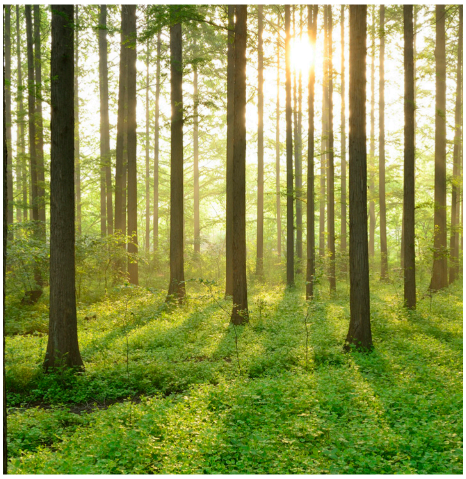
ROBOTICS IN NUCLEAR APPLICATIONS

REPORT 2021:796



NUCLEAR

DIGITALIZATION IN
NUCLEAR APPLICATIONS

Energiforsk

Robotics in nuclear applications

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Foreword

Robotics is used more and more in conventional industry, and the technology is developing rapidly. There are motives for also trying the technology in nuclear applications, for example to carry out tasks in areas of high radiation, retrieve information that would not be feasible with other means or to reduce maintenance costs.

In this study senior expert Ville Lestinen has investigated how robots are used in other industries, for applications that could also be used in nuclear. Furthermore, pilot projects in nuclear and ongoing R&D projects have been mapped. The project is part of the Energiforsk Digitalization in nuclear applications program, financed by Vattenfall, Uniper/Sydkraft Nuclear, Fortum, TVO, Skellefteå Kraft and Karlstads Energi.

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.

Summary

Use of robotic has already a long history in many kinds of industries. Robots so far have been mainly parts of industrial processes, software robots or case specific mobile robots. Currently technology of robotics is developing on such mature level, that industrial applications of mobile robots is growing rapidly.

Technical progress of robotics gives lots of new possibilities also to nuclear industry where robots are so far used mainly on special cases such as accidents. Another area which has applied robotics in nuclear industry is spent fuel handling. However, now there is a right moment to take one step forward and take robotics in wider use also in nuclear industry.

This moment has been noticed in research communities and there are many research programs ongoing around robotics in industry generally, but also in nuclear industry. One good example is RIMA project by EU. Also, Institut for Energiteknik (IFE) in Halden in Norway, is taking steps against research of digitality and robotics. In England and France there are many ongoing activities around research of nuclear robotics as well as OECD NEA is active on this sector.

There are lots of possibilities and needs in Nordic NPPs to apply robotics already now. Several workshops have arranged as a part of this work to find out most urgent and important possibilities and needs. Results of the workshops are classified according to operations and processes in NPPs and they are linked with existing reference examples. This helps to find out possible robots, which can be taken in operational use as soon as needed.

When robots are taken in operational use, it is important to take into account also authority requirement and safety questions. Nuclear industry is strongly guided by authorities and dialogue with authorities is necessary. Safety questions both in a sense of power plant infrastructure and human safety is important consider.

In this phase it is important to create common robotics strategy in nuclear industry at least on Nordic level. This strategy creation process can take lots of benefits from international research and cooperation activities. The main proposal of this report is that such strategy preparation should be started as soon as possible with all Nordic nuclear operators.

Keywords

Robotics, Robot, Digitalisation, Nuclear, Industry, Operation, Maintenance

Sammanfattning

Robotteknik har redan en lång historia inom många typer av industrier. De har hittills huvudsakligen varit delar av industriella processer, mjukvarurobotar eller mobila robotar designade för en specifik applikation. Robottekniken har nu nått en mogen utvecklingsnivå och industriella applikationer för mobila robotar växer snabbt.

Tekniska framsteg inom robotteknik ger massor av nya möjligheter även till kärnkraftsindustrin, där robotar hittills huvudsakligen används i specialdesignade tillämpningar. Bland dessa tillämpningar finns exempelvis hantering av använt bränsle. Det finns dock möjligheter ta ett steg framåt och undersöka möjligheterna att använda robotar brett inom kärnkraftsindustrin.

Forskningsvärlden har identifierat denna möjlighet och det pågår många forskningsprogram kring robotar inom industrin i allmänhet, men också inom kärnkraftsindustrin. Ett bra exempel är EU: s RIMA -projekt. Institut for Energiteknik (IFE) i Halden i Norge tar också steg mot forskning om digitalisering och robotteknik. I England och Frankrike finns det många pågående aktiviteter kring forskning om robotar i kärnkraftstillämpningar och även OECD NEA är verksamt inom denna sektor.

Det finns massor av möjligheter och behov hos nordiska kärnkraftverk där robotar kan göra nytta redan nu. Flera workshops har arrangerats som en del i detta arbete för att ta reda på de mest angelägna behoven och utvecklingsmöjligheterna o. Resultaten har klassificeras efter tillämpningar och processer i kärnkraftverken och har kopplats till referensexempel. Via dessa tabeller kan lämpliga robotar identifieras för olika behov.

När robotar implementeras i kärnkraftsindustrin måste hänsyn tas till myndighetskrav och säkerhetsfrågor. Kärnkraftsindustrin styrs starkt av myndigheter och dialog med myndigheter är nödvändig. Säkerhetsfrågorna behöver prövas både utifrån kraftverkets infrastruktur och människors säkerhet.

I denna fas är det viktigt att skapa en gemensam robotstrategi i kärnkraftsindustrin åtminstone på nordisk nivå. Denna strategiskapande process kan ta lärdom av internationell forskning och samarbeten. I denna rapport föreslås att en sådan strategiprocess genomförs med deltagande av alla nordiska kärnkraftsoperatörer.

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1 INTRODUCTION

Robotics has a relatively long history in some industries, but currently use of robotics is getting more and more common in a wider scope. Many kinds of mobile and more or less autonomous robots are becoming common in industrial applications. Also measuring and observation tools as well as data analysis methods are currently developing fast.

In nuclear industry development of robotics has been done so far mainly in decommissioning business. In other parts of nuclear power plants robots has not yet been widely seen. However, as an environment nuclear power plant is an ideal place for robots. In nuclear power plants there are lots of places which are not very welcoming for human beings. For example, high radiation doses or temperatures are not uncommon in nuclear power plants. Even if robotics is not widely used yet in nuclear power plants, discussion of the subject has already relatively long history as IAEA-TECDOC-668 The role of automation and humans in nuclear power plants from year 1992 demonstrates.

Aim of this work is to create basement for using robotics in nuclear power plants especially in Nordic countries. The content of work is presented in Table 1.

Table 1 Content of robotics studies for Energiforsk

Step	Mission
Part 1: Mapping of global industry experience	Investigate the current situation and upcoming trends on robotics at the global industry.
Part 2: Mapping of NPP experience	Investigate the current situation on robotics in both international and Nordic nuclear power plants. This may also include interviews.
Part 3: Next step for Nordic NPPs	Investigate what could be done in Nordic nuclear power plants to achieve higher level of utilization in robotics. What are the areas where robotics are not yet utilized in nuclear power plants, but have demonstrated benefits in global industry.

2 TERMS

Even if robotics is widely used in some industries, such as automobile industry, many industries including nuclear industry are not very familiar with use of robotics except some special cases. So, it is natural that terminology is not yet well-established. Mostly it can be said that when application of new technology or way or working is started, it is important to define terminology. Otherwise, risk of potentially dangerous misunderstandings increases remarkably.

Lots of glossaries of robotics can be found easily, but one good starting point to develop common Nordic glossary would be standard ISO 8373:2021 Robots and robotic devices – Vocabulary.

3 ROBOTICS IN INDUSTRY

3.1 BENEFITS OF ROBOTICS

This chapter includes some ideas of possible benefits of robotics in industry. These ideas are based on public discussions and literature around the subject. One example of this discussion is article of professor Richard Mitchel (University of Reading) in Future Learn.

Possible benefits of robotics can be divided for example in following three main areas:

1. Quality and productivity
2. Safety and security
3. Costs and savings

Benefits of robotics are not coming from just using robots instead of humans, but increasingly from cooperation with humans and other technological solutions. Robot itself doesn't make necessarily big difference, but when robot is "an extension" of capabilities of human and/or an autonomous (or non-autonomous) robot is combined with for example motion sensors, machine vision, voice or image recognition and advanced software benefits can be remarkable.

