) software platform.
- APM can help identify equipment/system risks to reduce unplanned maintenance, resolve problem components, and optimize preventative maintenance.
- GE is developing the predictive and prescriptive models/digital twins for the future fleet using Humble AI … progress here is expected to benefit existing fleet.

- GE continues to evolve its digital technology to help the existing and future nuclear fleets operate safely and at a reduced O&M cost.

Presentation was closed with several public references to IAEA, GE and OECD.

2.2.8 Implementation of IIoT and Wireless Technologies in US NPPs

Presenter:

- Chad Kiger, AMS Corporation

Link to the slide set:

- https://energiforsk.se/media/30652/7_ams-presentation-for-energiforsk-seminar.pdf

Link to the Youtube video:

- https://youtu.be/UQBeDDkU3p0

Synopsis of the presentation:

Mr. Chad Kiger, EMC Engineering Manager from the AMS Corporation held next the presentation with the title of "Implementation of IIoT and Wireless Technologies in US NPPs". [10]

He started with the outline of the presentation, where the main topics were the summary of AMS activities associated with wireless technology, overview of IIoT and wireless sensor selection and implementation, considerations associated with wireless technology and addressing EMI/RFI concerns.

The first topic was some of the research projects conducted by AMS Corporation with some key topics from them. he mentioned that with the EPRI ID code, the reader can find more information about these projects from the EPRI Internet-pages. These projects were the:

- Sensor Specification (EPRI ID: 3002011818; Published: 2018) with the key objectives of:
  - × Identified commercially available wireless sensors capable of deployment in a nuclear facility for various condition monitoring applications. These included e.g. vibration, temperature, and pressure sensors applicable in NPPs.
  - × Developed implementation guideline for implementation of wireless sensors in NPPs
  - × Characterized the electromagnetic emissions from several wireless sensors
- Wireless Technology Assessment (EPRI ID: 3002012707; Published: 2018) with the key objectives of:
  - × Characterized the electromagnetic emissions from commonly used mobile wireless devices such as cell phones, tablets, and laptops
  - × Developed exclusion zones for various wireless protocols (Wi-Fi, Bluetooth, LTE) including a risk-informed analysis approach
- Spectrum Management (Under Development) with the key objectives of:

  - × Documenting techniques for determining/monitoring the wireless spectrum
  - × Developing strategies for wireless coexistence to prevent interference and allow for future expandability
  - × To be finalized and published in 2022

Next Mr. Kiger presented an example project about the wireless monitoring of Arkansas Nuclear One (ANO) containment fans, which was executed about 10 years ago. Purpose of the project was to test, is it possible to deploy wireless monitoring system in a nuclear containment. As background, he told that in this site there are four fans to circulate air in a containment and single fan failure puts the plant into 72 hour limiting condition of operation and the repairs take typically 5 days. According to the event history, this failure happens every 5 years. The problem was that the fans are not accessible for routine monitoring during plant operation and previously data was collected once per every 18 months. problem was solved in the project by developing a wireless system that will routinely collect vibration data from all four fan motors and the wireless Wi-Fi network was installed in the containment. Wired communication with copper and fibreoptics was done through the containment wall.

Following this project, he discussed about important wireless sensor characteristics and considerations to be taken into account, when deploying these technologies. In U.S., many NPPs have installed and used Wi-Fi as their wireless solution. Protocol-wise, the benefits are the single infrastructure and established co-existence, but the disadvantage is that it is a limited solution. If the selection is done choosing the best sensors, the benefit is to get an optimal solution, but it often brings the need of additional infrastructure. The considerations choosing the wireless system are the coverage needs, throughput, power requirements and frequency issues.

Mr. Kiger continued to talk about the condition monitoring of NPP equipment using IIoT technologies. Examples of equipment being monitored were:

- Pumps and Motors
  - × Feedwater
  - × Heater Drain
  - × Condensate
  - × Intake, Component, and Turbine Cooling Water
  - × Reactor Coolant and Circulating Water
- Valves
  - × Main Feedwater Regulating Valves
  - × High Pressure Feedwater Heater Level Valves
- Transformers
  - × Start-Up Transformers
  - × Main Transformers
  - × Auxiliary Transformers

IIoT technologies and sensors to be used for these consisted of vibration sensors, wireless gauge readers and data mining algorithms combining new and existing sensor data.

Next Mr. Kiger discussed about using walkdown activities (Figure 21) to plan the monitoring and instrumentation of the plant. Walkdowns will provide lot of information, which can be used in the planning phase. They can be used e.g. to evaluate plant environment and the existing technologies, exclusion zones, potential monitoring locations and coverage mappings. They can also be used for identifying possible EMI Issues for possibly susceptible equipment and deficiencies in equipment installation.

