



NKS-490  
ISBN 978-87-7893-586-1

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# Data4decom

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December 2024

## **Abstract**

Safely decommissioning a nuclear site is a complex, long-term technological and organizational challenge due to its intricate nature, the necessity for knowledge transfer to future generations, and the presence of contamination.

When planning, training, and executing the dismantling process, having information about the actual design and the current state of the plant is paramount for performing the work safely, efficiently, and at acceptable economic costs.

Safe work hinges on thorough planning, which should be based on detailed data about the materials, environment, proper procedures, and the plant's history. This holds true for both operating, maintaining and decommissioning a nuclear site.

Due to safety concerns, the nuclear industry tends to be conservative, favouring the continued use of well-known procedures and technology, even when it would be apparent in comparable industries to adopt a more modern approach.

Exploring and implementing new methods can be time-consuming and costly.

However, obtaining accurate data through effective methods and proper organization is crucial.

In planning a work scenario, access to input data that describes the environment is needed. This includes not only radiological data but also information about the physical environment.

The project invited stakeholders in the Nordic nuclear professional environment to share their experiences and best practices from data collection in their decommissioning processes. This included the advantages and disadvantages of their chosen approaches, as well as the time and costs involved in obtaining and preparing the data for use in decommissioning.

Additionally, the project organized an online workshop on 9th April 2024 and conducted a literature review to find publications about the same issues. The collected material has been published in the current NKS report.

In conclusion, the choice of the right tool, method, and organization is essential for success in all aspects of safely decommissioning a nuclear site.

## **Key words**

Safe nuclear decommissioning, planning, data gathering, stakeholder experiences, best practices.

# **Data4decom**

## **Final Report from the NKS-R Data4decom activity**

**(Contract: AFT/NKS-R (23)137/4)**

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**Acknowledgements**

The NKS Data4decom project group likes to thank all who have taken their time and effort to contribute to the project, the survey, the workshop and the report.

NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

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## 1. Introduction

Decommissioning a nuclear site safely is a long-term technological and organizational challenge due to the plant's complexity, the need to transfer knowledge to future generations, and contamination issues. When planning, training, and performing the dismantling of a nuclear site, having accurate information about the plant's design and current state is crucial for ensuring the work is done safely, efficiently, and cost-effectively.

Safe operations require meticulous planning based on detailed data about materials, the environment, proper procedures, and the plant's history. This is true for both operating and decommissioning a nuclear site. Due to safety concerns, the nuclear industry tends to be conservative, often preferring well-known procedures and technology over more modern approaches used in other industries. Exploring and implementing new methods can be time-consuming and costly, making it essential to obtain accurate data through effective methods and proper organization.

Planning work scenarios in a nuclear environment requires access to comprehensive input data describing the environment. Besides radiological data, information about the physical environment is also necessary. For example, geometrical data can be collected through manual measurements, blueprints, or advanced methods like laser scanning (LIDAR) and photogrammetry. Manual methods require minimal knowledge, organization, and technology but can be time-consuming and prone to errors if blueprints are outdated or in poor condition. Advanced methods, while requiring investments in equipment, software, training, and organization, are efficient for projects needing precise, as-built 3D models. However, they may generate more data than needed for the current scenario, necessitating additional effort to extract the most important details. Therefore, choosing the right tools, methods, and organization is crucial for success.

The Data4decom project engaged stakeholders in the Nordic nuclear professional environment to share their experiences in collecting data needed for decommissioning. This included the pros and cons of various approaches, as well as the time and costs involved in obtaining and preparing the data for use. The project aimed to provide recommendations on the resources needed and potential new approaches for decommissioning. A literature review supplemented this effort.

The findings are published in this NKS report, and a digital workshop on the topic was held at the end of the project on April 9, 2024. The report includes presentations, comments, and questions from the workshop.

The Data4decom project group included IFE (Norway), AFRY (Sweden), and Fortum (Finland). The team members were Niels-Kristian Mark (IFE), Link Hauge Lindskog (IFE), Micaela Hamberg (AFRY), Wilma Falk (AFRY), and Jere Luukkanen (Fortum).

## **2. Project Work Method**

The Data4decom project engaged stakeholders in the Nordic nuclear professional environment to share their experiences in collecting various types of data necessary for decommissioning. This included discussing the pros and cons of their chosen approaches, as well as the time and costs involved in obtaining and preparing the data for decommissioning. This NKS report presents the results of the NKS Data4decom project.

In the summer of 2023, a survey was sent to approximately 50 potential contacts in the Nordic nuclear environment, asking for their assessment of decommissioning data and their interest in contributing to the NKS report and participating in the workshop. The survey text is provided in Appendix 1. Of the invited contacts, nine responded to the survey.

Based on the survey data, the project group decided to gather additional information by interviewing some of the survey participants who had indicated their willingness to be interviewed. Representatives from AFRY and Fortum were interviewed in the autumn of 2023. The results of these interviews were used to strengthen the survey analysis and prepare for the workshop. Information about the interviews is provided in sections 7.1 and 7.2.

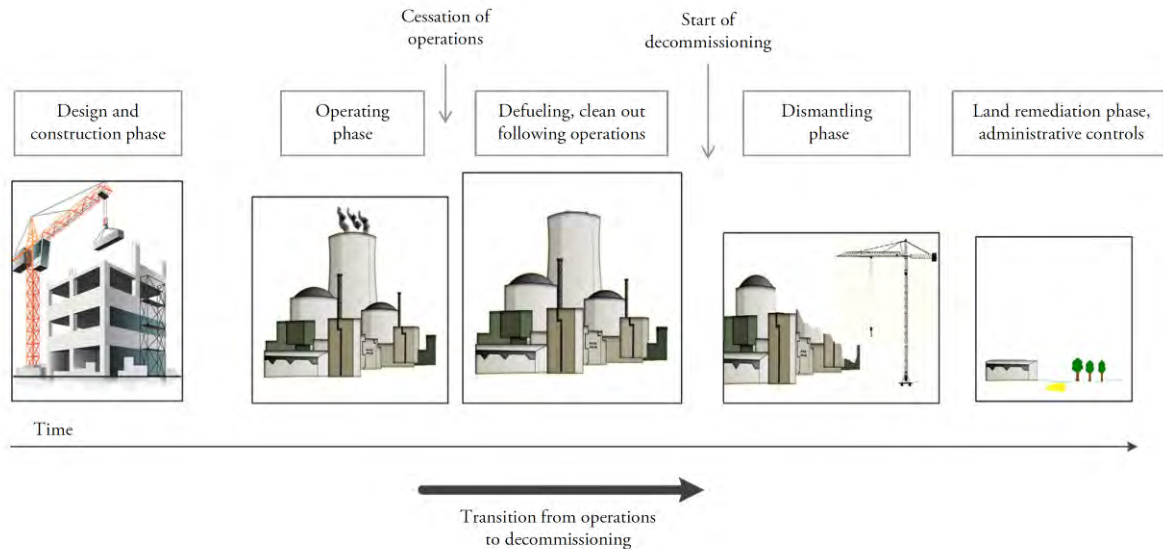
The NKS Data4decom workshop was held on Teams on Tuesday, April 9, 2024, with 15-20 participants throughout the day. The workshop featured presentations by leading Nordic and international experts on completed, ongoing, and planned data collection projects in the Nordic countries and elsewhere. Additionally, various technologies and methodologies were presented. The presentations and discussions were of an advanced technical level. Summaries of the presentations, including Q&A sessions, are in section 8, and copies of the slides can be found in Appendix 3.

In addition to the survey, interviews, and workshop, the project group conducted a literature review to find publications focusing on the assessment of data for use in decommissioning. The result of the review is described in section 9.

The project group held several online meetings between IFE, Fortum, and AFRY. After the workshop, the project group worked on summarizing the workshop, finalizing the report, and publishing the materials. The conclusions are provided in section 10.

### 3. The Nuclear Decommissioning Process

Nuclear decommissioning involves administrative and technical actions to remove regulatory controls from an authorized facility, allowing its site to be reused. This process includes planning, physical and radiological characterization, decontamination, dismantling, and materials management.



**Figure 1** Life cycle of a nuclear power plant as an example of a nuclear facility's life cycle [1, p. 18]

Decommissioning is a standard part of a nuclear facility's lifecycle and should be considered from the earliest stages of development. During initial authorization, a decommissioning plan is created to demonstrate feasibility and ensure provisions for associated costs. At final shutdown, a detailed decommissioning plan outlines the strategy for safe dismantling, radiation protection for workers and the public, environmental impact management, materials handling (both radioactive and non-radioactive), and termination of regulatory authorization.

A crucial aspect is the management of data about the facility throughout its lifetime and decommissioning.

Planning and implementing a decommissioning project are a complex, multidisciplinary process involving both technical and non-technical aspects, requiring effective and timely management. A fundamental requirement is ensuring the safety of workers and the public from radiation, both now and in the future. This also includes managing industrial and non-radiological hazards and protecting the environment during and after the project.

Decommissioning typically takes 15 to 30 years, though it may extend over several decades if an interim safe storage period is used for radioactive decay. The ultimate goal is to restore the environment to its natural state (referred to as "greenfield status") before the facility's construction. This means that, once fully decommissioned, no radiological danger should remain. The facility's license is terminated, and the site is released from regulatory control.

In summary, nuclear decommissioning involves meticulous planning, rigorous execution, and environmental restoration to ensure the safe closure of nuclear facilities.

## **4. Importance of Data in Nuclear Site Decommissioning**

Decommissioning a nuclear site is a complex and critical process that requires meticulous planning and execution. The importance of data in this process cannot be overstated for several reasons:

### **4.1 Safety Assessment**

The primary concern in nuclear decommissioning is safety. Accurate data about the facility's structure, the type and amount of radioactive material, and its location is crucial to ensure the safety of the workers involved and the surrounding environment. This data helps in assessing potential hazards and implementing appropriate safety measures.

### **4.2 Waste Management**

Proper waste management is a critical aspect of nuclear decommissioning. Detailed data about the type and quantity of waste helps in planning for its safe disposal or recycling. This ensures that radioactive waste is handled in a manner that minimizes environmental impact and complies with regulatory requirements.

### **4.3 Cost Estimation**

Decommissioning a nuclear facility is a costly endeavour. Detailed data can help in creating a realistic budget and avoiding unexpected expenses. It allows for better planning and allocation of resources, which can significantly reduce costs. Accurate cost estimation is essential for securing funding and ensuring the financial viability of the decommissioning project.

### **4.4 Regulatory Compliance**

Nuclear facilities are subject to strict regulations. Compliance with national and international regulations is a cornerstone of nuclear decommissioning. Accurate data is necessary to demonstrate compliance with these regulations, avoid penalties, and ensure a smooth decommissioning process. Regulatory bodies require comprehensive data to ensure that the decommissioning process complies with all safety and environmental standards.

### **4.5 Project Planning and Execution**

Accurate data aids in creating a detailed project plan, setting realistic timelines, and monitoring progress. It helps in identifying potential challenges and mitigating risks. Using a Work Breakdown Structure (WBS) can be one method in detailed planning and cost estimation since it interfaces well with scheduling. However, it can be complex to develop and requires a thorough understanding of decommissioning processes. Organizational issues can also be a challenge since it needs integration with project management and financial planning.

Another method is the Data Quality Objectives process, which ensures that the data collected meets the specific needs of the decommissioning project. This involves defining the problem by clearly stating the objectives and the decisions that need to be made. It also includes determining the data needs, identifying the type, quantity, and quality of data required, and establishing performance criteria for setting acceptable levels of uncertainty and error for the data.

### **4.6 Stakeholder Communication**

Engaging with stakeholders is vital for the success of the decommissioning project. Understanding the concerns and expectations of the local community is essential. Accurate data

is crucial for transparent communication with stakeholders, including the government, regulatory bodies, local communities, and the media. Data on the workforce involved in decommissioning, including training and safety records, plays a role in employee relations. Public communication plans are part of the strategy for keeping the public informed about decommissioning activities. This helps build trust and ensures everyone is informed about the decommissioning process.

#### **4.7 Conclusion**

In conclusion, accurate data plays a pivotal role in nuclear decommissioning. It contributes to safety, cost-effectiveness, regulatory compliance, effective waste management, efficient project execution, and transparent stakeholder communication. Therefore, it is imperative to invest in data collection and validation methods to ensure the success of the decommissioning process.

## 5. Gathering Data for Decommissioning

Nuclear decommissioning is a complex process that requires meticulous planning and data collection. Accurate and comprehensive data is crucial for ensuring the decommissioning process is safe, efficient, and compliant with regulatory standards. Each data collection method has its trade-offs, and the choice depends on project-specific requirements, available resources, and safety considerations. Organizational issues often revolve around the need for specialized skills, coordination among various departments, and adherence to safety and regulatory standards.