Robots used by this way as a part of "a big picture" can handle increasingly intelligent work by interacting with and continuously learning from their environment and people. It is very probable that relatively soon robots will replace human labor on a large scale and not only for routine works.

Contents of the benefit areas listed above are discussed in the following chapters.

3.1.1 Quality and productivity

Robots are precise workers and quality of their work is uniform. Robots are working all the time without brakes or holidays. Robots are in many cases also faster than humans.

One of the main differences between human worker and robot is that as long as robot has no physical faults or software bugs, it is repeating its work tasks accurately. So, human errors does not exist when robot is doing works. When robots are technologically progressing and they are starting to use for example Artificial Intelligence (AI), they are getting more complex and capable, which may make them more prone to software errors due to human errors in design and manufacturing phases.

Using robots has a potential to increase quality and productivity in many cases. However, it is important to find out best ways to guarantee quality and reliability of robots getting more complex. When it is not anymore possible to test all features and functions, new ways shall be developed to control quality of the products to avoid software bugs and also physical failures. It is important to find out balance between technological advance and reliability especially in a safety sensitive environments like nuclear industry.

3.1.2 Safety and security

Robots are excellent workers in difficult or dangerous places. For example, heavy lifting, poor lighting, big drops, narrow channels, high or low temperatures, toxic or radiative areas or other possible hazardous places are difficult for humans, but much easier for robots.

Using robots give remarkable possibility to increase human safety in many kinds of industries. In NPPs there are many places especially during outage when robots can replace humans in dangerous places, but there are those possibilities also during normal power plant operation.

3.1.3 Costs, savings and social aspects

There are tasks where robots have advantage over humans. They can for example work without or at least with less breaks as well as longer working periods. Robots can also track and record precisely their work tasks, which helps to develop the process faster and more efficient. With AI robots can improve their working processes even during the work.

However, possible social risks shall be taken into account, when robots replace humans in working places. Robot as a "work mate" can be challenging to accept for humans for example if people lose their jobs because of robots. Social contacts are decreasing and working can feel more isolated. Even in cases where robots are for example economically clearly more efficient than humans these social effects can decrease real benefits of the robots.

Another question is effect of robotics to economy of countries and welfare. If robots just widely replace humans in different works, it can cause economical imbalance, which is not risk just for personal economy of humans, but by decreasing consumer demand robotization can be a risk to productivity of many consumer-based businesses as well as to economy of countries. However, with co-operation of robots and humans many crucial global problems could be solved and also productivity increased, which would give a possibility to share economic well-being to wider population globally. Currently there are no direct answers to these questions, and they can be also irrelevant in the short term, but it is good to understand and discuss also this kind of possible impacts of robotics.

3.2 GENERAL TRENDS IN ROBOTICS

According to International Federation of Robotics (IFR) (Top Trends Robotics 2020 - International Federation of Robotics (ifr.org)) top trends of the robotics are:

- Robots get smarter.
- Robots collaborate with workers.

Robots get smarter due to combination of better digital sensors and software. Robots start to learn first by demonstration of humans and later by trial-and-error optimizing their movements by themselves. This feature will give huge possibilities in difficult or hazardous environments, which are typical also for nuclear industry.

When nowadays robots and humans operate alongside each other, more intelligent technology gives possibility to increase collaboration of robots with workers so that robots will be kind of "extension" of human workers. True responsive collaboration is needed between robots and humans to reach this target. This means that robots shall be able to recognize voice, gesture and intent from human motion. Figure 1 presents types of collaboration with industrial robots.

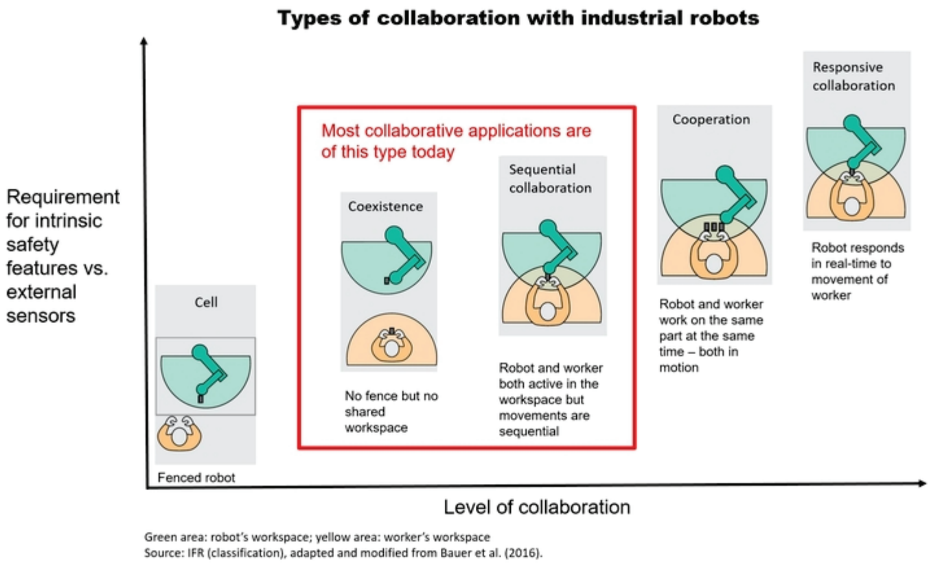


Figure 1 **Types of collaboration with industrial robots (Top Trends Robotics 2020 - International Federation of Robotics (ifr.org))**

Currently autonomously moving robots are getting more and more common in different industries. Those robots are typically crawling, walking or flying robots, but there are also floating or diving robots. Moving robots can be important for example for logistics companies, when use of mail ordering is increasing, but they will have an important role also in industry for example again in difficult and hazardous places.

An AI, Virtual Reality (VR) and teleoperation will be powerful tools to improve efficiency of robotics in industrial applications. All of these supports powerful collaboration between humans and robots.

AI improves both self-learning of the robots and learning from other robots, if cloud services are used to store data collected by the robots. When developed sensor and measuring technologies are combined with AI features, it opens really powerful possibilities to use robotics in many industries. These possibilities don't touch just technological questions, but also business planning.

VR gives workers possibility to "stay on-site remotely" in hazardous places and areas. Teleoperation means generally remote control of a robot with some kind of visual contact to the robot and its environment. When VR is combined with teleoperation practices, the combination gives huge possibilities for O&M working in hazardous places.

Machine vision and sensor technologies are becoming embedded part of robots working especially in difficult places. Using different kind of vision and sensor technologies give robots possibility to optimize their movements by themselves. It gives remarkable possibilities to improve working in difficult environments. Vision and sensor technologies are also important in a sense of data collection.

Data collections is getting smarter and more powerful all the time, same concerns data analysis. Computers are getting more and more efficient and "big data" type data analysis methods are able to give important information both during operation and afterwards. This gives lots of new possibilities for O&M operations.

Another development area will be business models. In near future many companies shall decide how they want to use robots. Is the best way to own robots or use external service providers? It is probable that some kind of Robots-as-a-Service (RaaS) businesses will grow significantly in near future.

3.3 ROBOTIC APPLICATIONS IN INDUSTRY

Robotics is currently developed on all areas of human activity such as many kind of industries, urbanization, consumer, healthcare, agriculture etc. One good source of information concerning industrial robotics is 4-year EU funded project RIMA, Robotics for Inspection and Maintenance, which is shared in industry sectors and challenges presented in Table 2.

The RIMA industry sectors (Water, Energy, Oil & Gas, Nuclear, Urban and suburban transport routes and buildings and Transport cargo and mobility) describe the wide industry interest in robotics. Ongoing projects of RIMA project are studied, but also other sources of history of use of robotics are utilized to create a view of history and current status of state of the art of robotics.

It is important to notice that in most cases use of robots is not industry specific, but robots can be applied cross the industrial sectors. Practically all of industry sectors of RIMA are such which can have clear synergy with needs of nuclear industry. So, when new robotic applications are developed, it is important to study whole industrial field of robotics.