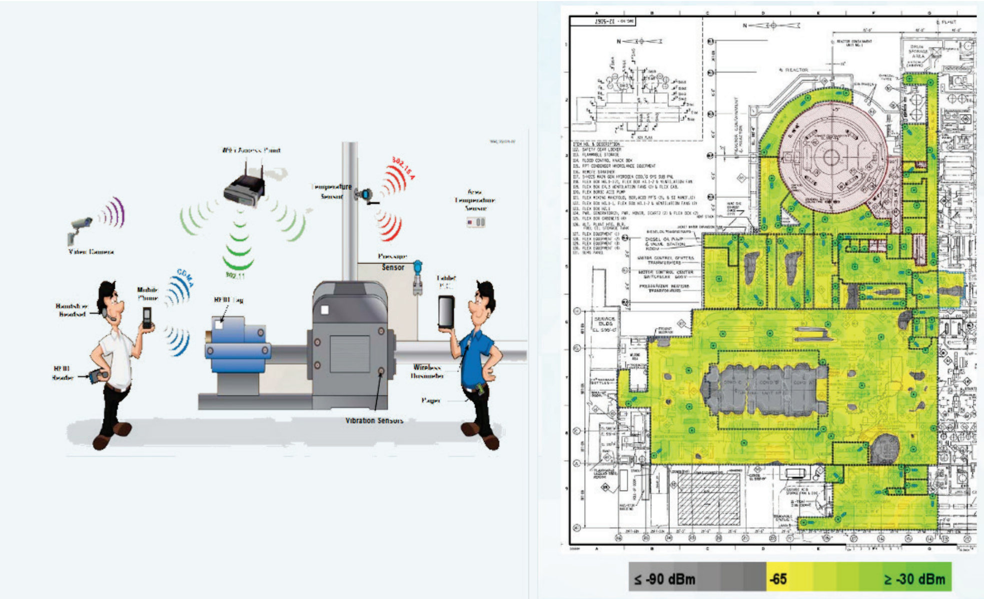

Figure 21 Potential walkdown activities.

Example strategies for wireless equipment condition monitoring were collected in a table (Table 2) for some requested parameters and monitoring options for them. He pointed out that it might be good strategy to select one or two protocols for the sensors instead of multiple different protocols to make the wireless planning easier.

Table 2 Example strategies for wireless equipment condition monitoring

Requested parameter	Monitoring options
Pump Suction & Discharge Pressure	**Non-Intrusive:** Wireless Gauge Reader or Wireless Camera **Intrusive:** Analog Gauge Replacement with Wireless Gauge Reader, Secondary Digital Gauge with Wireless Capability, or Digital Gauge Replacement with Wireless Capability
Pump Vibration	**Non-Intrusive:** Stand-Alone Wireless Vibration Transmitter or Wireless Transmitter Connected to Multiple New Accelerometers
Motor Bearing Temp	**Non-Intrusive:** Wireless Gauge Reader or Wireless Camera **Intrusive:** Gauge Replacement with Wireless Capability

Motor Vibration	**Non-Intrusive:** Stand-Alone Wireless Vibration Transmitter or Wireless Transmitter Connected to Multiple Accelerometers/Proximity Probes
Motor Current	**Semi-Intrusive:** Current Transducer Connected to Wireless or Wired Transmitter (Line Powered)

Mr. Kiger mentioned several times in his presentation that in U.S. exclusion zones have been traditionally used to allow wireless equipment usage in the NPPs and avoid interference. Calculation formula and some wireless device exclusion zone distances were presented, which can be seen in Figure 22.

$$d = \frac{\sqrt{30 P_t G_t}}{E} \,(meters)$$

Where:
d = exclusion zone distance (in meters)

P_t = the effective radiated power of the EMI/RFI emitter (in Watts)

G_t = the gain of the EMI/RFI emitter (dimensionless)

E = the allowable radiated electric field strength of the EMI/RFI emitter (in Volts/meter).

Wireless Device	Exclusion Zone Distance (feet)
Wireless Dosimetry	1
Laptop Computer	3
iPad 4	8
Walkie Talkie	13

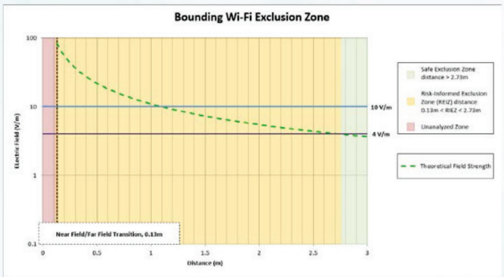

Figure 22 Exclusion zone calculations and distances

He mentioned also that for the modern high frequency radio protocols the calculations give bigger exclusion distances compared to the measured field strengths, because the emission power is distributed across bigger spectrum. The calculation formula contains additionally a large safety margin. The other option to define the exclusion zones is to perform measurements of the emissions instead of calculating them with this formula.