Effective planning and management are essential to address these challenges and ensure the safe and efficient decommissioning of nuclear facilities. A combination of different methods, tailored to the specific decommissioning project, yields the most comprehensive data for informed decision-making and effective project management.

Here are examples of methods for collecting data along with their pros and cons, and organizational issues:

### Document Review and Analysis

One of the primary sources of information for nuclear decommissioning planning is existing documentation. This includes:

- **Facility design drawings:** These provide detailed information about the layout, structures, and equipment of the facility.
- **Operating manuals:** These contain instructions for operating and maintaining the facility's equipment.
- **Maintenance records:** These documents track the history of equipment maintenance and repairs.
- **Regulatory correspondence:** This includes communications between the facility operator and regulatory agencies.

### Pros:

- **Cost-effective:** Document review is often less expensive than other methods.
- **Historical perspective:** Documents can provide valuable insights into the facility's history, operations, and potential hazards.
- **Baseline data:** Documents can establish a baseline for comparison with current conditions.

### Cons:

- **Limited scope:** Documents may not contain all the necessary information, especially for older facilities.
- **Quality issues:** The quality and reliability of documents can vary.
- **Time-consuming:** Reviewing and analyzing large volumes of documents can be time-consuming.

**Organizational issues:**

- **Access:** Ensuring access to all relevant documents can be challenging, especially for older facilities.
- **Data management:** Developing a system for organizing, storing, and retrieving documents can be time-consuming.

**Site Surveys and Inspections**

Site surveys and inspections are essential for gathering firsthand information about the physical condition of the facility. This includes:

- **Visual inspections:** Examining the facility's structures, equipment, and systems for signs of deterioration, damage, or contamination.
- **Radiation surveys:** Measuring radiation levels in different areas of the facility to identify hotspots and potential hazards.
- **Waste surveys:** Identifying and characterizing waste materials, including radioactive waste, hazardous waste, and general waste.
- **Environmental surveys:** Assessing the condition of the surrounding environment, including air, water, and soil quality.

**Pros:**

- **Direct observation:** Site surveys provide firsthand information about the facility's current condition.
- **Identification of hazards:** Surveys can help identify potential hazards, such as structural integrity issues or contamination hotspots.
- **Data validation:** Surveys can be used to validate information obtained from other sources.

**Cons:**

- **Safety risks:** Conducting site surveys can pose safety risks to personnel due to radiological hazards or other dangers.
- **Time-consuming:** Surveys can be time-consuming, especially for large or complex facilities.
- **Limited scope:** Surveys may not capture all relevant information about the facility.

**Organizational issues:**

- **Planning:** Careful planning is required to ensure that surveys are conducted safely and efficiently.
- **Equipment:** Obtaining and maintaining the necessary equipment for surveys can be costly.
- **Personnel training:** Personnel conducting surveys must be adequately trained to ensure accuracy and safety.

## Sampling and Analysis

Sampling and analysis are used to obtain quantitative data on the presence and concentration of contaminants, including radionuclides, hazardous substances, and other pollutants. This involves:

- **Collecting samples:** Taking samples of materials from different areas of the facility, such as soil, water, air, and equipment.
- **Laboratory analysis:** Testing the samples in a laboratory to determine the presence and concentration of contaminants.
- **Data interpretation:** Analyzing the laboratory results to assess the extent of contamination and identify potential risks.

### Pros:

- **Quantitative data:** Sampling and analysis provide quantitative data on contaminant levels.
- **Risk assessment:** The data can be used to assess the potential risks associated with the facility.
- **Regulatory compliance:** Sampling and analysis are often required by regulatory agencies.

### Cons:

- **Costly:** Laboratory analysis can be expensive, especially for large-scale sampling programs.
- **Time-consuming:** The sampling and analysis process can be time-consuming.
- **Safety risks:** Collecting samples in areas with high radiation levels can pose safety risks.

### Organizational issues:

- **Sample management:** Developing a system for managing and tracking samples can be challenging.
- **Laboratory selection:** Selecting a qualified laboratory with the necessary expertise and equipment can be difficult.
- **Data quality assurance:** Ensuring the quality and accuracy of the laboratory results is essential.

## Remote Sensing Technologies

Remote sensing technologies can be used to gather data about the facility and its surroundings from a distance. This includes:

- **Aerial photography:** Taking high-resolution images of the facility from the air.
- **LIDAR:** Using laser technology to create detailed 3D models of the facility and its surroundings.
- **Ground-penetrating radar:** Using electromagnetic waves to detect underground features, such as buried pipes or tanks.

**Pros:**

- **Non-invasive:** Remote sensing methods do not require physical access to the facility.
- **Large-scale coverage:** Remote sensing can provide data for large areas, including the surrounding environment.
- **Rapid data acquisition:** Remote sensing data can be collected quickly and efficiently.

**Cons:**

- **Resolution limitations:** The resolution of remote sensing data may be limited, depending on the technology used.
- **Interpretation challenges:** Interpreting remote sensing data can be complex, especially for inexperienced users.
- **Cost:** Remote sensing technologies can be expensive, especially for high-resolution data.

**Organizational issues:**

- **Equipment:** Obtaining and maintaining the necessary equipment for remote sensing can be costly.
- **Data processing:** Processing and analyzing remote sensing data requires specialized software and expertise.
- **Integration:** Integrating remote sensing data with other data sources can be challenging.

**Interviews and Surveys**

Interviews and surveys can be used to gather information from facility personnel, contractors, and local communities. This can include:

- **Historical information:** Gathering information about the facility's history, operations, and past events.
- **Local knowledge:** Obtaining insights into local environmental conditions, cultural sensitivities, and community concerns.
- **Stakeholder perspectives:** Understanding the views and concerns of different stakeholders, such as regulatory agencies, environmental groups, and local residents.

**Pros:**

- **Qualitative data:** Interviews and surveys can provide valuable qualitative data that cannot be obtained through other methods.
- **Stakeholder engagement:** Engaging with stakeholders can help build trust and support for the decommissioning process.
- **Identification of issues:** Interviews and surveys can help identify potential issues and concerns that may not be apparent from other sources.

**Cons:**

- **Subjectivity:** The information obtained through interviews and surveys can be subjective and biased.

- **Time-consuming:** Conducting interviews and surveys can be time-consuming.
- **Limited scope:** Interviews and surveys may not provide quantitative data.

**Organizational issues:**

- **Planning:** Careful planning is required to design effective interviews and surveys.
- **Respondent selection:** Selecting representative respondents can be challenging.
- **Data analysis:** Analyzing qualitative data can be time-consuming and requires specialized skills.

**Conclusion**

The selection of data gathering methods for nuclear decommissioning planning depends on various factors, including project-specific requirements, available resources, and the desired level of detail. By carefully considering the advantages, disadvantages, and organizational issues associated with each method, planners can choose the most appropriate approach to ensure they have the data needed for informed decision-making and successful decommissioning.

## 6. The NKS Data4decom survey

As the initial task of the project, a survey was conducted among professionals involved in the operation, maintenance, or decommissioning of nuclear facilities. The survey focused on the methods and tools used for data gathering, the organization of assessments, and the post-processing and utilization of the data.

The survey was distributed to approximately 50 individuals and organizations within the Nordic and international nuclear sectors. Its purpose was to gauge interest in the Data4decom project and identify those willing to contribute with their experiences to the report or to participate in the workshop.

Created using Microsoft Forms, the survey included an introductory text about the project and its objectives, followed by 17 questions. These questions were a mix of open-ended and multiple-choice formats. The questions are listed below, and a copy of the survey is provided in Appendix 1.

1. *How is your organisation involved in the operation, maintenance or decommissioning of nuclear facilities?*
2. *What is your organization's focus (f.ex. operator, regulator, R&D)?*
3. *Are you gathering data for use in the planning of work tasks or for use in the actual work in areas with radiation?*
4. *Would you like to share your own or your organizations experiences from gathering data with the Data4decom project?*
5. *If so, what type of data do you work with?*
6. *Which methods or tools do you use for gathering the data?*
7. *How is the assessment organised?*
8. *Is there some postprocessing of the data before they are used further?*
9. *What are the data used for?*
10. *Are there any special reasons for the way you have chosen to organise the data gathering and postprocessing?*
11. *What are the pros and cons of how you have gathered the data?*
12. *Would you be interested in contributing to the whitepaper?*
13. *Data4decom plans to arrange a 2-day workshop in the autumn at IFE in Halden. Would you like to participate?*
14. *Would you be interested in giving a presentation at the workshop?*

15. *If you like to contribute to the NKS report or the workshop, may we please have your email address so that we can contact you?*

16. *If you haven't time to contribute or if you are not interested, may we kindly ask you to either forward this survey to someone who you think might be interested or tell us who you propose that we should contact?*

17. *Do you have any comments, questions, or proposals?*

Out of approximately 50 invited participants, only 9 responded to the survey. Due to the low response rate, a statistical analysis was not feasible. Therefore, a summary was created based on the work group's subjective interpretation.

Here's the summary of the responses:

1. **Organizational Involvement:**  
The respondents represent a diverse range of roles within the nuclear industry, including R&D, consultancy, operators, and regulatory bodies. Their organizations are involved in various stages of nuclear facility lifecycle, from operation to decommissioning.
2. **Data gathering:**  
The respondents gather data for both planning work tasks and actual work in areas with radiation. The types of data collected include radiological and dosimetric data, meteorological, geological and hydrological data, ecological, biological, social and human habit data, and more.
3. **Methods and tools:**  
Various methods and tools are used for data gathering, including systems' radioactivity data collection, laser scanning of premises, engineering data systems, sample tools, MCNP, Navvis, and others.
4. **Assessment organization:**  
The organization of assessments varies depending on the task, ranging from manual work with documentation to big-data analysis.
5. **Data postprocessing:**  
Most respondents indicated that there is some postprocessing of the data before they are used further.
6. **Data usage:**  
The collected data is used for a variety of purposes, including safety assessments, design reviews, waste estimates, dose risk assessments, and more.
7. **Reasons for data gathering and postprocessing methods:**  
The need for knowledge management, the use of qualified personnel, and the availability of technologies were cited as reasons for the chosen methods of data gathering and postprocessing.
8. **Pros and cons:**  
The respondents mentioned the easy accessibility of data and the use of digital modelling tools as advantages. However, they also pointed out challenges such as the

high cost of sampling, the need for a large staff, and the difficulty in finding specific information due to the sheer amount of data.

9. Contributions to the whitepaper and workshop:

Most respondents expressed interest in contributing to the whitepaper and participating in the workshop, either physically or online.

The survey provided valuable insights into the practices and challenges faced by professionals in the nuclear industry regarding data gathering and usage. It underscores the importance of effective data management and the potential benefits of digital tools in improving efficiency and accuracy. By addressing the identified challenges and leveraging the strengths of existing methods, organizations can enhance their data management practices and support the safe and efficient operation, maintenance or decommissioning of nuclear facilities.

## **7. Interviews for Strengthening the Survey Analysis**

To enhance the survey analysis with additional background data and prepare for the workshop, online interviews were conducted via Teams with two representatives from AFRY and Fortum respectively in autumn 2023.

### **7.1 Interview with AFRY**

The interview with AFRY took place online on December 6, 2023. Participants from AFRY included Andreas Buhlin (Sales Manager) and Benedict Jaeschke (Technical expert in radioactive risk management). Niels-Kristian Mark from the project group conducted the interview, while Wilma Falk took notes. The content of this interview is reflected in the presentations given at the workshop by Andreas Buhlin and Benedict Jaeschke.

### **7.2 Interview with Fortum**

The interview with Fortum was conducted online on December 15, 2023. Participants from Fortum included Matti Kaisanlahti (Senior Expert in Decommissioning) and Jesse Lavonen (Design Engineer in Decommissioning). The interview was done by Niels-Kristian Mark with Jere Luukkanen taking notes. As Fortum did not participate in the workshop, a summary of the interview is provided here.

Fortum has been a pioneer in nuclear decommissioning and waste management for over 30 years. Their comprehensive services cover the entire decommissioning process, from planning and licensing to waste management and final disposal. The decommissioning team consists of approximately 200 engineers and project personnel, with a total of 600 to 700 nuclear professionals involved in various capacities.

Fortum's decommissioning projects are meticulously planned to comply with all regulatory requirements. The company prepares comprehensive licensing documentation and safety analyses to ensure that all decommissioning activities meet the highest safety standards. This rigorous approach to licensing and safety engineering underscores Fortum's commitment to responsible decommissioning.