Some existing results of RIMA project as well as collection of nuclear specific applications from Reference /1/ as well as other sources are listed in Appendix 1. The listing is absolutely incomplete but gives a good overview of both long history of robotics in nuclear industry and its current fast development in whole industry. It can be said that all kind of problems can be solved using robotics with existing technology. The main issue is to find out those applications where use of robotics is bringing improvement to current processes and practices. Technology is not anymore limiting use of robotics in industry.

Table 2 **Industry sectors and challenges of RIMA project**

Water

- Challenge 1: Reduction of clean water loss.
- Challenge 2: Increase efficiency of water quality control.
- Challenge 3: Ensure water infrastructures are operational and safe.
- Challenge 4: Robotics to isolate workers from risky inspection in confined facilities.

Energy

- Challenge 1: Hydro power inspection and maintenance.
- Challenge 2: Electrical power and heat distribution infrastructure I&M.
- Challenge 3: Solar power I&M.
- Challenge 4: On-shore wind power I&M.
- Challenge 5: Marine energy generation.
- Challenge 6: Open.

Oil & Gas

- Challenge 1: Data harvesting and data analysis.
- Challenge 2: Above ground storage tank inspection, cleaning and maintenance.
- Challenge 3: Pressure vessel inspection and damage classification.
- Challenge 4: Process piping inspection and maintenance in challenging environments.
- Challenge 5: Remote operators.
- Challenge 6: Offshore installation inspection, maintenance and repair.

Nuclear

- Challenge 1: Mapping of site infrastructure.
- Challenge 2: Health monitoring of components during lifetime.
- Challenge 3: Inspect / support repair of equipment.
- Challenge 4: Clean robustly (parts of) nuclear infrastructure equipment.
- Challenge 5: Waste disposal and decommissioning activities.
- Challenge 6: Open.

Urban and suburban transport routes and buildings

- Challenge 1: Increase efficiency in the I&M activities of civil infrastructure.
- Challenge 2: Reduce risk for workers during I&M activities on civil infrastructures.
- Challenge 3: Ensure that civil infrastructure is operational and safe.
- Challenge 4: Clean robustly (parts of) nuclear infrastructure equipment.
- Challenge 5: Waste disposal and decommissioning activities.
- Challenge 6: Open.

Transport, cargo and mobility

- Challenge 1: Perimeter infrastructure.
- Challenge 2: Waterways, quay walls and locks.
- Challenge 3: Runaways.
- Challenge 4: Vegetation.
- Challenge 5: Rails.
- Challenge 6: Maritime; ships and ports.
- Challenge 7: Open.

3.4 STANDARDISATION

Standardisation has been historically remarkable booster of development on many industrial sectors. For example, standardized sea container has had an important role in global economic growth during last decades. So, it can be assumed that also robotization could benefit of standardization in current situation when it is relatively new thing for most industrial areas.

International Organization for Standardization (ISO), which is probably the most referred industrial standard in European environment, has Technical Committee ISO/TC 299 to develop standards for robotics. This committee has published 23 standards and 9 standards are under development. Published standards include for example vocabulary and standards for test methods, mechanical interfaces and safety requirements. Short history of ISO/TC 299 and other standard development around robotics is given in an article of IEEE Standards University.

4 ROBOTIC APPLICATIONS FOR NPP

In this chapter current situation of robotics in nuclear industry is investigated. Results are based on literature research, workshops with Finnish NPPs as well as some other interviews. Appendix 1 includes collections of existing robots in industry generally and also grouping how different kind of robots could be used in NPPs.

4.1 NUCLEAR SPECIFIC NEEDS AND REQUIREMENTS

Nuclear industry has some special requirements and conditions in comparison to all other industrial areas. The Expert Group on the Application of Robotic and Remote Systems in the Nuclear back-end (EGRSS) has made a survey of barriers and impediments of use or robotics in nuclear sector. The most answers were given by companies from industrial companies with employees above 250 persons and fully involved in nuclear industry.

In the survey biggest worries were concentrated around:

- Concerns around effects of radiation and other difficult or hazardous environments or conditions.
- Technological questions such as equipment reliability.
- Capabilities (or lack of them) of the robots including robots that are too task specific.
- Economical questions.
- Problems in implementation of new technology.
- Acceptance by safety authorities.

These worries and all other nuclear and case specific requirements shall be taken into account when use of robots is planned in nuclear industry.

4.2 CURRENT USE OF ROBOTICS IN NPPS

So far use of robotics in nuclear industry is concentrated on accident cases or some specific applications such as managing example radiative materials in nuclear fuel industry or in research purpose. One area where robotic systems are more widely developed so far are final disposal projects in Sweden and Finland. However, in NPPs in operation, use of robotics is very rare.

Reasons for this are surely partly technical, but also safety first attitude has led to precaution in implementation of new technologies and systems in operational use.

4.3 WHERE COULD ROBOTS BE USED IN NPPS?

NPPs are typical area where robots could be widely use. There are areas in NPPs, which are hazardous for humans due to radiation or other unpleasant conditions. To increase use of robotics in NPPs, the first requirement is technical suitability of robots. Part of that is usability of robots. They shall give some additional value, which can be related for example to improvement of work processes, safety, quality or economic issues. Safety is also an important question in NPPs. Robots shall be safe to use for both humans and NPP itself.

When it is proved that robots or robotic systems can be beneficial and safe in NPP environment, also attitudes against their use will change. In current phase of development, it is important to find out pilot applications, which demonstrate efficiently benefits of robots and give positive impact to development of use of robotics in NPPs.

5 RESEARCH PROGRAMS TO DEVELOP ROBOTICS

There are several research programs and organizations nowadays around robotics. Some mainly European examples are listed with links and shortly described here:

RIMA Project

Robotics for Inspection and Maintenance (RIMA) is 4-year EU funded project. Industrial areas included are presented in Chapter 3.3 as an example of wide scope of robotics in today's industry of robotics. RIMA project share totally 8.1 million € for small and medium sized enterprises (SME) in two Open Call rounds (2019/2020). According to RIMA target of the project is to "Connect research, technology & service providers, industry sectors, investors and certification bodies under one roof.". By that way project attempts to create new industrial activity to EU area.

Robots for Hazardous Environments

This research is focused on the safe dismantling of all of the nuclear assets in UK. The research is global and includes currently two multi-partner EPSRC-funded projects as well as the second, hub project, being financed via ISCF funds. EPSRC-funded Programme Grant project is led by Manchester University, with partners BRL-UWE and Birmingham University and virtual reality and teleoperated projects are playing an important role in the research.

National Centre for Nuclear Robotics (NCNR)

NCNR is a consortium of 8 universities led by University of Birmingham. The consortium is concentrated to develop technology to solve the problem of nuclear waste. In addition to human expertise, target is to use for example AI and sensor technology to create efficient robotic systems. Currently about 42 million GBP has been invested to NCNR by research institutions, industry, the Engineering and Physical Sciences Research Council and private investors. NCNR includes experts from 8 British universities and over 30 partners from nuclear industry.

Robotics for Nuclear Environment (RNE)

RNE is a five-year collaborative research program, which is bringing together robotic and nuclear engineering experts and developing next-generation Robotics and Autonomous Systems. The program is facing on the challenges in the UK and international nuclear industries especially on decommissioning and disposal of nuclear waste. Target is to make major scientific and technological advances to nuclear robots in a very short timescale. The research is made in participant organizations and at the Dalton Cumbrian Facility, in west Cumbria. The program is being funded by The Engineering and Physical Sciences Research Council, industrial partners and the Italian Institute of Technology.

Robotics and AI in Nuclear (RAIN)

In nuclear industry conditions restraining human access are common. These conditions would be idea for robotic applications, but so far robotic systems have had very little impact on the industry. The RAIN initiative has been created to address these issues by developing the advanced robotics and artificial intelligence that will be essential for future nuclear operations. Target is to create robotic systems, which will be usable also in other industrial sectors such as pace exploration, in-orbit satellite design, offshore operations and mining. The overall objectives of the program are to lower costs within the nuclear industry, reduce timescales, reduce risk, improve safety, promote remote inspection and reduce the chances of human exposure to radiation and other hazards. RAIN is funded by the Industrial Strategy Challenge Fund (ISCF). The fund is delivered by UK Research and Innovation and managed by EPSRC. Participating organizations are The University of Manchester (project lead), Lancaster University, The University of Oxford, The University of Liverpool, The University of Sheffield, The University of Bristol, The University of Nottingham and RACE (Robotics and Remote Applications in Challenging Environments).