As the last topic of his presentation, Mr. Kiger discussed about the in-situ immunity testing and emissions mapping instead of the previously mentioned calculations. In this approach the wireless equipment is brought into the plant and injecting noise to the plant equipment. Normally this is done during the outages, but sometimes it has been done also, when the plant is in operation. But in the operation phase the test has been done only to some non-critical equipment, like radiation monitoring. Another option to test the equipment immunity against radio interference on certain field strength levels is to do it in the laboratory or development area of the plant. Mapping the emissions characterizes the environment and can even in the best case reveal some malfunctioning legacy equipment. As an example he told that the ambient noise revealed a degraded relay and failing shown on the right side of Figure 23, describing the emissions mapping concept.

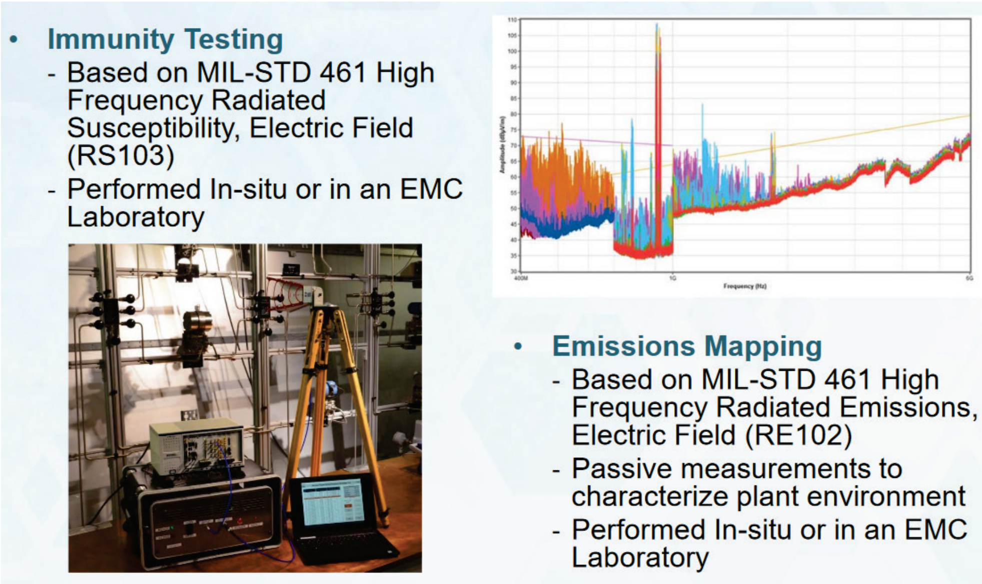

Figure 23 Immunity testing and emissions mapping.

Mr. Kiger summarized his presentation concluding that there are many sensors available, which can be used. Although there is the challenge to choose the right ones to be used in the NPPs, there are ways to address them. Considerations with wireless technologies apply to the coverage and spectrum management. Coverage and redundancy need e.g. applies to the about of needed access points. Spectrum management is one major tool to address EMI/RFI concerns. Other tools are the exclusion zones and verification of equipment immunity.

3 Conclusions

On the 18th of November 2021 held Energiforsk Industrial Internet of Things (IIoT) in nuclear online seminar gave a good overview of the IIoT current state and evolution in the NPPs.

Seminar started with the outline of IIoT and technologies under this umbrella and moved to show the current state and technological wishes in the Nordic NPP with examples. Our international speakers expanded the view to show that the adoption of IIoT and related technologies have already gained increasing foothold in the plants outside of Nordic countries. International vendor and consultant addressed that despite of the emerged challenges due to the new technology adoption exist, there are means to overcome them and adopt the IIoT into use also in the nuclear plants.

Although Nordic NPPs have still been conservative, when considering the adoption of wireless technologies and IIoT in general, the presentations showed promising advancements that the wishes are slowly turning to actions to move towards new technology use both in Swedish and Finnish nuclear plants. Advancements in the international nuclear field will encourage this development and vendors can show increasing amount of successful use case implementations. This ensures that the Nordic NPPs do not have to act as pilot laboratories, but they can benefit from the mature solutions available in the market.

4 References

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INDUSTRIAL INTERNET OF THINGS (IIOT) IN NUCLEAR SEMINAR REPORT

An online seminar was held in November 2021 featuring presentations on Industrial Internet of Thing (IIoT) in nuclear applications, research projects together with vendor and consultant insights from the IIoT field.

This seminar report provides an overview of the presentations held in the seminar. The presentations confirmed that wireless and IIoT technology adoption is advancing in the nuclear field and despite of existing challenges, gaining also increasing foothold.

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