Fortum's approach to decommissioning heavily relies on data utilization. The company employs advanced digital tools to optimize decommissioning processes. For instance, laser scanning and 3D modelling are integral to their strategy, providing precise measurements and detailed visualizations of decommissioned sites. This data-driven approach ensures accuracy and efficiency, reducing the risk of errors and enhancing safety.

Laser scanning (LIDAR) has emerged as a crucial tool for Fortum in decommissioning, offering speed, reduced labour hours, and cost efficiency. It is primarily used for dimensioning and checking component sizes during decommissioning planning. Jesse Lavonen highlighted that while old drawings can be unreliable, laser scanning provides accurate measurements. Although photogrammetry is not widely used, 360-degree cameras document rooms and waste management areas. All drawings are converted to PDF format for ease of use.

Inventory data, including weight, volume, and nuclide-specific activity, is meticulously recorded. Jesse Lavonen focuses on modelling, while other team members handle scheduling and field actions. Radiation protection plans are developed by a separate team, undergoing multiple review cycles to ensure safety.

The 3D modelling work is conducted in-house, supported by a dedicated database. The team utilizes a range of software tools, including Leica, Navvis, SolidWorks, MicroStation, Autodesk, and Dassault, for various aspects of the decommissioning process. Visualization is enhanced using VRdose from IFE and MCNP modelling software.

Effective waste management is a cornerstone of Fortum's decommissioning projects. The company has developed streamlined processes for handling and disposing of nuclear waste, minimizing potential bottlenecks and delays. Fortum's expertise in waste characterization, packing, and logistics planning ensures that all waste is managed safely and efficiently.

In terms of radiological data acquisition at the Loviisa NPP in Finland, the waste management team employs the MCNP method, leveraging existing knowledge and historical data. All drawings are digitized into PDF format, ensuring easy access and organization.

Jesse Lavonen explained the use of a unique robot owned by VTT Finland, originally designed for painting but now repurposed for contamination measurement. This robot exemplifies the innovative reuse of existing technology in decommissioning processes.

In summary, the interview underscored the importance for Fortum of innovative technologies and meticulous planning in the decommissioning of nuclear facilities, highlighting the collaborative efforts of experts in ensuring safe and efficient processes. Fortum's extensive experience and commitment to safety and efficiency make them a leader in the field of nuclear decommissioning.

More information can be found here:

<https://www.fortum.com/services/nuclear/nuclear-decommissioning>

**FROM SHUTDOWN TO START OF DISMANTLING**

Experiences from the FiR 1 TRIGA Reactor and VTT's Radioactive Materials Laboratory in Finland

([https://conferences.iaea.org/event/288/papers/26455/files/9621-Decom2023\\_116.pdf](https://conferences.iaea.org/event/288/papers/26455/files/9621-Decom2023_116.pdf))

## 8. The NKS Data4decom online workshop 9<sup>th</sup> April 2024

The online workshop was held on Teams on Tuesday, April 9, 2024, from 09:30 to 15:00. The workshop was recorded, and the programme is outlined below.

### NKS Data4decom workshop in Teams Tuesday 9<sup>th</sup> April 2024

#### WORKSHOP PROGRAM:

#### **09:30 - 11:00: SESSION 1**

09:30 – 09:45 Welcome and short about the NKS Data4decom project (N-K. MARK/IFE)

09:45 – 10:10 Plus and cons with different methods for getting geometrical data, for ex. measurements, 3D scanning, etc. (N-K. MARK/IFE)

10:10 – 10:35 NUTRONIC Radiation Management System (L. PETERSON/NUTRONIC)

10:35 – 11:00 AI and Robotics for remote sensing and manipulation in decommissioning (O. ZAHRA & M. JARALLAH/IFE)

#### **11.00 - 11.10: BREAK**

#### **11.10 - 12.00: SESSION 2**

11:10 – 11:35 Radiation Imaging and Robotics in Hazardous Environments (R. FAWKES/CREATEC)

11:35 – 12:00 Use of site data in VRdose for decommissioning planning (J. BRATTELI/IFE)

#### **12.00 - 12.30: LUNCH**

#### **12.30 - 13.20 SESSION 3**

12:30 – 12:55 AFRY Intelligent Scenario Modelling (B. JAESCHKE/AFRY)

12:55 – 13:20 Real Digital Twin (A. BUHLIN/AFRY)

#### **13.20 - 13.30: BREAK**

#### **13:30 - 15:00: SESSION 4**

13:30 – 13:55 Data gathering and use during Chernobyl decommissioning (F. LANSKYKH/ChNPP)

13:55 – 14:20 Characterization of Radioactive Contamination under Post-Accidental Conditions at Unit 4 of Chornobyl NPP (M. SAVELIEV/ISP NPP)

14:20 – 14:45 Integrated digital support concept for nuclear – new approach to data (I. SZŐKE/IFE)

14:45 – 15:00 Summing up and closing the workshop (IFE)

**Figure 2 NKS Data4decom workshop program**

Throughout the day, the number of participants ranged from 15 to 20. A list of participants is provided in Appendix 2.

The next section contains 1–2-page summaries of each presentation. Copies of the slides are available in Appendix 3.

## 8.1 Session 1

### *Plus and Cons with Different Methods for Getting Geometrical Data*

By Niels-Kristian Mark (IFE)

Acquiring geometrical data is a crucial step in many projects, including decommissioning efforts. This data provides a visual representation of the environment, detailing the layout and appearance of various elements. However, the specific type of data required often depends on the project's objectives. For instance, a simple task may only need a basic blueprint sketch, while more complex projects may necessitate a detailed 3D model.

Several methods can be used to obtain geometrical data. The most straightforward approach involves taking measurements directly in the field. While this method is simple, it can be time-consuming and challenging, especially for large-scale projects. Even in smaller spaces, such as meeting rooms, measuring elements like chairs, lamps, or ceiling details can be difficult due to their intricate shapes and placements.

Blueprints and drawings can also serve as sources of geometrical data. However, their accuracy is often questionable, as they may be outdated, damaged, or even contaminated. This raises concerns about reliability and accuracy, making it essential to verify their information before relying on them.

Photographs can provide a visual representation of the environment. However, the accuracy of the data derived from photos depends on factors like the angle, lighting, and overall quality of the image. To ensure accurate results, it is crucial to capture photos under optimal conditions.

3D models can be created manually using software like AutoCAD. These models can be based on measurements, blueprints, photos, or other documentation. Existing models can also be used, provided they are up-to-date and accurate. However, creating 3D models can be time-consuming and requires specialized software knowledge. Additionally, it demands a keen eye for detail to ensure that all elements are accurately represented.

High-precision and high-cost methods involve the use of LIDAR (Light Detection and Ranging, i.e. laser scanners). These devices capture highly accurate data and generate point clouds that can be converted into 3D models. However, they are expensive to buy or rent and require specific expertise. Furthermore, they produce large amounts of data, some of which may not be relevant to the project. This excess data can lead to information overload, making it difficult to identify the necessary information.

Photogrammetry, a technique that uses photos to measure distances between objects, can also be used to create 3D models. However, this method requires many photos and detailed knowledge about their capture conditions. It can be time-consuming and requires a high level of precision to ensure accurate results.

Once the data is acquired, it needs to be processed. Point clouds, for example, must be converted into a 3D mesh or 3D model. This process can be performed using various tools, including open-source options. The final 3D model can then be used in other applications, such as software for planning work tasks in a nuclear environment.

In conclusion, acquiring geometrical data is a complex process that involves selecting the appropriate method for data collection, processing the collected data, and considering the

organization's resources and requirements. Whether it's manual measurement, using blueprints, or employing advanced technologies like LIDAR or photogrammetry, each method has its advantages and disadvantages. Understanding these methods and their implications can significantly improve the efficiency and accuracy of geometrical data acquisition, ultimately leading to more successful project outcomes.

#### Questions and Comments

Maxim Saveliev (ISP NPP) expressed his appreciation for the presentation, highlighting its comprehensive nature and the value it would bring to his colleagues at ISP NPP. He looked forward to sharing it with his team to guide their work.

Niels-Kristian Mark (IFE) expressed his hope to initiate a Norwegian-funded assistance project at Chernobyl involving 3D scanning in cooperation with ISP NPP.

Maxim Saveliev responded positively to this idea, stating that such a project would be highly welcome and necessary. He hinted that he had explained the reasons for this need in his own presentation, emphasizing the project's current relevance.

The conversation concluded with Niels-Kristian Mark expressing his satisfaction with the discussion and thanking Maxim for his input.

## ***NUTRONIC Radiation Management System***

By Lars Peterson (NUTRONIC)

NUTRONIC's newly developed Radiological Data System (RDS) is a digital solution for managing radiological measurement data at nuclear sites.

NUTRONIC AB operates in two primary areas. First, it is an instrumentation company that designs and manufactures radiological smear test instruments. Second, it provides personnel services, supplying Radiation Protection (RP) staff for all stages of a nuclear site's operation, including normal operation, outages, and decommissioning. This dual focus uniquely positions the company to identify collaborative opportunities between instrumentation and operational RP services.

The presentation highlighted some challenges in handling radiological data for decommissioning. Regulatory authorities often have more stringent requirements for documentation during decommissioning compared to normal operation. Additionally, many manual methods for data transfer are still in use, relying on pen and paper and notebooks. While some instruments have memory cards or cable connections for data transfer, each manufacturer's system is proprietary, leading to a lack of standardization. These systems typically only handle raw measurement data, without provisions for adding metadata such as location, system number, project number, or calibration status. The absence of a unified database for data from different instruments makes it difficult to combine various types of instrument data for use in decommissioning, particularly in free release work, which is the final stage of decommissioning.

To address these challenges, NUTRONIC has developed the Radiological Data System (RDS). This system integrates the most commonly used instruments by radiation protection technicians, including the Frisker probe, the Automess instrument, the ANTI 200 (NUTRONIC's own smear test instrument), and a newly developed floor monitor. These instruments and probes communicate via Bluetooth with a handheld computer, which collects data during measurements. When the handheld computer connects to the Wi-Fi network of the database server, all measurement data, pictures, and notes are transferred to the server.

The key concepts of the RDS are to replace pen and paper with a rugged handheld computer, unify all instrument data used by radiation protection technicians on a daily basis, and transfer data via Bluetooth from the instrument or probe to a handheld computer. The handheld computer has an industrial-grade bar and QR code scanner, allowing users to label objects with room numbers and system numbers, scan them, and link this information to their measurement data. Measurements are stored in the database along with pictures and notes, and users can add tags for various elements.

NUTRONIC believes the main benefits of this system are that the handheld computer replaces all readout instruments, significantly improves data quality by reducing human operator errors, and simplifies data searching through the use of tags. As an instrument manufacturer, NUTRONIC also offers the ability to enforce daily pre-operational checks on the instruments and a zero test, as well as a calibration expiry check before each use.

Some considerations for a successful system implementation include the use of low-power radio transmission (Bluetooth Low Energy) and the need for some training to operate the app and read out values from the instruments. The system was showcased at the World Nuclear

Exhibition in Paris 2023, and NUTRONIC plans to release it to the general public in the second half of 2024. NUTRONIC has already received the first order for the floor monitor from a Swedish customer for use in decommissioning their site. NUTRONIC is currently producing these instruments and actively seeking cooperation with other manufacturers to integrate more instruments into the RDS.

#### Questions and Comments

Niels-Kristian Mark (IFE) asked Lars Peterson (NUTRONIC) if they had conducted any experiments or tests comparing their new method with traditional methods. He was interested in understanding the differences and improvements their instruments could offer.

Lars Peterson responded that they hadn't conducted any such comparisons as their system was newly developed. He mentioned that the first customer installation would be for a Swedish customer. He also stated that they had developed this system based on their knowledge and close collaboration between their instrumentation manufacturing and RP staff.

Maxim Saveliev (ISP NPP) offered Ukraine as a test environment for their system, stating that they were ready to provide the best test environment in the world. He expressed his appreciation for their work and mentioned that they were moving in the same direction. He also asked about their experience working with Mirion on apparatus personal dosimeters and red eye instruments, both of which have Bluetooth communication.

Lars Peterson confirmed that they were familiar with both instruments. He mentioned that Mirion was their distributor in France and that they planned to cooperate with Mirion to integrate their instruments into the system. He also acknowledged that they were aware of the Bluetooth adapter for the red eye instrument and were seeking cooperation to get the protocol.

Maxim Saveliev expressed interest in any feedback they might receive from Thermo Fisher Red Dye. He also shared his experience with Mirion's compatibility with Android and iOS platforms and their own application but questioned the integration with other instruments.

Lars Peterson thanked Maxim for his comments and expressed his willingness to share experiences.