South-West Nuclear Hub

South-West Nuclear Hub is focusing on civil nuclear research, innovation and skills in the South West of the UK. The hub is bringing together a strategic alliance of academic, industrial and governmental members. The vision of the hub is helping to realize the zero-carbon economy. The hub is an alliance of academic, industrial and governmental institutions. Development of the robotics is not a main focus of the hub, but the focus is to create the new technologies that enable nuclear to make the maximum possible contribution and robotics is part of those technologies.

OECD NEA Expert Group on the Application of Remote and Robotic Systems in Nuclear Back-end (EGRRS)

The EGRRS was established in 2019 in order to support member country efforts to optimize national radioactive waste management and decommissioning programs through the application of robotic and remote systems. The group examines issues related to the implementation of robotic and remote systems in radioactive waste management, decommissioning and legacy management at both the national and international levels.

IAEA - Nuclear Science and Instrumentation Laboratory (NSIL)

The NSIL is part of the Physical and Chemical Science Division and implements the nuclear science program. It provides support to member states in the development a broad range of nuclear applications and effective use of related instrumentation. NSIL carries out Adaptive Research & Development (AR&D) in, for example, X-ray fluorescence spectrometry used for testing of materials in diverse fields such as biomedicine, pharmaceuticals, agriculture, environment, and for the analysis of cultural heritage objects. Robotic systems are also part of the research.

Institute for Energy Technology (IFE)

IFE has a long tradition in nuclear research. IFE has operated research reactors in Halden and Kjeller for several decades carrying out remarkable nuclear fuel and material research. Target of IFE is to build bridges between research, education and industry. IFE has extensive infrastructure and full-scale laboratories where theoretical models are transformed into commercial activities. IFE has unique expertise and systems within radiation protection and environmental monitoring of radioactive and chemical emissions. Digitalization is future focus in IFE and currently projects related to robotics and decommissioning are ongoing and planned.

In addition to these, there are lots of other research activities both locally and globally. As an example, Business Finland is supporting also research of robotics in Finland.

6 ROBOTICS IN NORDIC NPPS

In this chapter possibilities to achieve higher level of utilization in robotics Nordic nuclear power plants are investigated. Applications where robotics is already utilized and those where it could be utilized in future are studied by workshops in Loviisa and Olkiluoto NPPs and by discussion with several external parties and internet research.

Workshop with Loviisa NPP was arranged 12 April 2021 and with Olkiluoto NPP 11 May 2021. Results of the workshops and earlier studies and discussions are presented in following chapters.

Following potential main areas to apply robotics in NPP were found.

Content of the main areas is discussed in following chapters with tables including information of target application, current practice for the application and possible future practice with reference example.

6.1 MAINTENANCE, INSPECTIONS AND OBSERVATIONS (BACK TO INDEX)

In the NPP there is need for many kind of inspections. Some applications related to inspections and other observations are presented in the following tables. Table 3 presents possible robotic applications related to maintenance operations during outage, Table 4 to inspection of pressure vessels, pipes, pools, water channels and tunnels, Table 5 to Inspections of different structures and buildings and Table 6 to Observation of trends.

Table 3 Maintenance operations during outage (back to index)

Target	Present	Future	References examples
Refueling machine	Manually operated machine	Case dependent automated machine	Remote technology applications in spent fuel management, IAEA-TECDOC-1433 New generation refueling machine information and control system Automatic refueling platform for BWR power plant
Foreign material extraction	Manually	Human and robot together	PELICAN, Framatome SUSI, Framatome
Maintenance of bolts of covers of main circulation pumps, steam generators and reactor	Manually	Robot or human and robot together	Several robotic manipulators and systems are developed to support bolt maintenance works
Internals of the reactor (cleaning, inspections etc.)	Manipulators operated by humans Human labor	Autonomous manipulators All kind of robots depending on a case	Dekra has developed state of the art methods for inspections of reactor internals
Seal inspections and cleaning	Manually	Human and robot together	Robotic reactor o-ring seal inspection and cleaning by Diakont
Assisting robots	Manually	Human and robot together	Cobotics, Framatome

Table 4 Inspection of pressure vessels, pipes, pools, water channels and tunnels (back to index)

Target	Present	Future	References examples
Inspection and cleaning of horizontal steam generator	Manually	Floating robot controlled by human	ROBOSTEAM, Fortum
Inspections and cleaning of spent fuel pools	Not done regularly	Robot controlled by human or autonomous robot	ROBOSTEAM, Fortum
Pressure vessels, pipes and tubes	Manipulators operated by humans Human labor	Autonomous manipulators All kind of robots depending on a case	SUSI, Framatome FORERUNNES, Framatome

Individual weld seams	Manipulators operated by humans Human labor	Autonomous manipulators All kind of robots depending on a case	Several robots developed. Two examples (page 245 and 249) from nuclear industry mentioned in report Application and Standardization Trend of Maintenance and Inspection Robot (MIR) in Nuclear Power Station /1/ Another example is Robotic Remote Welding system by Diakont
Cooling water channels (sea water) and water tunnels	Human labor	Diving or swimming robots	Loxus

Table 5 **Inspections of different structures and buildings (back to index)**

Target	Present	Future	References examples
Inspections of pull-out chutes of generators Inspections of diesel container Other targets which could be inspected by drone	Human work	Drone	There are many drone solutions in industry. One good example is Flyability whose drones are very capable in difficult, tight and hazardous environments
Visual inspections in high radiation areas	Human work	Mobile robot Drone	These are strongly case specific robots. Drones would be possible in many applications, but also robots moving on ground or water. Many nuclear specific applications are presented in report Application and Standardization Trend of Maintenance and Inspection Robot (MIR) in Nuclear Power Station /1/

Table 6 **Observation of trends (back to index)**

Target	Present	Future	References examples
Observations of functionality of processes	Human work	Robots applying machine vision, high speed cameras, thermal cameras, listening devices or other observations tools	Many existing robot platforms can be used for this purpose. Platform itself should be chosen depending on an application environment and tools needed to transport. Good commercial examples are: • Spot, Boston Dynamics • Elios2, Flyability

6.2 RADIATION AND CONTAMINATION (BACK TO INDEX)

In this chapter radiation and contamination related robotic application needs and reference examples are presented. Table 7 includes applications for external radiation and contamination measurements and Table 8 for internal ones.

Table 7 **External radiation and contamination measurements (outside the NPP) (back to index)**

Target	Present	Future	References examples
External backyard radiation measurement	Twice a year by "wheelbarrow" moved by human	Autonomous mobile robot (walking, crawling or rolling)	For example Createc has developed radiation measurement tools using commercial robotic platforms. Another example is Ground Vehicle by Kromek
Air radiation measurements	Measuring masts	Autonomous drone	RISER by BlueBear Several existing drones could be used to carry air radiation measurement tools.
Decontamination of parts, tools and equipment	Human work	Human and robot together Decontamination truck or container	This task could be carried out using several applications of robotics. For example robotic arms, mobile transport robots and automatic decontamination containers could be used. One practical example could be Warriors by Shanghai Jiaotong University mentioned in page 247 of Reference /1/

Decontamination of structures and surfaces	Human work	Autonomous mobile robot	Remote robotic cavity cleaning and decontamination system by Diakont High-pressure water decontamination system developed by Hitachi for Fukushima
Surveillance	Human work	Autonomous drone	Drones are idea for surveillance applications. One good example is Flyability.

Table 8 **Internal radiation and contamination measurements (inside the NPP) (back to index)**

Target	Present	Future	Reference examples
Sweeping samples of contamination	Human work	Autonomous mobile robot Robot controlled by human	Robotic arms combined with some kind of moving robotics platform could carry out this task. One commercial solution could be Spot by Boston Dynamics with its available robotic arm.
Radiation measurements in highly radiative areas	Human work	Autonomous mobile robot Drone	UGV RadRover by Kromek RISER by BlueBear

6.3 LOGISTICS (BACK TO INDEX)

Table 9 presents some application ideas related to power plant logistics.