## ***AI and Robotics for Remote Sensing and Manipulation in Decommissioning***

By Omar Zahra and Mustafa Ali Hadi Jarallah (IFE)

Research scientists Mustafa and Omar Zahra presented their innovative work in visual-guided robotics grasping. Mustafa, with a background in physics simulation and data application tasks, introduced the project, emphasizing its relevance in AI, formal sensing, and decommissioning.

The project, developed at IFE's HADRON Lab, focuses on modelling hazards in nuclear and other domains using physics and machine learning models. Robotics play a crucial role in performing tasks in these complex environments. Mustafa highlighted a field demonstration in an industrial site, showcasing the challenges robots face in understanding and interacting with dynamic scenes.

The team began their experiments in the radiopharmaceutical field, using a robotic manipulator in a radiological environment. They tested prototypes in a hot cell with medical vials, which are transparent and challenging to detect. The initial approach involved recognizing the circular cap of the vial and placing them in a predefined matrix for the robotic arm to accurately locate.

Traditionally, creating a training dataset for object recognition involves capturing numerous images from different angles and lighting conditions, followed by extensive annotation. However, the team sought a more general application by exploring foundation models. These models, trained on diverse internet-scale data, can perform various tasks without additional training.

Using foundation models, the team tested object tracking and segmentation. The models performed well out of the box, detecting objects in cluttered scenes without prior training. By prompting the model, they could highlight specific objects, demonstrating the model's ability to recognize and segment objects accurately.

Omar Zahra explained the integration of visual information with robotics. The robot needs precise calibration to understand the camera's location relative to its body. This calibration ensures accurate grasping, as even a slight drift can affect the process. The robot identifies objects, processes their attributes, and generates possible grasping methods using AI.

The team demonstrated the robot's ability to grasp objects using an RGBD camera, which provides depth information. The robot evaluates different grasping options, selects the best one, and executes the command. The process is visualized in real-time, showing the robot's successful grasping of a cup.

Mustafa and Omar's work highlights the potential of foundation models in enhancing robotic perception and grasping capabilities. Their approach reduces the need for extensive training datasets, making it a promising solution for complex industrial applications. The integration of AI and robotics in hazardous environments showcases the advancements in technology and its practical implications.

### **Questions and Comments**

Niels-Kristian Mark (IFE) asked Mustafa Ali Hadi Jarallah (IFE) when their robotic system would be commercially available and capable of operating in a nuclear site.

Mustafa Ali Hadi Jarallah responded that their solutions are becoming robust enough to understand complex scenes and perform robust grasping or manipulation tasks. He mentioned that these models would be best operated with a human in the loop and predicted that full autonomy might require a couple more years.

Niels-Kristian Mark expressed his admiration for the segmentation photos and the process of splitting things based on images. He acknowledged the importance of this task, especially considering the complexity of doing it manually.

Mustafa Ali Hadi Jarallah agreed and emphasized the complexity of the grasping task, especially when dealing with different types of objects with awkward geometries. He expressed confidence that their models would significantly advance this area. He also mentioned that their models are open source, and everyone can use them along with the dataset that comes with the models.

## 8.2 Session 2

### *Radiation Imaging and Robotics in Hazardous Environments*

By Ross Fawkes (CREATEEC)

CREATEEC has developed innovative radiation imaging products and robotics designed for hazardous environments. CREATEEC's core expertise lies in robotics, radiometrics, sensing, and inspection, with a focus on providing digital models of survey areas to assist customers in making informed decisions.

One of the primary objectives is to provide a digital output, such as a digital model of a survey area. This approach offers numerous benefits, including enabling customers to make informed decisions, potentially reducing costs, and improving safety.

One of the key tools and core products from CREATEEC is the N-Visage scanner, a 360-degree gamma imager. The scanner, designed in a cylindrical shape, can be inserted through small ports into cells where access might typically be challenging or undesirable. The version of the scanner shown on the slides operates between 50 microsieverts and two sieverts. Other versions, including an older version that can go down to 10 microsieverts, are available but are significantly larger and heavier. The choice between the two depends on the specific needs of the user. The N-Visage scanner provides a panoramic image output with an intensity heatmap, showing source locations and directions.

CREATEEC is also developing a custom scanner in collaboration with their Japanese customers, designed to operate in very high-dose areas. It is specifically designed to be used inside the containment vessel of a fusion reactor.

The N-Visage scanner provides a snapshot of the area, showing source locations and direction. It is particularly useful for a first look inside an area, revealing details that might not have been previously known. For example, in a tank used to filter pond water, it was discovered that the highest dose rate was coming from a corner, contrary to the customer's assumption that the dose rate would be evenly distributed across the tank.

If one takes multiple snapshots across the survey area, one can use CREATEEC's software, N-Visage Fusion, to stitch those together and triangulate sources. This is a powerful tool that can help estimate dose rates across a survey area, allowing for predictions of what the dose rate would be for someone entering the area and moving around.

Another product CREATEEC has in development is the Explore, a robotic deployment system. The system, which includes a main detector, dose probes, and a LIDAR component, can be used to take measurements in a survey area. This system can walk around a survey area and provide a trail of dose measurements. It can be automated to periodically get up from its charging station, walk around, and collect data. This allows for monitoring of any changes in the environment and removes the human from potential harm's way in high-dose areas.

Furthermore, CREATEEC offers a product called Deep, which assesses how far contamination has penetrated into concrete. By knowing the depth of contamination, only the contaminated concrete needs to be classified as waste. This helps to reduce waste by cutting down only the contaminated concrete, thus saving costs.

Mobile robotics can perform operations in highly contaminated areas, providing high-quality imagery and precise measurements. They can perform operations such as surface monitoring and debris clearance, and can even carry other devices, such as the N-Visage NV3 scanner.

Robotics can be operated remotely, reducing the need for human presence in hazardous environments. They can also carry mesh network ports to maintain data access in environments with many concrete walls. Robotics offer a powerful tool for operating in hazardous environments, providing high-quality imagery and precise measurements while keeping humans out of harm's way. They can be used for a variety of operations, from surface monitoring to debris clearance, and can be controlled remotely, even from overseas.

In conclusion, CREATEC is at the forefront of leveraging robotics and radiation imaging to improve safety and efficiency in hazardous environments. Their innovative products are not only revolutionizing operations but also paving the way for future advancements in the field.

#### Questions and Comments

Niels-Kristian Mark (IFE) asked Maxim Saveliev (ISP NPP) if he would like to use CREATEC's technology in Chernobyl.

Maxim Saveliev responded that they are currently using other platforms in Chernobyl for radiation mapping. He mentioned that they are familiar with the technology but do not have it in their lab. He expressed hope for future cooperation to acquire the technology.

Niels-Kristian Mark then asked Ross Fawkes (CREATEC) about the duration required for the N-Visage NV3 to perform scanning.

Ross Fawkes explained that the scanning usually takes a minimum of around 2 hours 45 minutes, but it can vary depending on the environment and the complexity of the area. He mentioned that the analysis afterwards could take a few days to a few weeks.

Maxim Saveliev asked Ross Fawkes about the type of sensor used for precise measurement.

Ross Fawkes clarified that both the NV3 and the NV Explore use a CZT detector. However, the NV Explore uses content imaging, which limits its capability to up to 100 mSv/hr.

## *Use of Site Data in VRdose for Decommissioning Planning*

By Joachim Bratteli (IFE)

Joachim Bratteli introduced VRdose, a software designed to assist in the planning of decommissioning operations. He has been working with VRdose for several years and shared his insights on how the software can integrate data to bridge the gap between normal operations and decommissioning.

The planning process in VRdose is highly iterative. It begins with defining a use case and identifying the type of data needed for the operation. This data is then structured, and an analysis method is chosen to create a plan. The results of this method are integrated back with other data to bridge the gap using a traditional method for dose calculation. This iterative process allows for continuous refinement and decision making.

Case analysis is where gaps in knowledge are identified. The main goal is to gather as much relevant knowledge as possible and identify unknowns that need to be addressed. For instance, while one might know the normal working conditions and have descriptions of maintenance operations, the work operation for decommissioning might be unknown. This is where VRdose comes in, helping to define alternative work operations and perform dose rate simulations to identify hazards.

Once the necessary data has been gathered and structured, it's time for data analysis. This involves modelling and extrapolating on the data to enhance its value. If the data is insufficient, the process may need to be extended with additional data gathering.

A crucial part of the process is dose rate analysis. Depending on the data and operation, different models and metrics can be used for this assessment. Interpolation of industry presets might be sufficient for typical maintenance work. However, if things are being moved around, more complex methods might be needed.

After modelling and analysis, the next step is to integrate and filter the data. This involves looking at how to mitigate hazards and making decisions based on the outputs of the analysis. Considerations at this stage include potential conflicts with other operations, resource usage, and public regulations.

In conclusion, VRdose is a powerful tool that can revolutionize the planning process for decommissioning operations. By integrating data and providing comprehensive analysis tools, it can help bridge the gap between normal operations and decommissioning, making the process safer and more efficient.

### Questions and Comments

Niels-Kristian Mark (IFE) asked Joachim Bratteli (IFE) if there are plans for a new release of VRdose.

Joachim Bratteli confirmed that a new release is on its way. He explained that as a research institute, IFE has limited resources for software development and needs to align with people who have issues that should be met in the system's development. He mentioned that they have been receiving inputs from different places and that a new release with small feature updates is expected soon.

Maxim Saveliev (ISP NPP) commented on the practicality of VRdose. He praised VRdose for its accuracy in finding the right points of sources during an allegation survey and its correspondence to practical measurements. He expressed happiness about the software's continuous development and wished Joachim Bratteli good luck.

### 8.3 Session 3

#### *AFRY Intelligent Scenario Modelling: An Overview*

By Benedict Jaeschke (AFRY)

AFRY is a company that specializes in the development of a modernizing platform known as AFRY Intelligent Scenario Modelling.

AFRY Intelligent Scenario Modelling was previously called “Ecolego” which was still effective at the time of the presentation at the workshop. The change of name took place during the period between the presentation and the publication of this report.

AFRY Intelligent Scenario Modelling is a product of over 25 years of dedicated development, designed to fulfil the need for practical models for transport and dosimetry modelling associated with geological repositories, particularly in the realm of radioactive waste disposal. While it is tailored to cater to various types of risk assessments, its versatility extends to all kinds of mathematical modelling requirements, not just in the nuclear industry but also in other sectors. AFRY Intelligent Scenario Modelling can be used for predictive environmental modelling, simulating how radionuclides or other materials might transport within an environment. It can model various scenarios, such as fires or flooding events, and can predict potential doses that humans might be exposed to under these conditions.

In the realm of risk assessment and mathematical modelling, AFRY Intelligent Scenario Modelling has emerged as a robust platform, catering to a wide array of requirements in the nuclear industry and beyond. Today, it stands as a comprehensive tool for creating mathematical models that simulate static or dynamic systems, particularly useful in risk assessment scenarios.

AFRY Intelligent Scenario Modelling's versatility lies in its ability to create generic models that can be adapted to various scenarios. This flexibility extends to risk assessments, quality assurance, and even nuclear transport modelling. The platform has found applications in waste management, planned operations for nuclear sites, new builds, and decommissioning tasks such as site clearance and management of radioactive wastes.

The system serves as a platform for the creation of mathematical models that illustrate dynamic systems and simulate both static and dynamic systems for risk assessment purposes. It has proven particularly beneficial in waste management, planned operations for nuclear sites, new builds, and has been extensively utilized for decommissioning tasks, especially in site clearance or planning of radioactive waste management.

AFRY Intelligent Scenario Modelling boasts an intuitive user interface that simplifies the process of building mathematical models from conceptual models. The software allows for the creation of a library of models, which can be selected and combined to simulate processes for specific use cases. This feature makes it straightforward to create optimized models for different iterations of a process or to test different scenarios.

The software handles data management efficiently, allowing for the importation of entire datasets via an Excel sheet. The software also includes databases of useful information, such as radionuclide characteristics. For quality assurance, AFRY Intelligent Scenario Modelling provides tools for unit checking, data consistency checks, and internal review of the data used in the models.

One of AFRY Intelligent Scenario Modelling's standout features is its use of probabilistic simulators. Instead of using a best estimate point of data, a probability density function can be used to represent the characteristics of a site and assess the uncertainty within datasets. This feature is particularly useful for environmental data, where variation over periods of days, years, or even thousands of years is expected.

The platform also offers several ways to visualize the model, including an interaction matrix, a graph view, and a relationship view. All these models are interactive, allowing users to access information about the mathematical model for each component, the parameters used, and what is represented in each compartment.