Table 9 **Power plant logistics (back to index)**

Target	Present	Future	Reference examples
Automatisation of tool storage	Human work	Automated storage system	Automated storage systems are widely used in many industries and technology is in mature level.
Transportations inside and outside of the power plant	Human work	Conveyers Mobile robots	Many kind of solutions can be used depending on a case including walking or other ground robots or even drones. Good commercial examples are: • Spot, Boston Dynamics • Elios2, Flyability

6.4 NUCLEAR WASTE (BACK TO INDEX)

Nuclear waste related applications are presented in Table 10.

Table 10 **Nuclear waste (back to index)**

Target	Present	Future	References examples
Inspections of nuclear waste caves	Human work	Drone	There are many drone solutions in industry. One good example is Flyability whose drones are very capable in difficult, tight and hazardous environments
Inspections of long vertical channels	Human work or impossible	Drone	
Follow-up of mass spreading to fuel silos	Machine aided by human	Drone	
Transportations in nuclear waste caves	Human work with machines	Automated machines or robots	Many kind of solutions could be applied depending on case. For example SKB has done lots of development work on that area. See Appendix 2
Inspections and/or analysis of liquid waste storages	Practically impossible or at least very difficult now	Floating robot controlled by human	Possibly robot, developed for steam generators in Fortum: ROBOSTEAM, Fortum

6.5 DECOMMISSIONING (BACK TO INDEX)

In Table 11 includes two application examples related to decommissioning.

Table 11 **Decommissioning (back to index)**

Target	Present	Future	References examples
Cutting works in the reactor vessel	Case specific	Robotics systems	Eloise, Framatome
Cutting works on pipework	Case specific	Robotics systems	Charli, Framatome

6.6 OTHERS ROBOTIC APPLICATIONS (BACK TO INDEX)

Others chapter includes application examples of security control (Table 12) and NPP related external infrastructure (Table 14) as well as nuclear accidents (Table 15) as an example without more detailed discussion.

Table 12 Security control (back to index)

Target	Present	Future	References examples
Security control	Human work	Drones Mobile robots	Many existing robot platforms can be used for this purpose. Platform itself should be chosen depending on an application environment and tools needed to transport. Good commercial examples are: • Spot, Boston Dynamics • Elios2, Flyability

Table 13 NPP related external infrastructure (back to index)

Target	Present	Future	Possible robots / tools
Electricity lines	Human work by helicopters etc.	Drones	For example Hepta provides automated power line analysis system including drones with data gathering and analysis tools.

Table 14 Accidents (back to index)

Target	Present	Future	Possible robots / tools
Task in environments where humans are not able to enter	Robots	More intelligent robots	Development of nuclear specific robotics has so far strongly linked to nuclear accidents. For example Reference /1/ gives a good view on that.

6.7 SOFTWARE ROBOTICS (BACK TO INDEX)

Software robotics will be more and more part of all robotic applications. Here software robotics means such things as big data, virtual reality and artificial intelligence. Those will be remarkable part of performance and skills of future robots. Already now one important motivation to use robots is their capability to gather much more detailed and comparable data from different processes than human worker ever would be able to do.

Table 15 Sofware robotics (back to index)

Target	Present	Future	References examples
Analysis of existing processes and practices	Human work	Big data and other efficient computational methods	Case specific big data, virtual reality, and artificial intelligence related software.
Planning and training of possibly hazardous maintenance operations	Careful planning of the works or training in mock-up environment	Virtual training environment with help of artificial intelligence and virtual reality	
Remote maintenance operations	Not possible	Virtual reality Artificial intelligence	

7 AUTHORITY AND SECURITY ASPECTS

When we are discussing nuclear industry, authority and security aspects are always important. If these aspects are not taken into account from start, there is risk that use of robots get unnecessary resistance from authorities or security people.

Authorities are mainly interested in safety classified functions and operations in NPPs and it is important to argue possible use of robots in safety classified areas of NPP based on safety questions. In every case it is crucial that robot doesn't threaten plant of human safety. When use of robots is planned, the one of the most important requirements is to guarantee plant safety in every phase. Naturally robots have big potential to also remarkably increase plant safety.

Another question are security aspects, which are naturally very important in NPPs. If use of robots is made in co-operation with security people, they can improve also security aspects. However, there are of course also possible risks, which shall be investigated right from the start.

8 DEVELOPMENT OF ROBOTIC STRATEGY

Development of robotics strategy is case dependent process. Different end users need different strategies. Starting point for development of robotic strategy in energy production industry is asset management strategy. Primary purpose of use of robotics is to make management of assets more efficient. So, development of robotic strategy is part of development of asset management strategy. In Nordic NPPs some kind of common practices could be useful especially because there are lots of synergies in asset management strategies between Nordic NPPs. Development of robotic strategy has some alternatives, which are discussed in this chapter. This content is based on References /2/ and /3/.

Traditionally robots used in nuclear industry has been mainly developed from scratch for case specific purposes. Benefit of this kind of strategy is that robot is able to do exactly task needed. However, it is expensive to develop separate robot for each application. Another strategy would be to use commercial off-the-shelf (COTS) solutions. That means using existing robots without modifications. Even if a price of individual robot can be high, lack of development costs will decrease costs. It can be also assumed that company specialized to robot development is more capable to develop robots than average end user. Even if COTS solutions is simple way to progress with use of robotics, many applications require some kind of modifications to the robots. This kind of robots can be called as modified off-the-shelf (MOTS) solutions. Even if modifications are needed, it is probably easier way to progress than developing robot from scratch.

In addition to own the robots, it is possible to rent or lease those with or without operational service. There are already many companies who are developing commercial robotic services based on commercial robots. If need of the robot is occasional, that kind of services can be a good alternative for owning the robots.

So, the first strategy decision in use of robotics is to decide if it is reasonable to own the robot. If decision is that owning is the best solution, then it should be decided the way how the robot would be acquired. Each of three alternatives presented above have their benefits. However, in most industrial applications end users are not developing tools, but they are developed by organizations specialized to those. It is uncommon that tools are developed from scratch for each demand. It is quite clear that in a case of use of robotics in nuclear industry, COTS and MOTS will be the best ways to progress or at least they will be part of the solution. It is very probable that in many cases the best solution is to combine different solutions to solve the problem. For example, COTS robot can transport some specialized robot developed from scratch to working place, which can be difficult to reach by human workers.

Despite chosen strategy, its costs can be decreased by cooperation on Nordic level. If there are common crucial needs on power plant for example during outages which require developing needed robot from scratch, common development projects decrease costs per power plant. Similarly, cooperation can decrease costs of COTS and MOTS solutions.

Cooperation is needed also on other areas of robotics. These areas are such as common terminology, technical standardization, nuclear specific requirements to robotics including authority questions and other requirements.

Common terminology is important on every commercial application to reach efficient working practices. With standard terminology all parties understand all aspects immediately by the same way, which helps to save time in both development and operation phases.

Technical standardization has had an important role on many industrial and non-industrial sectors in global history. One classic solution is a standardized sea container, which has enabled way how our global economy and industry is working nowadays. When technical solutions are sufficiently standardized, savings are remarkable in every industry.

Nuclear environment place lots of industry specific technical requirements to robotics. Such requirements can be for example tolerance to radiation or other demanding conditions. When these conditions are commonly mapped in nuclear industry and communicated clearly to robotics industry, cost savings and quality improvements are certain.

On the other hand, authorities have lots of nuclear specific requirements for technologies and operations in NPPs. They are currently strongly country specific, but around robotics there are not yet specific rules, instructions or practices set by authorities practically at all. So, now there is still possibility to reach internationally common authority requirements for robotics in nuclear industry with strong cooperation.

In addition, there are lots of requirements not related to nuclear industry itself. Understanding these is as well important part of successful applying robotics. Common work for creating understanding non-nuclear requirements helps to find out all necessary and important requirements.

Cooperation on these areas is a foundation to create technologies, which are easy to use and operate. More there are standard technical structures, software, operational and authority practices, more economical and efficient use of robotics will be. Cooperation not needed just on Nordic level, but also on international level on nuclear industry. It is important to create common understanding of all aspects affecting efficient use of robotics in Nordic NPPs as well as globally. One example of results of such work would be widely verified, validated and approved robotic operating system.

Creation of common strategy requires cooperation between NPP operators not just in Nordic countries but also globally. Strategy process would need carefully defined targets and proven process to be followed during the work. Paper Strategic road mapping of robotics technologies for the power industry: A multicriteria technology assessment presents an application of a strategic technology management tool in the power sector /2/. It would be strongly advisable and beneficial to start Nordic strategy creation process around robotics to reach best value of their benefits.

9 CASE STUDIES

As mentioned earlier, robots can be developed from scratch for case specific purposes, readymade commercial off-the-shelf solutions can be used or those available solutions can be modified, which are called then modified off-the-shelf solutions. Examples of each strategy are given below.

9.1 DEVELOPMENT FROM SCRATCH: STEAM GENERATOR OF LOVIISA NPP

Fortum is operating two VVER-440 reactors in Loviisa in Finland. These reactors are pressurized water reactors (PWR). Each reactor has six horizontal steam generators, which are inspected and cleaned every four years. This work has been done so far by human workers. Figure 2 presents structure of horizontal steam generator of VVER-440 NPP.

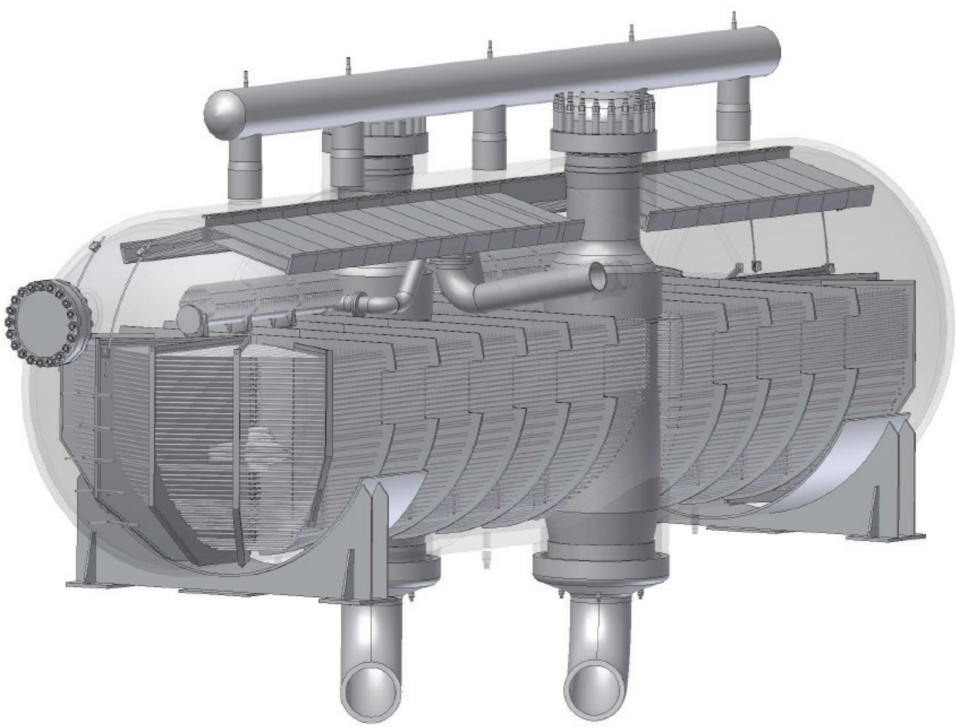


Figure 2 Horizontal steam generator of VVER-440 reactor in Loviisa NPP.

During inspection and cleaning steam generators are filled by water to decrease radiation levels. In addition to still high radiation levels, temperature and humidity are high inside the steam generator. Furthermore, the manhole of the steam generator is small for human workers. So, inspection and cleaning of the steam generator can be said to include remarkable occupational safety risks, which means it is an excellent work done by robot assisted.

The development project of a steam generator inspection and cleaning was started by mapping existing applications. All existing solutions were taking support from tube bundles of the steam generator and due to risk of primary to secondary circuit leakage risk, those applications were not possible in Loviisa NPP. Based on this mapping, a decision was made to start development of the robot from scratch in Fortum's own R&D program. Article of the project is published also in World Nuclear News 25 May 2021.

Firstly, several alternatives were considered including robot moving on for example on rails or flying, but finally floating device was evaluated to be the best alternative for the case. Development of the robot was started evaluating basic requirements including physical conditions inside and around the steam generator as well as requirements for inspection and cleaning work.

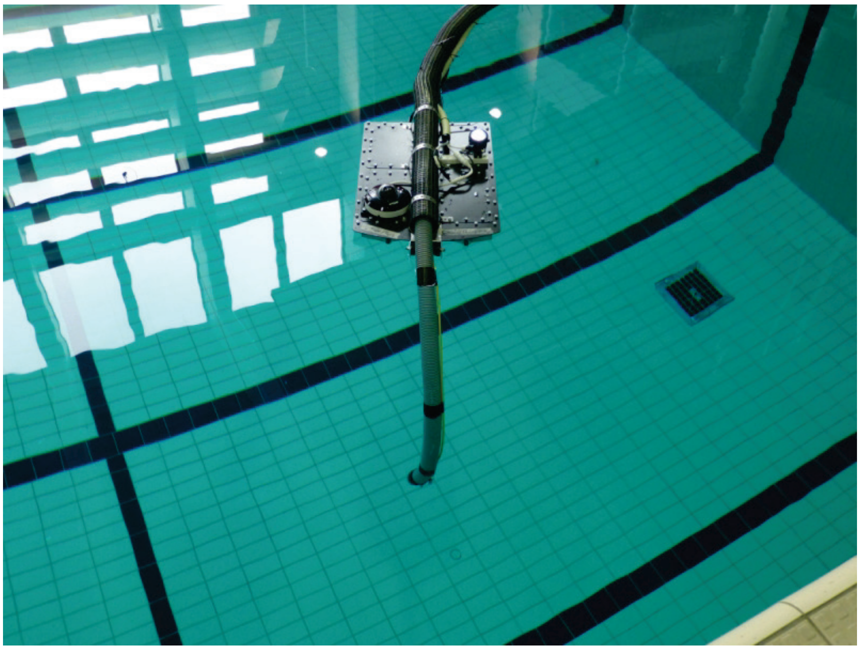


Figure 3 **One of the first versions of robotic raft for steam generator inspection and cleaning.**

The main tasks of the robot were inspections and cleaning of bottom of the steam generator. So, float needed to carry camera and lights for inspections of structures above the water level, camera to make inspections below the water level and steering system. For structure above the water level fisheye camera was chosen to reach wide enough view with one camera. Endoscope was decided to use for inspections below water level. Steering was realized by water jets to each direction. Pressurized water for steering was produced by compressor located outside of the steam generator. Also hoovering hose needed to conduct through the raft to the bottom of the steam generator.

One of the first challenges was amount of water above tube bundles. There is normally just few centimeters of water above the tubes. Water level can be raised a bit depending on protection plate used in manhole to block water flowing out from the steam generator. The main challenge was to optimize total weight of the raft so that it is carrying all necessary cameras, lights and other necessary equipment and still float high enough not to touch tubes. The problem was solved by using as light and thin materials as possible. Pontoons were made of very thin aluminum and deck of carbon plate.

Another problem was size of the raft. The first limiting factor was diameter of the manholes as well as spaces in front of them. In addition, internals caused problems. The space inside the steam generators is shared in two by transverse feedwater pipe, which is blocking rear end of the steam generator together with two vertical collectors. Size of the raft was optimized so that it can easily entrance to the steam generator, and it carries out all necessary equipment floating high enough. Unfortunately, the first version of the raft was not able to reach rear end of the steam generator.

Lowering endoscope and hoovering hose to the bottom of the steam generator was kind of challenge too. A decision was to lower them through floating flexible protection tube, but friction between the hoovering hose and the tube caused problems. Finally, the protection tube with very low internal friction was found and it work for the purpose very good.

The robot was tested in outage of Loviisa 2020. The test was a success despite challenge to reach rear end of the steam generator. Quality of videos and photos above water level was excellent and they were successful recorded for later use. Both endoscope and hoovering hose were successfully lowered until the bottom of the steam generator. Unfortunately hoovering itself was not tested due to schedule challenges of the outage. Also steering of the raft was very easy by joysticks on steering panel located outside of the steam generator.