The primary applications of AFRY Intelligent Scenario Modelling are found in the nuclear industry and nuclear transport. It has been employed for the transport of released radionuclides from operational facilities and for the clearance of remediated or decommissioned sites for repurposing. Furthermore, AFRY Intelligent Scenario Modelling has been used for the disposal of specific clearable waste or specifically clearable waste. In these cases, a risk assessment and a modelling basis are employed to manage and treat radioactive waste that may be towards the lower end of the scale, or just above the level of clearance.

AFRY Intelligent Scenario Modelling has been embraced and implemented by a wide array of both nuclear and non-nuclear institutions. It has earned the endorsement of the IAEA and has been used to implement models and modelling strategies recommended by the IAEA. Its use extends to various countries in the Nordic region and beyond, for operation, post-operation, and planned utilization of the nuclear industry.

AFRY Intelligent Scenario Modelling is a comprehensive modelling platform that caters to a wide array of requirements in risk assessment and mathematical modelling. With its versatile functionalities, intuitive user interface, efficient data management, and robust quality assurance tools, AFRY Intelligent Scenario Modelling stands as a reliable tool for both the nuclear industry and beyond. Its wide-ranging applications, coupled with its ability to handle probabilistic simulations, make it a valuable asset in the realm of risk assessment. It comes with built-in functionality for risk assessments and quality assurance and has seen widespread adoption in both nuclear and non-nuclear institutions. As AFRY Intelligent Scenario Modelling continues to evolve and adapt to the changing needs of the industry, it promises to remain a vital tool in the field of risk assessment and mathematical modelling.

#### Questions and Comments

Niels-Kristian Mark (IFE) asked Benedict Jaeschke (AFRY) about the speed of using their software, specifically in the event of an incident like Chernobyl, and whether it could be used to predict the spread of contamination in real time.

Benedict Jaeschke explained that the speed of using the software depends on the information available and the complexity of the system. He mentioned that developing a model from scratch could take days, weeks, or even months. However, if a model that broadly describes the process of interest already exists, it can be rapidly adapted to represent the site by identifying the relevant processes and parameters. He added that the adaptation of existing models is quick, and parameterization can be done relatively quickly. Also, a simple scenario could be modelled in a day, while more complex models or probabilistic assessments could take longer due to the number of variables and computing power required.

## ***Real Digital Twin***

By Andreas Buhlin (AFRY)

Andreas Buhlin, the Head of Development RDT Digitalisation at AFRY, provided an insightful overview of the Real Digital Twin (RDT).

The journey from the first industrial revolution, characterized by mechanization, to the fourth, marked by automation, has been transformative. As we navigate the fourth industrial revolution, discussions about the fifth are gaining momentum. One interpretation of the fifth revolution is the Digital Twin Revolution, where different types of digital twin tools are used to solve various problems. The vision is to create a complete digital twin laboratory where everything can be tested in different tools in a digital twin environment without doing anything in real life.

Digital twin tools can be categorized into four areas. The first is visualization tools, which provide advanced visualization and are often used for layout or safety validation. The second category is simulation twins, used for system design and validation at the early phase of building a new factory. The third type is emulation digital twins, which mimic a system to create an exact digital replica of a production system. The final category is optimization digital twins, which often involve some sort of AI like machine learning or predictive maintenance to help predict and correct the future.

The RDT is a comprehensive system that can be applied to any type of automation system, regardless of whether it's in nuclear, pharma, or manufacturing. The system involves building all the assets and components exactly as they work, behave, and communicate. This allows for the testing and debugging of control systems in a computer environment. It allows for iterative testing throughout the project, enabling all disciplines to test along the way and agree on what is happening or what kind of mistakes have been made. This system is designed to test and debug control systems in a computerized environment, allowing for iterative testing throughout a project's lifecycle.

The RDT is a precise replica of the factory floor or the process. It's a virtual representation of a real production system. AFRY concentrates 100% on details, constructing equipment that behaves exactly as it does in reality. RDT emulates, not simulates, using the precise state machines and communication behaviour.

The RDT helps customers gain early control of automation projects, leading to better understanding, structured workflow, early testing and verification, and early failure detection. It also allows for virtual tests before physical installation.

The RDT is a standardized software package solution used as a virtual testbed to test, deploy, and reduce risks in automation projects. It can be used with various automation suppliers, reducing supplier dependency and can help reduce cost, enhance productivity, ensure quality, and minimize risks. It allows one to identify failures early, rectify issues promptly, and facilitate knowledge sharing across disciplines. This allows for early testing, thus shortening overall test time and moving some activities from the physical factory area to the simulator. Thereby, the RDT shortens on-site testing time.

The RDT is a virtual representation of a real production system and a replica of the factory floor. It focuses on details, building equipment exactly how it behaves, and emulating stuff with no simplifications. It uses the exact right state machines and the exact right communication

behaviours. The RDT delivers hardware emulation and process dynamics simulation for PLC code testing. It is used to connect PLCs in development test commissioning and can connect to any type of supervisory system. It is also used for operator training courses. RDT architecture is divided into three layers: I/O emulation/Electro-Hydraulic model, hardware simulation, and process simulation. Each layer has a specific function and contributes to the overall effectiveness of the system. It enables iterative testing of developed OT systems, endless virtual stress tests, and realistic operator training in OT/IT systems. It can be used to verify and improve PLC code, find and correct issues before deployment, and commission a control system with higher quality and faster ramp-up time.

Data is a crucial part of the RDT system. The system requires an understanding of whether the project is supposed to follow any type of standard, the number of unique components, and what standards are supposed to be followed. The system also requires an IO list, which is a unique signal name for each purpose.

The RDT can replace simplified self-tests with a more precise testbed, resulting in up to 95% readiness before physical implementation, up to 80% reduction in commissioning and ramp-up time, and up to 30% reduction in project development time.

The RDT has been successfully implemented in various industries. For instance, Novo Nordisk, a pharmaceutical company, has been using the tool for about 18 months in building a new pilot plant for insulin production in Copenhagen. The tool helped them ensure they were following the standard by setting up their side and washing the data from day one. This approach helped them find many faults and fix them early on.

In a wastewater project for Ringhals power plant, the system was used to stress test scenarios. The test bed was used to simulate a flow through the system and examine various scenarios, such as what happens when a valve is closed while a pump is still running. This kind of testing can reveal potential issues in the system before they become problematic in a real-world setting. It allows the team to see what kind of flow they would get through the system, whether they would get the right controlling, and whether they would get the right alarms.

Another example is Scania, a lorry manufacturing company in Sweden. In a project at a factory in Södertälje, Sweden, the RDT system was used to simulate a robotic cell. The system allows for 3D visualization and was connected to a visualization tool, Robot Studio, which allowed for interaction between the system and the 3D world. A complete factory was going to be set up in China and it started by helping the IT side according to the ISA 95 model. A twin was set up and the whole IT stack tested, which helped them debug it and ensure a smooth installation in China later.

The RDT is a powerful tool that is revolutionizing industrial processes. By providing a virtual testbed that supports real-time testing and debugging of control systems, it allows developers to work in an agile manner, reducing costs, increasing productivity, assuring quality, and minimizing risks. With its successful implementation in various industries, including nuclear power, helping to improve efficiency and accuracy, the RDT is set to play a pivotal role in the fifth industrial revolution, the Digital Twin Revolution.

AFRY has been involved in several projects within the nuclear industry. They have worked on projects such as an elevator for end-of-life fuel, decommissioning of one of a reactors' cooling

and ventilation systems, and a wastewater project. The RDT system can be used in brownfield projects, greenfield projects, or decommissioning.

The RDT is primarily a virtual testbed used to reduce cost, increase productivity, assure quality, and minimize risks. By providing a testbed, it enables developers to work in an agile manner, for example the IT side. This approach allows developers to fail early, fix issues earlier, and gain knowledge in between disciplines. The outcome is a reduction in total cost, higher quality, and faster time to production.

### Questions and Comments

The Q&A session revolved around the use of the RDT in the nuclear sector, specifically for decommissioning tasks.

Andres Buhlin (AFRY) mentioned one project from Sweden in decommissioning about the reconfiguration of a control room to a new controller. A digital twin was built and used in the development project to verify that everything would work as expected. Another project was at the Ringhals NPP on the West Coast of Sweden, where a new wastewater system was being built. A detailed twin was built for an ABB 800xA system and used in the development project for testing at a very accurate detail level.

Andreas Buhlin also mentioned smaller projects, such as a switch gear change control system where the plant commissioning was completed in one day instead of the planned 14 days, resulting in significant cost savings. More information can be found at the new RDT website: <https://afry.com/en/service/afry-real-digital-twin-framework>

Maxim Saveliev (ISP NPP) highlighted the importance of having a library of models of equipment like pumps, tanks, pipes, valves, etc., for efficient simulation. Andreas Buhlin agreed and explained that their system is divided into three layers: IO communication, devices with a state model, and process simulation. The process simulation layer can use different tools depending on the project's needs, including Siemens' SIMIT Flownet, Aspen HYSYS, or MATLAB models.

The discussion also highlighted the importance of simulation logic and the use of different tools for high fidelity results. The system's flexibility and adaptability make it a valuable tool in the nuclear industry.

## 8.4 Session 4

### *Data Gathering and Use during Chernobyl decommissioning*

By Fedir Lanskykh (ChNPP)

In the aftermath of the 1986 Chernobyl disaster, the world witnessed one of the most catastrophic events in the history of nuclear energy. Fedir Lanskykh, a leading engineer with 27 years of experience, has been at the forefront of the decommissioning process of the Chernobyl Nuclear Power Plant (ChNPP). Lanskykh's work encompasses a range of activities, including repair operations, 3D modelling, visualization, and providing scientific and technical support. His presentation sheds light on the intricate and critical operations involved in this monumental task.

Chernobyl, once synonymous with nuclear disaster, is now a beacon of recovery and resilience. The ChNPP, located in the north of Ukraine, 140 kilometres from the capital, Kiev, has undergone a transformation from a site of tragedy to one of scientific and technical innovation.

Following the accident, the entire facility and its surrounding territory were contaminated with radioactive material. It wasn't until the end of the year 2000 that Ukraine shut down the last operational unit of the ChNPP, a move that marked the beginning of an extensive decommissioning process. By 2002, the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) issued a license for the ChNPP to engage solely in decommissioning activities.

The decommissioning process involves transforming the shelter object into an ecologically safe system, managing spent nuclear fuel, and handling radioactive waste. The collection and analysis of data are crucial to the decommissioning efforts. ChNPP employees, contractors, and representatives of scientific organizations collaborate to perform engineering and radiation surveys, process archival information, and conduct new scientific investigations. This data includes information on the technical status of buildings, systems, and equipment, as well as the radiation status of the facilities.

Moreover, the data encompasses details about nuclear fuel, radioactive materials, and other hazardous substances. This comprehensive information is used to make informed decisions, tackle challenges during decommissioning, and preserve knowledge for future use.

The presentation not only highlighted the technical aspects of the decommissioning process but also underscored the unwavering spirit of those involved in turning a site of devastation into one of hope. As the world continues to watch, Chernobyl's journey from ruin to restoration serves as a testament to human determination and the power of science in overcoming adversity.

#### Questions and Comments

Niels-Kristian Mark (IFE) asked Fedir Lanskykh (ChNPP) about the methods ChNPP uses to gather data about the appearance of buildings. He inquired whether they use scanning equipment, photos, old drawings, or measurements.

Fedir Lanskykh explained that they use a variety of methods, including visual inspections, photos, videos, and tools for measuring radiation and geometrical indicators. They also use design documentation and drawings, as well as other information available in their archives.

Maxim Saveliev (ISP NPP) added that ChNPP significantly uses the equipment of the Chernobyl Decommissioning Visualization Centre that was developed in cooperation with IFE in a Norwegian funded assistance project.

## ***Characterization of Radioactive Contamination under Post-Accidental Conditions at Unit 4 of Chernobyl NPP***

By Maxim Saveliev, Institute for Safety Problems of Nuclear Power Plants, National Academy of Sciences of Ukraine.

The presentation, prepared in collaboration with Viktor Krasnov and Maksym Pantin, provides an in-depth analysis of the aftermath of the worst nuclear accident in history, which occurred on April 26, 1986.

The catastrophic event at Chernobyl's Unit 4 was a result of a dramatic combination of deviations in operational procedures and reactor design flaws. The reactor core, measuring 7 meters in height and 11.8 meters in diameter, contained approximately 190 tons of nuclear fuel, which was destroyed. This led to the release of more than 10,000 petabecquerels of radioactive material into the environment.

The first attempts to assess the radiation conditions were conducted by military vehicles equipped with radiation reconnaissance tools. However, these efforts were limited due to the lack of access to the Unit 4 premises and the extremely high dose rates, which saturated the available sensors. Successful radiation assessments were later carried out using helicopters with collimated sensors, performing over 2,000 measurements from a height of 200 meters on the first day of the accident.

Twenty-four days after the disaster, a decision was made to construct a facility to contain the damaged power unit. Known as the Chernobyl Sarcophagus, this shelter object was built over 206 days, from June to late November 1986. Alongside its construction, significant efforts were made to assess the state of the nuclear fuel and conduct simulation calculations to evaluate potential risks, such as continuing nuclear chain reactions and the release of radioactive materials into the soil.

The main risks considered were the possibility of a continuing nuclear chain reaction, the destruction of the foundation of the reactor building, and the release of radioactive materials into the soil under the reactor. Fortunately, these risks did not materialize. This allowed for the approval of the report of completion of the construction of the shelter object, with the following main conclusions: there were no changes in the geometrical and state of the nuclear fuel, and radiation values were in line with those calculated during the design of the shelter object.

The completion of the shelter object allowed for the first assessment of the gamma field distribution in the former central reactor hall of Unit 4. This was achieved using rod detectors lowered from the roof of the newly constructed shelter. The data collected provided valuable insights into the radiation levels within the reactor hall.

Despite the construction of the shelter object, questions remained about the state of the reactor, nuclear fuel, and main sources of contamination. Preliminary knowledge was gathered by a reconnaissance group of scientists who penetrated deep into the premises of the former power unit, risking their lives to obtain crucial information. One notable figure in this effort was Arthur Korneev, who passed away on October 28, 2022.

The task of designing and constructing the New Safe Confinement (NSC) to cover the shelter object required additional research to determine the gamma field distribution. Measurements were made using balloons, helicopters, and unique devices developed by the institute. The data

obtained facilitated the development of optimal technologies for implementing the sheltering and mitigation plan, including the construction of the NSC.

The NSC was constructed away from the shelter object. With the completion of the Shelter Implementation Plan, the final step was the creation of the NSC.

The NSC enables safe retrieval and disposal of the nuclear and radioactive inventory of the shelter object. Key tasks include monitoring the fuel and fuel-containing masses of the reactor, contamination of premises inside the shelter object, and radioactive aerosols and waters. The NSC's main crane system plays a significant role in these efforts, allowing for precise measurements and future planning of decommissioning activities.

The use of digital twins and simulation models has been crucial for understanding and planning the removal of radioactive and nuclear content from the shelter object. Robotics has also played a vital role in characterizing radioactive contamination and decommissioning activities. Various robots, developed in collaboration with institutions like the University of Bristol, have been employed for tasks such as video and radiation surveillance, air sampling, and concrete sampling.

Today's nuclear decommissioning is impossible without precise knowledge of the facility, and it requires the development of assumptions like a digital twin or building information models. We use blueprints, design documentation, and photos to reconstruct this information in 3D models. This information has significant importance because it can be used to install additional sensors and understand the geometrical allocation of the sensor, which can improve our models of the fuel-containing materials.

The characterization of radioactive contamination at Chernobyl Unit 4 has been a complex and ongoing process. The efforts of scientists and engineers, combined with advanced technologies and international collaboration, have provided valuable insights and solutions for managing the aftermath of the disaster. The work continues, with a focus on ensuring the safety and stability of the site for future generations.

We are open for collaboration and have already worked with various organizations, including IFE, FOI, the University of Bristol, Fraunhofer Institute, and Berkeley University. We welcome you to Ukraine and to Chernobyl.

Unfortunately, a huge layer of scientific development is hidden from international research groups since the main publications are still mainly in Russian or Ukrainian, and only a few publications are in English. We hope to change this in the future.

#### Questions and Comments

Niels-Kristian Mark (IFE) asked Maxim Saveliev (ISP NPP) about the time perspective of their project.

Maxim Saveliev explained that their work was significantly impacted first by COVID-19 and then by the war. They completed the NSC just before COVID-19 in 2019 and had plans to do the mounting of unstable constructions in the next three years. However, these plans were disrupted. He mentioned that they still have about 10 years for all the work, but the war brought a lot of uncertainties. He highlighted the financial challenges Ukraine faces, the need for safe operation of the new safe confinement, and the importance of data collection and saving. He

also stressed the need to build a digital twin of the new safe confinement and the shelter object. Maxim Saveliev compared their progress to that of Fukushima Daiichi, noting that Fukushima is moving forward faster. He ended by emphasizing the urgency of restarting all their activities before people who know the conditions pass away or retire.

## ***Integrated Digital Support Concept for Nuclear – New Approach to Data***

By István Szőke (IFE).

In the rapidly evolving world of technology, the nuclear industry is not far behind. The focus is shifting towards digitalization and robotics, with a specific emphasis on data. The presentation discussed the concept of HADRON, which stands for “Hazard Aware Digitalisation and Robotics in Nuclear and other domain”. This is a strategic area that includes the use of digitalization and robotics in nuclear and other safety-critical environments.

HADRON is not a department but a collaborative effort involving different people from IFE, spanning various departments. The inception of HADRON was when the industry recognized the increasing initiatives about digital twins, virtual augmented reality, and robotics. The question was, could we have a more holistic perspective on these technologies?

The focus was not merely on developing cool tools for the nuclear industry. Instead, it was about understanding the current process of work, specifically in the nuclear back end, and how digitalization, AI, and robotics could revolutionize this process.

There are numerous technologies available, such as 3D process simulation, semantic information systems, logical mapping technologies, advanced project management scheduling tools, and AI. However, these technologies often work in their own bubbles, lacking integration, especially in the nuclear industry.

The core of HADRON is to integrate these technologies into something more comprehensive that aids people throughout the entire process. This integration led to the development of the HADRON ecosystem, an integrated concept that combines 3D scanning, BIM modelling, hazard mapping, mission planning for robotics, and campaign planning.

At the heart of this concept is data. The realization of HADRON depends on a data structure that allows all these different systems that can provide data, such as databases and analysis tools, to work together with this integrated concept.

The data structure enables a seamless data exchange between these capabilities, leading to an integrated system that extends the already existing integrated system used in the building industry. This approach aims to reach an agile approach, recognizing that uncertainties always affect our ability to carry out work.

The EURATOM project PLEIADES implemented part of this vision. It was built around the BIM technology, specifically using the open BIM IFC standard, to develop a BIM compatible digital support system for the nuclear back end. The core of this project was the data in an ontology, a data model.

The project analysed the types of data in the nuclear back end, the needs in terms of data, and the expectations. It identified two large types of data - structured and non-structured data - and compared the advantages and disadvantages of different solutions to handle these types of data.

The integration of digitalization, AI, and robotics in the nuclear industry is a significant step towards a more efficient and sustainable process. This approach also provides additional benefits such as 3D simulation-based education material, public information, and higher knowledge retention.

The collaboration with CREATEC aims to realize parts of this overall concept by integrating robotics technologies from Boston Dynamics and sensor technologies by CREATEC with the integrated digital twin concepts at IFE. This integration between AI data and robotics and their application in the nuclear back end has led to a designation from the International Atomic Energy Agency (IAEA) as an international collaborating centre. The future holds promising developments as we continue to roll out the first demonstrations and systems developed together.

The integrated system is a result of various national and ongoing international projects. It involves different organizations, including IFE, and partners like CREATEC. The system integrates various tools for deploying sensors and 3D radiological mapping technologies, along with BIM technologies. It also includes radiological characterization, work planning, training, risk management, compliance management, and waste management platforms.

Data plays a crucial role in this integrated concept. The system now has a vast amount of structured data, which means tools like AI can act on this data. The next step is to integrate this data with applications that can make more sense of it.

One important side effect of this integrated concept is the possibility of a more circular approach to nuclear decommissioning. The data, including radiological data and 3D data, is fed into BIM systems and radiological characterization support systems. Using additional tools, the path of the waste from the facility to different treatments, temporary storages, and disposal can be modelled. Reuse options can also be factored in.

The DORADO Euratom project aims to take the integrated full-scope decommissioning support digital concept and integrate it with AI-powered methodologies. The goal is to develop a smarter, full-scope digital decommissioning system or waste management backend support system.

The Norwegian Nuclear Research Centre is working on two research topics, including RT3, which is about nuclear simulations. The focus is on integrating various radiological or radiation models with AI techniques.

In five years, the hope is to realize a phase where people don't have to go into these areas. Everything becomes remote, and the actual work is carried out by robotics. All the tasks, including managing waste and compliance, are integrated into one concept. The goal is to act on digital twins, and the actual work is carried out by robotics.

However, there are important discussions about how much these systems can be trusted. As they become more automated, it's still our responsibility to ensure everything is safe. The discussion about where the human ends and the AI and robotics begin is very interesting and will shape the future of this integrated approach.

István Szóke highlighted the importance of integrating digitalization, AI, and robotics in the nuclear industry. The HADRON concept, with its focus on a holistic approach and the integration of various technologies, is a step towards revolutionizing the process of work in the nuclear industry. The role of data in driving this integration cannot be overstated, and the team's work on developing a data structure that enables seamless data exchange between different capabilities is a significant achievement. With the agile approach, the team hopes to better

manage the uncertainties that come with decommissioning work, leading to more efficient and effective processes in the nuclear industry.

He concluded the presentation by inviting further interaction on these topics. He mentioned several initiatives, including the DECOM cluster, the Norwegian Nuclear Association, a Nordic collaboration initiative, and the DigiDECOM platform for collaboration, which includes a conference. These initiatives aim to help people put these innovative concepts into practice in their businesses and to further develop these concepts. The goal is to ensure the safe decommissioning of radiologically hazardous areas and to train the new generation of people who will take on this role.

#### Questions and Comments

Niels-Kristian Mark (IFE) asked István Szőke (IFE) about the status of their project in five years. He wondered if they would have a commercial app based on PLEIADES that could handle all their tasks.

István Szőke explained that their integrated concept is a continuous process with much to do. He hoped that in the future, everything would become remote, with digital twins and robotics handling the routine and dangerous tasks. He mentioned that they are moving towards integrating all their tasks into one concept, with AI applications making sense out of all the data and making important suggestions. However, he also highlighted the ongoing discussions about how much they can trust these systems as they become more automated. He expressed his curiosity about where the line between human and AI/robotics will be drawn.

## 9. Literature Review

As part of the project, a literature review was conducted using internet searches and Microsoft's Copilot chatbot. The review revealed a limited amount of literature directly addressing the issues of this NKS project. Several sources emphasize the importance of selecting appropriate methods for gathering data for decommissioning, but few provide detailed procedures or share their experiences. While some sources describe what was done, they rarely discuss the pros and cons or alternative methods, often focusing primarily on technical details. Over the past decades, some workshops have included this issue in their agendas and presentations, but experiences and best practices are only occasionally explained.

A notable report is the "Multi-Agency Radiation Survey and Site Investigation Manual" (MARSSIM) from the U.S. Environmental Protection Agency, published in 2000. It introduces the term historical site assessment (HSA) and provides a comprehensive overview of data gathering for nuclear decommissioning planning. A revised version is expected in 2025.

[https://www.epa.gov/sites/default/files/2015-06/documents/marssim\\_chapter3.pdf](https://www.epa.gov/sites/default/files/2015-06/documents/marssim_chapter3.pdf)

Another significant report is the TECHNICAL REPORTS SERIES No. 411, titled "Record Keeping for the Decommissioning of Nuclear Facilities: Guidelines and Experience," published by the International Atomic Energy Agency (IAEA) in 2002. This report offers insights based on experience on how to identify, maintain, and update necessary records for decommissioning. It highlights the importance of record keeping avoiding costly misallocation of resources and safety problems. The report covers design and operational data requirements, retention of decommissioning records, quality assurance, and the management of new records, but does not provide detailed methods for data gathering.

<https://www.iaea.org/publications/6566/record-keeping-for-the-decommissioning-of-nuclear-facilities>

Further searches yielded few references to the No. 411 report, suggesting that little has been published on this issue. Since record keeping involves managing gathered data for later use, it seems reasonable to expect more references when reporting on data-gathering methods.

One of the larger sources found was material from an international workshop organized by the Nuclear Energy Agency (NEA) from November 29th to December 1st, 2022, on "Innovative Techniques and Technologies to Support Characterization and Decommissioning of Complex and Legacy Sites." The workshop, organized by the NEA Working Party on Technical, Environmental, and Safety Aspects of Decommissioning and Legacy Management (WPTES), focused on four areas:

- Risk management in support of decision-making.
- Sampling, characterization, and data evaluation.
- Innovative decontamination and decommissioning technologies.
- Materials management.

The workshop aimed to understand the state of the art in technologies and techniques related to the characterization and decommissioning of complex and legacy nuclear sites, identify key issues and challenges, and explore good practices and methods considering risks to workers, the public, and waste generation.