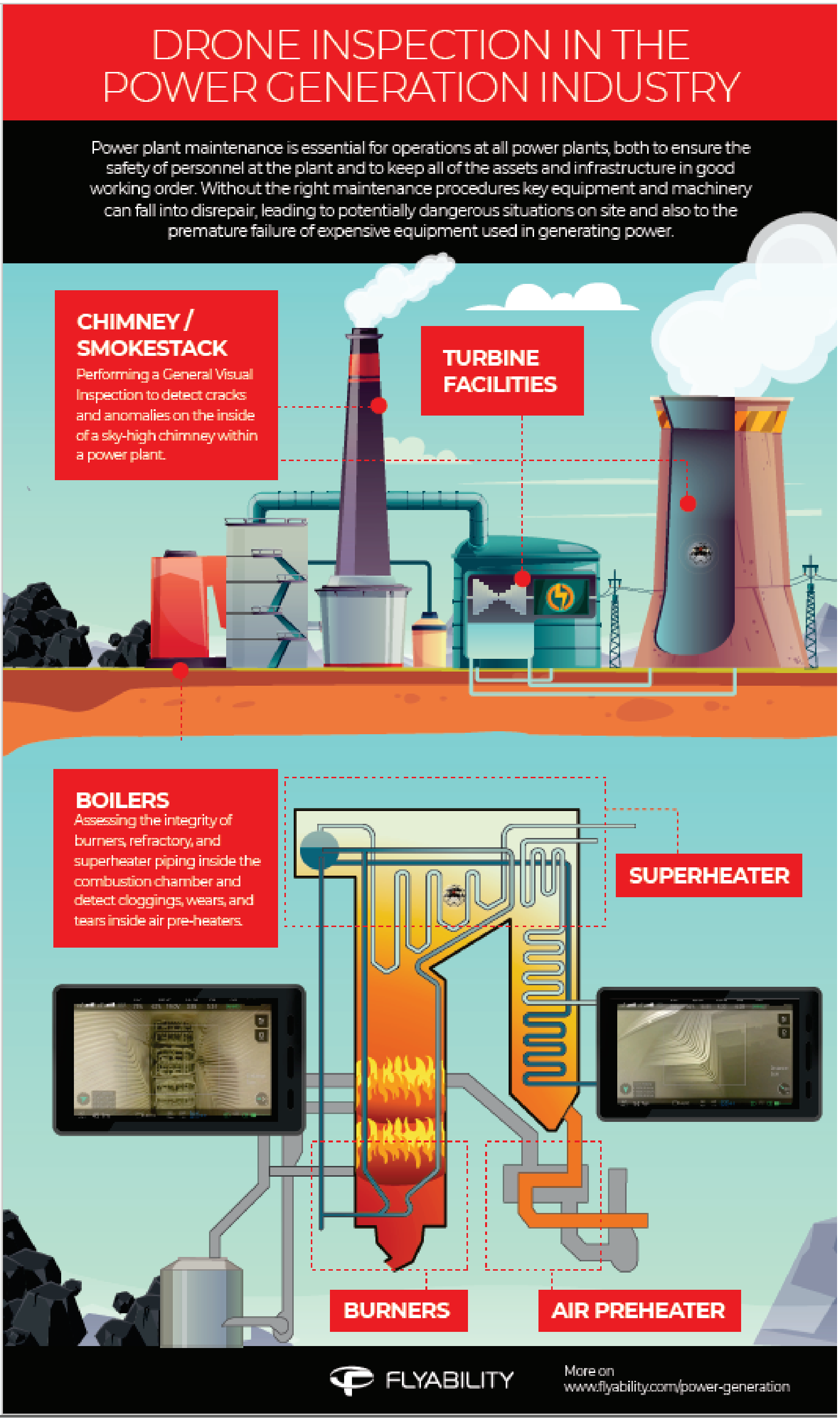
The main improvement target observed in the first test was capability reach rear end of the steam generator. However, this test gave a good knowledge of internal dimensions of the steam generators. Another conclusion was that equipment shall be easier to assemble. Based on these experiences, development work has been decided to continue so that next target is to develop such version, which can entrance also to rear end of the steam generator and its purpose is to carry out just visual inspections. If this target will be reached, the next step will be probably continuation with cleaning functionalities.

9.2 COMMERCIAL-OFF-THE-SHELF (COTS) SOLUTION: FLYABILITY AND BOSTON DYNAMICS

Typical examples of COTS solution are drones of Flyability and SPOT robot of Boston Dynamics. Both companies have developed very capable robots, which are easy to take in operation. By using this kind of solutions, a client saves all development costs and resources, which can be a remarkable saving even if a price of the robot is relatively high.

9.2.1 Flyability: Pressure Vessel Inspections

Flyability’s main product is Elios 2 drone, which is used for inspections in many kinds of industrial applications. Infographic of Flyability below shows some application examples in power industry.



There are lots of case studies from different industrial areas including power generation in homepage of Flyability. Pressure vessel inspection is one of the case studies. More detailed information can be read from the homepage of Flyability, but here is a short summary of the case study:

Pressure vessels are inspected regularly. Typically, inspections are time consuming and include also occupational safety risks. Non-destructive methods are typically used to inspect pressure vessels. Those are mainly visual inspections, but for example ultrasonic *thickness measurements can be part of the inspection. Anyway, entrance of human workers to pressure vessel is always a process, which requires good planning and careful implementation. Mostly also several people need to be involved in the process including safety related personnel. According to Shell even 98% of the inspection costs are related to EHS and preparation and only 2% to inspection itself. So far, such tools as controllable robotic arms or magnetic-wheeled robots are applied, but many cases they have limitations for example with obstacles.*

One possible solution to replace human workers or currently used robotic tools in pressure vessel inspections is a drone. For example, Flyability has developed already for relatively long-time collision safe drones, which can be successfully used for example in inspections of pressure vessels. A pilot test was arranged 2020 in collaboration with Chevron's energy sector.

The pilot was performed by two persons. One was operating the drone, and another was adjusting the live video transmission. The pilots demonstrated that both horizonal and vertical pressure vessels can be inspected by the drone successfully with high quality results. The pilot was a success also otherwise. The drone was for example easy to operate, and results were stored for later analysis. Also, preparations were easy and human workers did not have to enter the steam generator.

9.2.2 Boston Dynamics: Spot

Spot is a kind of flagship product of Boston Dynamics in automated sensing and inspection tools. The Spot can be described as dog. So, it has 4 legs and its walking on them. This gives Spot lots of freedoms to move in difficult environments. Boston Dynamics has also very clear and open pricing system. You can simply go to Boston Dynamics Shop and buy the Spot Explorer with such add-ons you need. This is very easy way to buy the robot for clients who know that Spot is exactly what they need.

Boston Dynamics is presenting case studies in their homepage. As an example, it is presented here how Australian energy company Woodside is using Spot to automate routine inspections and sensing at its processing facilities. More detailed presentation can be read from here.

Woodside is the largest natural gas producer in Australia. Gas production plants are complex and potentially hazardous places where continuous monitoring and inspection is needed. Woodside has invested to Internet of Things (IoT) technologies, but huge amounts of smart sensors required by IoT systems have found to be impractical and expensive. Instead, wheeled robots have been used instead of sensors, but uneven terrain and large distances have caused problems for them. So, Woodside has decided to test Spot as a part of broader intelligent asset workstream, which is meant to significantly reduce annual maintenance costs.

Spot is planned to be used to increase occupational safety. There are many places on gas production plants of Woodside both during operational and emergency situations as well as during periodic shutdowns when Spot can be crucial part to guarantee safety of employees.

The pilot test was made 2020 on plants of Woodside by Boston Dynamics. The first impression was that Spot is able to move on difficult terrain on plant area. In the beginning *just one main problem occurred with mesh metal stairs, but the problem was later solved by software update. Another successful feature was easiness to operate the Spot and its speed to make inspections on large areas.*

In the beginning six potential application were identified for Spot: gauge reading, leak detection, noise anomaly detection, thermal inspection, gas detection and remote inspection. Target was that the Spot would be able to record and report the data by cameras, microphones or other peripherals, freeing up employees for other tasks. Also, quality of data recording by Spot is more uniform that by human workers. This is a result of two main issues, technical quality of observations and punctuality of observation route.

In addition to high quality observations Spot is releasing human workers to higher value works. When routine works are done by robot, human workers can concentrate for example on making processes safer. Woodside has been very satisfied to Spot and they are comparing Spot to mobile phones. Initially it was difficult to see all possibilities of the mobile phone, but when they were taken in wide use, new applications started to grow rapidly. In the case of robotics it is important to start using robots to find all their potential benefits and useful applications.

9.3 MODIFIED-OFF-THE-SHELF (MOTS) SOLUTION: DEVELOPMENT OF SEMI STANDARD ROBOTS IN SKB

As a case example of MOTS development of semi standard robotics in SKB is presented. The following text is written by:

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The final repository of spent fuel in Sweden is planned to be built approximately 500m below the surface. The site will have an array of different activities which will include fully automated vehicles and mobile robotics.

The different tasks which is carried out has been identified and filtered out into different categories through a function-based analysis process.

The three categories the machines and equipment's after the analysis are divided up into consists of these:

1. *Standard technology.*
2. *Semi-standard technology.*
3. *Special development.*

One of the functions which is performed in the deposition area of the facility is the backfilling of the deposition tunnels. This process was in a very early stage in the analysis work identified as a task which was suitable to automate in a higher grade.

In the process both pellets and blocks made out of bentonite clay is installed in the deposition tunnel to close it off and provide an engineered support and protection for the installed components. Cross-section of the tunnel is presented in Figure 4.

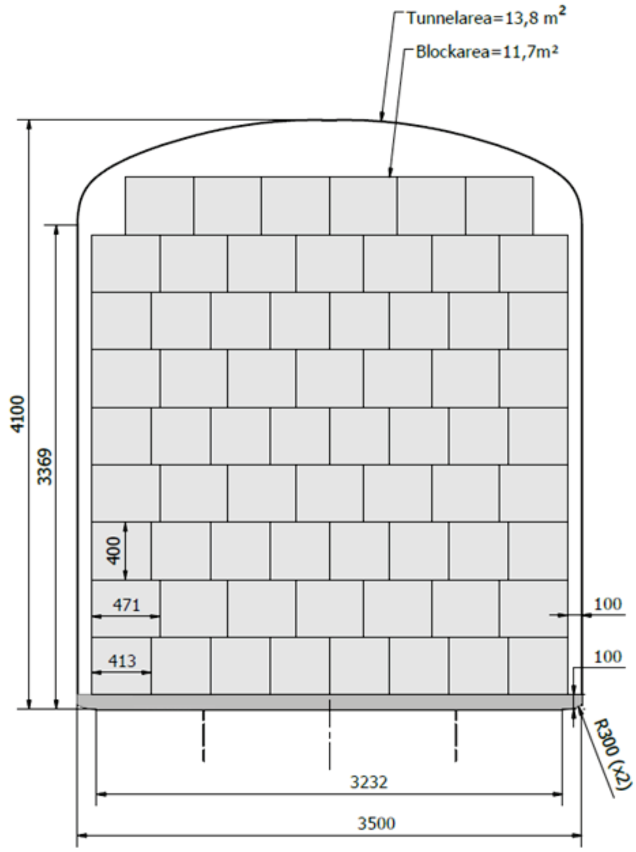

Figure 4 An example of the stacking pattern.

A typical deposition tunnel is approximately 300m long with an area of 14m2. To fill it requires over 190 000 bentonite blocks which has to installed in a specific order and within The technology development strategy at SKB strives to use as much as standard technology as possible. In this use-case SKB choose to look at the opportunity to use a standard heavy-duty industrial robot for the block stacking task. These robotics systems usually are mounted to a concrete floor in a fixed position, but in this application, it has to be able to be moved into position and initialized from the mobile platform, so this is what is called Semi-standard.

One use standard equipment as an industrial robot but for example apply a specialized interface for specialized functionality like mobility.a time limit of 1 minute per block. The average weight of one block is 240kg.

The technology development strategy at SKB strives to use as much as standard technology as possible. In this use-case SKB choose to look at the opportunity to use a standard heavy-duty industrial robot for the block stacking task. These robotics systems usually are

mounted to a concrete floor in a fixed position, but in this application, it has to be able to be moved into position and initialized from the mobile platform, so this is what is called Semi-standard. One use standard equipment as an industrial robot but for example apply a specialized interface for specialized functionality like mobility.

The robot also has to be able to be aware of how its working environment looks like and how it is restricted in its movements. For this task the choice landed on a laser scanner solution since it is not dependent of any light sources or any other aids to make a good measurement. To get the distance needed for the scans a standard volume laser was chosen. Figure 5 shows an example of how the robot see its environment.

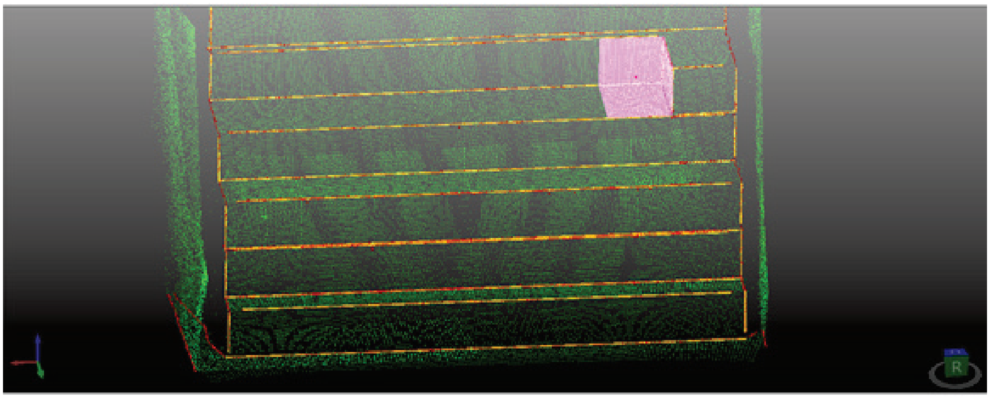

Figure 5 **An example of how the robot see its environment, the pink block represents the next stacking task.**

The mobile platform is a standard product which has been widened by the manufacturer to be able to straddle over a deposition hole, it is important the wheels don't compress the buffer material installed.

The standard chassis is equipped with a special navigation system which is designed to guide vehicles through the tunnel systems without the aid from satellites or any other aids except the natural shape of the tunnel. This has been realized by adopting a fast SLAM (Simultaneous Localization and Mapping) feature. The feature makes the introduction of a new machine to a unknown working environment much easier since the machine by itself learns how the working environment looks like and the operator just chooses which route it should go. This is a part of the specialized part of the robotics system.

Sensors are an important part of the development of mobile robotics, for years now this solution has relied on safety scanners which is used to create the safety zone in which the robot can safely work without any danger to the surrounding activities. This eliminates the need for an enclosed robotic cell and assures the mobility of the solution. Mobile robotic vehicle equipped with many sensors is presented in Figure 6.

Figure 6 **The mobile robotic vehicle is equipped with lots of sensors which also creates the safety feature of the robots work cell.**

The stack of three boxes is the new LiPoMn battery pack which also is being evaluated for use with mobile robotics. The benefits with this type of batteries are they have a higher energy density than LiPoFe batteries and thereby becoming lesser in weight. This is an important feature when designing for heavy- duty mobile robotics.

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ROBOTICS IN NUCLEAR APPLICATIONS

Robotics is used more and more in conventional industry, and the technology is developing rapidly. There are motives for also trying the technology in nuclear applications, for example to carry out tasks in areas of high radiation, retrieve information that would not be feasible with other means, assist in security or to reduce operational- and maintenance costs.

This is an overview of the current use of robotics in industry, position of nuclear industry in development of robotics, guidelines for development of robotics strategy as well as lists case studies. There is a potential to use more robotics in the nuclear industry, both within versatile multi-purpose robots and specialized robots carrying out specific tasks. To increase the use of robotics in the Nordic nuclear industry it is suggested to develop a joint strategy on use of robotics.

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