Presentations from the workshop are available on the NEA's website. As with other sources, the focus was primarily on methods and technology rather than organizational issues or pros and cons. According to the workshop website, proceedings were expected to be published in 2023, but no link is available.

The website mentions that break-out sessions were held to explore questions related to technology sharing, lessons learned, and challenges and gaps in characterization and decommissioning. It was agreed that "information sharing related to decommissioning innovation was important but challenging. Various databases, wiki sites, and other information-sharing hubs are available, but these sites can be difficult to access and maintain".

[Nuclear Energy Agency \(NEA\) - Innovative Techniques and Technologies to Support Characterisation and Decommissioning of Complex and Legacy Sites \(oecd-nea.org\)](https://www.oecd-nea.org/iaea/iaea-nea-workshop-2023-2024/)

[Nuclear Energy Agency \(NEA\) - Examining new technologies in decommissioning complex and legacy sites \(oecd-nea.org\)](https://www.oecd-nea.org/iaea/iaea-nea-workshop-2023-2024/)

In the Nordic nuclear environment, there are a couple of good places for meeting and sharing. One is the DigiDECOM conference, organized under IFE's designation as an IAEA Collaborating Centre and co-organized with the OECD NEA Halden HTO project and the Norwegian Nuclear Research Centre.

<https://ife.no/en/event/DigiDECOM-2024/>

Another is the Nordic Nuclear Forum conference with presentations and exhibitions.

<https://nordicnuclearforum.fi/>

Additionally, NKS plays an important role by offering funds for minor research projects and arrangements. The results are shared in reports and workshops.

<https://www.nks.org/>

Internationally, the IAEA's International Decommissioning Network (IDN), established in 2007, provides a forum for interaction and collaboration between professionals involved in decommissioning activities. Sharing of experiences and knowledge from decommissioning projects is facilitated through a wiki-based information resource maintained by the network.

<https://nucleus.iaea.org/sites/connect/IDNpublic/SitePages/Home.aspx>

Another is the NEA Working Party on Technical, Environmental, and Safety Aspects of Decommissioning and Legacy Management (WPTES), which aims to address technical, environmental, and safety issues in the decommissioning of nuclear installations and legacy management.

[https://www.oecd-nea.org/jcms/pl\\_81764/working-party-on-technical-environmental-and-safety-aspects-of-decommissioning-and-legacy-management-wptes](https://www.oecd-nea.org/jcms/pl_81764/working-party-on-technical-environmental-and-safety-aspects-of-decommissioning-and-legacy-management-wptes)

Furthermore, the IAEA CONNECT platform can be useful since it is an easy-to-use online environment that hosts a wide range of IAEA's professional networks. It brings together

professionals and experts from IAEA and its Member States to facilitate the sharing of information and capacity building while offering a centralized resource hub in their topical areas.

<https://nucleus.iaea.org/sites/connect/SitePages/Home.aspx>

Overall, the review indicates the need for more comprehensive and detailed literature on data-gathering methods in decommissioning, highlighting the importance of workshops and collaborative efforts in bridging this knowledge gap.

## 10. Conclusions

Decommissioning a nuclear site presents a complex, long-term challenge due to the intricacy of the plant, the need for knowledge transfer, and contamination issues. Ensuring safety, efficiency, and cost-effectiveness in planning, training, and dismantling necessitates comprehensive information about the plant's design, history, and current state. While exploring new data gathering methods can be time-consuming and expensive, accurate data collection and organization are paramount. The nuclear industry often leans towards established methods for data gathering due to safety considerations, even though contemporary approaches might offer more efficiency.

The Data4decom project engaged stakeholders from the Nordic nuclear sector to exchange their experiences in decommissioning data collection, including its advantages and disadvantages, time requirements, and costs. A survey was distributed to approximately 50 contacts, yielding nine responses. Further data was collected through interviews with representatives from AFRY and Fortum. The survey and subsequent interviews supplied valuable data that bolstered the overall analysis. An online workshop was conducted on Tuesday, April 9, 2024, featuring presentations on data collection projects and technologies. Alongside the survey and workshop, the project group performed a literature review to pinpoint relevant publications on data assessment for decommissioning.

This NKS report encapsulates the project outcome consisting of the survey, interviews, workshop presentations (including Q&A), and the literature review.

The survey underscored the varied roles and practices within the nuclear industry regarding data gathering, assessment, and post-processing. Despite the limited number of responses, the survey offered valuable insights into the methods and tools employed, the challenges encountered, and the potential benefits of effective data management. The findings highlight the importance of utilizing digital tools to boost efficiency and accuracy in data handling. By addressing the identified challenges and capitalizing on the strengths of current practices, organizations can significantly enhance their data management processes, thereby facilitating the safe and efficient operation of nuclear facilities. The respondents' interest in contributing to the report and participating in the workshop further underscored the industry's collaborative spirit to share knowledge and experiences for continuous improvement.

The interviews with AFRY and Fortum yielded valuable insights that supported the survey analysis and laid the groundwork for the workshop. AFRY's contributions were reflected in the workshop presentations, while the interview with Fortum underscored the company's extensive experience in nuclear decommissioning and their commitment to safety, efficiency, and innovation. Fortum's utilization of advanced digital tools, meticulous planning, and effective waste management practices exemplify professional work standards. The interviews emphasized the importance of proper organization and the integration of cutting-edge technologies in ensuring the success of decommissioning projects.

The NKS Data4decom workshop, conducted online on April 9, 2024, assembled a group of 20 leading experts to present completed, existing, and planned data collection. The presentations and discussions delved into advanced technical topics, equipping participants with a profound understanding of the latest developments in the field. The workshop also showcased various technologies and methodologies, offering practical insights that can be applied to future projects.

The literature review revealed a dearth of detailed sources directly addressing the project's specific issues. While some sources underscore the importance of selecting appropriate data-gathering methods for decommissioning, they often lack detailed guidance, experiential insights and best practices. The focus tends to be on technical aspects, with limited discussion on the pros and cons of different methods.

One significant report discovered was the IAEA's TECHNICAL REPORTS SERIES No. 411 from 2002, which emphasizes the critical role of record-keeping in decommissioning but does not provide detailed specifics on data-gathering methods. The absence of references to this report in subsequent literature further highlights the gap in published material on this topic.

Another source discovered was the international workshop organized by the NEA in late 2022 that offered valuable insights into innovative techniques and technologies for decommissioning complex and legacy sites. It aimed to share best practices, lessons learned, and address challenges in implementing these technologies.

Overall, the review underscores the need for more comprehensive and detailed literature on data-gathering methods in decommissioning, highlighting the importance of workshops and collaborative efforts in bridging this knowledge gap.

The findings from the NKS Data4decom project are anticipated to impact the future of decommissioning in the Nordic nuclear sector. By providing an overview of the status and potential future developments in data collection, the report and the workshop serve as a resource for stakeholders. The project underscored the importance of collecting a broad range of data, including technological, organizational, and methodological information. This holistic approach ensures that all aspects of decommissioning are considered, leading to more effective and efficient project planning and execution. The collaborative efforts of stakeholders have resulted in valuable insights that can guide the selection of tools, methods, and organizational structures, ultimately leading to more efficient and effective decommissioning projects. As the Nordic nuclear sector continues to evolve, the lessons learned from this project will be instrumental in shaping its future direction.

Reflecting on the NKS Data4decom project, the team encountered some difficulties in contacting people and with the chosen methods for collecting information. The fact that the group received only nine replies out of approximately 50 possible in the survey, including answers from organizations outside the Nordic countries, was disappointing and limited the analysis of the survey results. Also, the participation in the workshop could ideally have been higher. Previous experiences from other projects, including some funded by NKS, show that it is possible to achieve high commitment and support for decommissioning workshops and other arrangements. One difference from before is that today there are several large and regular workshops and groups in decommissioning, both physical and online ones. For example, the DigiDECOM conference. So, it may be more challenging for a new minor initiative to gain attention. Based on the experience, an alternative work method for the Data4decom project could have been to contact a few of the larger decommissioning projects in the Nordic countries and analyse in detail how they gathered data for use in the decommissioning and try to conclude some best practices.

## 11. References

1. Nick Barber, 2021, *Overview of Nuclear Decommissioning*  
(<http://large.stanford.edu/courses/2021/ph241/barber2/>)
2. IAEA, 2023, *Global Status of Decommissioning of Nuclear Installations*  
(<https://www.iaea.org/publications/15197/global-status-of-decommissioning-of-nuclear-installations>)
3. IAEA, 2023, *Nuclear Decommissioning: Addressing the Past and Ensuring the Future*  
(<https://www.iaea.org/bulletin/nuclear-decommissioning-addressing-the-past-and-ensuring-the-future>)
4. IAEA, 2001, *TECHNICAL REPORTS SERIES No. 401, Methods for the Minimization of Radioactive Waste from Decontamination and Decommissioning of Nuclear Facilities*  
(<https://www.iaea.org/publications/5841/methods-for-the-minimization-of-radioactive-waste-from-decontamination-and-decommissioning-of-nuclear-facilities>)
5. IAEA, 2002, *TECHNICAL REPORTS SERIES No. 411, Record Keeping for the Decommissioning of Nuclear Facilities: Guidelines and Experience*  
([https://www-pub.iaea.org/MTCD/Publications/PDF/TRS411\\_scr.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/TRS411_scr.pdf))
6. IAEA-TECDOC-1394, 2004, *Planning, managing and organizing the decommissioning of nuclear facilities: lessons learned*  
([https://www-pub.iaea.org/MTCD/publications/PDF/te\\_1394\\_web.pdf](https://www-pub.iaea.org/MTCD/publications/PDF/te_1394_web.pdf))
7. NEI, 2016, *Decommissioning Nuclear Power Plants*  
(<https://www.nei.org/resources/fact-sheets/decommissioning-nuclear-power-plants>)
8. OECD NEA, 2003, *The Decommissioning and Dismantling of Nuclear Facilities*  
([https://www.oecd-ilibrary.org/nuclear-energy/the-decommissioning-and-dismantling-of-nuclear-facilities\\_9789264184886-en](https://www.oecd-ilibrary.org/nuclear-energy/the-decommissioning-and-dismantling-of-nuclear-facilities_9789264184886-en))
9. OECD NEA 7374, 2018, *Preparing for Decommissioning During Operation and After Final Shutdown*  
(<https://www.oecd-nea.org/upload/docs/application/pdf/2020-12/7374-decom-prep.pdf>)
10. OECD NEA workshop, 29/11-1/12 2022, *Innovative Techniques and Technologies to Support Characterization and Decommissioning of Complex and Legacy Sites*  
([https://www.oecd-nea.org/jcms/pl\\_71664/innovative-techniques-and-technologies-to-support-characterisation-and-decommissioning-of-complex-and-legacy-sites](https://www.oecd-nea.org/jcms/pl_71664/innovative-techniques-and-technologies-to-support-characterisation-and-decommissioning-of-complex-and-legacy-sites))
11. U.S. Environmental Protection Agency, 2000, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*  
([https://www.epa.gov/sites/default/files/2017-09/documents/marssim\\_manual\\_rev1.pdf](https://www.epa.gov/sites/default/files/2017-09/documents/marssim_manual_rev1.pdf))
12. U.S. NRC, 2020, *Decommissioning Process*  
(<https://www.nrc.gov/waste/decommissioning/process.html>)

## Appendix 1 Survey questions



# How to gather nuclear site data for use in operation and decommissioning?

## A short survey from the NKS project "Data4decom"

NKS ([www.nks.org](http://www.nks.org)) is a governmental financed Nordic forum for research, competence building, experience exchange and networking in **nuclear and radiation safety** with focus on reactor safety, including decommissioning, and emergency preparedness. The Data4decom project is financed by NKS.

**Data4decom** hereby invites stakeholders in the Nordic nuclear environment to **share experiences about how to collect all sorts of data needed in operation and decommissioning**. This includes the pros and cons of the chosen approaches, as well as the time, organizational issues and costs for getting the data and preparing it for use.

When planning, training, and performing operation, maintenance or dismantling of a nuclear site, the need for **information about the actual design and the current state of the plant is of highest importance to perform work in nuclear areas safely, efficiently and with acceptable economic costs**.

Data4decom likes to hear about **all sorts of data, approaches, technologies, organization, and utilization** of gathered data since the purpose of the project is to give the nuclear sector an overview of today's status and possibilities for use in ongoing and future nuclear projects. That is, to **give access to recommendations about the resources needed, and possible new approaches to apply, when gathering data as part of the work in nuclear environments**. The sharing is meant to ease for you and your organization in future choices of tools, methods, and organization.

**The output will be a white paper and a workshop**, which will be in the autumn at IFE in Halden.

In Data4decom participate IFE (Norway), AFRY (Sweden) and Fortum (Finland). The project group

consists of Niels-Kristian Mark (IFE project manager, [niels.kristian.mark@ife.no](mailto:niels.kristian.mark@ife.no)), Link Hauge Lindskog (IFE), Micaela Hamberg (AFRY) and Jere Luukkanen (Fortum).

We in the project team **ask you and your organization to please contribute**. First step is this **initial survey to you** with a few questions for measuring your interest.

## **Short survey for mapping stakeholders and their interest in Data4decom**

We kindly ask you fill in this survey. You can answer the survey anonymously.

It has been sent to several persons and organizations in the Nordic and international nuclear environment who we think may be interested in the subject of the Data4decom project and in the outcome, and therefore hopefully like to contribute to the white paper with experiences or to participate in the workshop.

If you have comments or questions, please send them to [niels.kristian.mark@ife.no](mailto:niels.kristian.mark@ife.no).

1. How is your organisation involved in the operation, maintenance or decommissioning of nuclear facilities?

Enter your answer

2. What is your organization's focus (f.ex. operator, regulator, R&D)?

Enter your answer

3. Are you gathering data for use in the planning of work tasks or for use in the actual work in areas with radiation?

Enter your answer

4. Would you like to share your own or your organizations experiences from gathering data with the Data4decom project?

Enter your answer

5. If so, what type of data do you work with?

Enter your answer

6. Which methods or tools do you use for gathering the data?

Enter your answer

7. How is the assessment organised?

Enter your answer

8. Is there some postprocessing of the data before they are used further?

Enter your answer

9. What are the data used for?

Enter your answer

10. Are there any special reasons for the way you have chosen to organise the data gathering and postprocessing?

Enter your answer

11. What are the pros and cons of how you have gathered the data?

Enter your answer

12. Would you be interested in contributing to the whitepaper?

Please select at most 2 options.

Yes, I like to write an article (One page)

Yes, you may interview me

No

13. Data4decom plans to arrange a 2-day workshop in the autumn at IFE in Halden. Would you like to participate?

I would like to be there physically

I would like to participate online

No, I'm not interested, thank you

I will forward this to a colleague

14. Would you be interested in giving a presentation at the workshop?

Yes

No

Maybe

15. If you like to contribute to the white paper or the workshop, may we please have your email address so that we can contact you?

Enter your answer

16. If you haven't time to contribute or if you are not interested, may we kindly ask you to either forward this survey to someone who you think might be interested or tell us who you propose that we should contact?

Enter your answer

17. Do you have any comments, questions, or proposals?

Enter your answer

You can print a copy of your answer after you submit

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## Appendix 2 Participants at NKS Data4decom workshop 9<sup>th</sup> April 2024

Andreas Buhlin	AFRY	Sweden
Audun Sanderud	Norwegian Nuclear Decommissioning (NND)	Norway
Benedict Jaeschke	AFRY	Sweden
Dan Kristofer Ree	Norwegian Nuclear Decommissioning (NND)	Norway
Fedir Lanskykh	Chernobyl NPP	Ukraine
István Szőke	IFE (Digital Systems - Applied Physical Sciences dep.)	Norway
Jan Rønsen	IFE (Nuclear division)	Norway
Joachim Bratteli	IFE (Digital Systems - VR/AR dep.)	Norway
Lars Peterson	NUTRONIC AB	Sweden
Link Hauge Lindskog	IFE (Digital Systems - VR/AR dep.)	Norway
Maksym Pantin	Institute of Mathematical Machines and Systems Problems (ISP NPP)	Ukraine
Maxim Saveliev	Institute for Safety Problems of Nuclear Power Plants	Ukraine
Mustafa Ali Hadi Jarallah	IFE (Digital Systems - Applied Physical Sciences dep.)	Norway
Niels-Kristian Mark	IFE (Digital Systems - Applied Physical Sciences dep.)	Norway
Omar Zahra	IFE (Digital Systems - Applied Physical Sciences dep.)	Norway
Per Ytterberg	NUTRONIC AB	Sweden
Robin Webjørnsen	Norwegian Nuclear Decommissioning (NND)	Norway
Ross Fawkes	CREATEC	United Kingdom
Svein Tore Edvardsen	IFE (Digital Systems - Applied Physical Sciences dep.)	Norway
Wilma Falk	AFRY	Sweden

## Appendix 3 Slides from the NKS Data4decom workshop 9<sup>th</sup> April 2024

The slides will also be available on the NKS website.

### A3.1 Workshop session 1

*Plus and cons with different methods for getting geometrical data, for ex. measurements, 3D scanning, etc.*

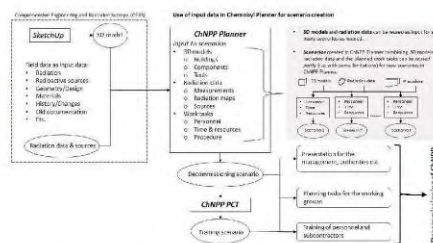
(Niels-Kristian Mark/IFE)



IFE

### What do we need the data for?

- What should the data be used for?
  - Visualisation?
  - Planning?
  - Designing?
  - Training?
  - Gaming?
- What sort of data do we like to have (f.ex. point clouds or blueprints)?
- Which data do we have access to (Can we go there? Drawings? Photos?)?
- How to capture the data?
- In which format do we need the data?
- Time and resources incl. our competence and organisation?



Example from ChNPP of the data flow when using ChNPP Planner in the Chernobyl Decommissioning Visualization Center

## How can we get a “copy” of the environment?

### Low level and low-cost methods

- Do measurements in the field
- Take measures from blueprints/drawings
- Use photos as basis
- Make the 3D model by hand in a 3D tool (f.ex. AutoCAD and Maya)
- Use existing (legal) 3D models from customers, vendors, 3D model sites etc.
- Takes time, not accurate, no extra work, nice models, you get only what you need

### High level and high-cost methods

- Use a laser scanner (Lidar) to create a point cloud (extra step to get a 3D mesh model)
- Take photos/video (by hand/use a drone) to create a 3D model using photogrammetry
- Scan using new technologies, f.ex. iPad with scanner
- Takes time, accurate, extra work, technical fine models but not always nice, you get all

Often best to combine the different methods

## Examples



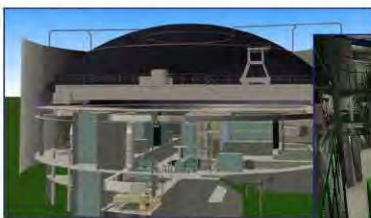
Handmade model based on measurements



Handmade model based on blueprints



Model from CAD with textures added



Model from CAD with coloring/shading

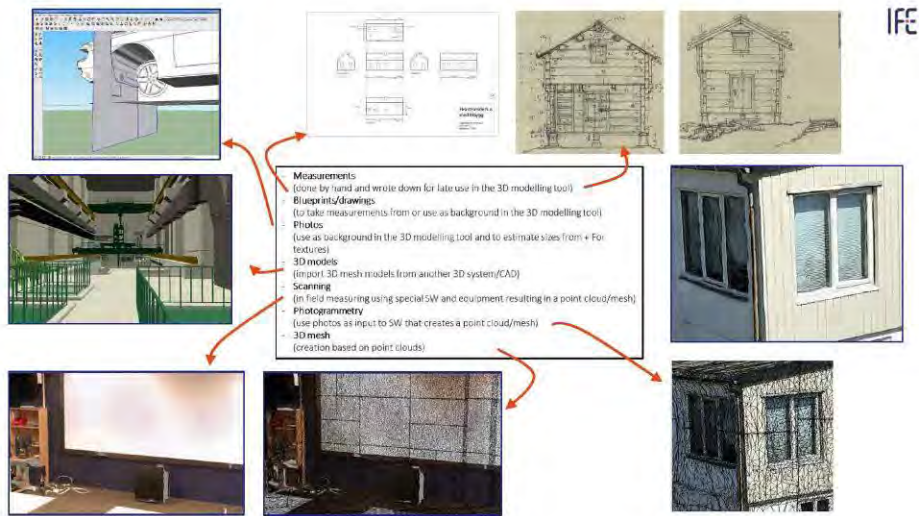
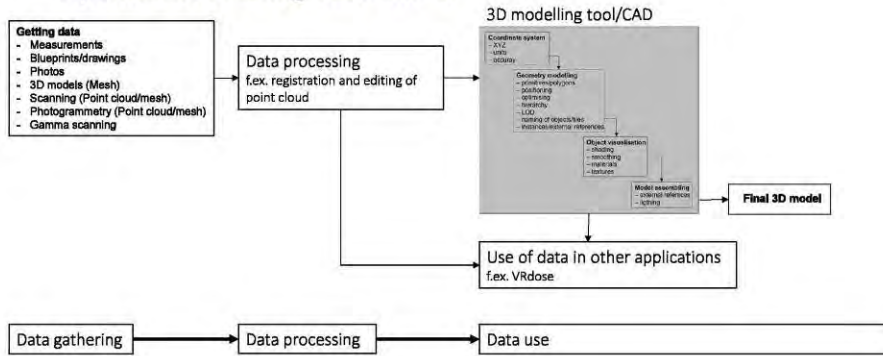


Model based on measurements

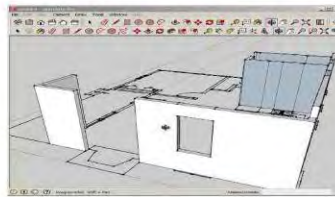
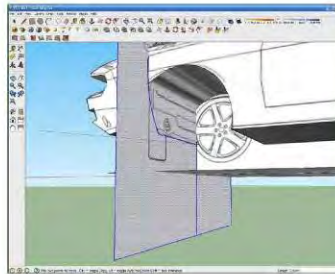


Model based on LIDAR scans

### Pipeline for making 3D models



IFE



Blueprints/drawings/photos can be used as background to build the 3D model on

IFE

### Example of use of measurements and photos

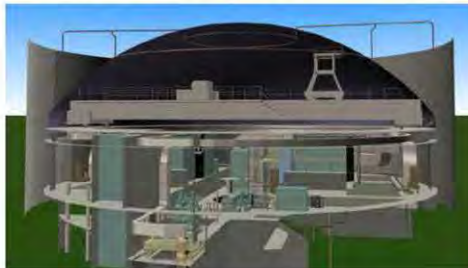
- Model of music studio from 2007
- Modelled by hand based on measurements and photos
- Used in Virtual Reality => Hardware and software limitations



## Use of existing 3D models

- Low level and low-cost method
- Use only legal/free 3D models from customers, vendors, 3D model sites
- 3D models from other 3D modelling tools (CAD, architectural, gaming)
- Are the 3D models up-to-date?
- Use as basis in the 3D modelling tool
- Possible problems: Import, scale, loss of data (textures), hierarchy, object naming etc.
- Edit the 3D mesh model by hand in a 3D modelling tool (f.ex. Autocad or Maya)
- Easy to use for all type of objects
- Textures may be included
- As accurate as the original 3D model is
- Takes less time, accurate, no extra work, nice models, you get only what you need

## Example of use of CAD



Example of a 3D model for VR based on existing CAD 3D models



### 3D models using LIDAR scanning



Photo from the BLK360 scanner

Leica BLK360 LIDAR scanner



- Measurements (done by hand and wrote down for late use in the 3D modelling tool)
- Blueprints/drawings (to take measurements from or use as background in the 3D modelling tool)
- Photos (use as background in the 3D modelling tool and to estimate sizes from + for textures)
- 3D models (to use as 3D mesh models from another 3D system/CAD)
- Scanning (in field measuring using special SW and equipment; resulting in a point cloud/mesh)
- Photogrammetry (use photos + output to SW that creates a point cloud/mesh)
- 3D mesh (creation based on point clouds)



Part of the point cloud

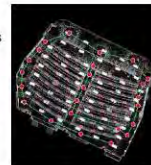


- For exact as-build-models
- Typically, larger objects like rooms and buildings
- Creates point clouds + 365-degree photos => Post processing needed
  - 3D mesh creation
  - 3D modelling by hand based on the point cloud
- Efficient way of documenting large areas (Ca. 5 minutes per scan)

### IFE's Auditorium

- Scanned the auditorium => Requires a lot of scans to cover all
- Less scans needed if one just likes to have the dimensions/measurements and position of objects

BLK360 scan positions



BLK360 point cloud

High density 3D mesh w/16 mill. polygons (85 % polygon reduction is possible)

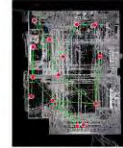


3D mesh model

## IFE's heating room 1/2

- Scanned the heating room
- Pipes are tricky, especially with blank, reflecting surface

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BLK360 scan positions



BLK360 photo



BLK360 point cloud



3D mesh model

## IFE's heating room 2/2

IFE

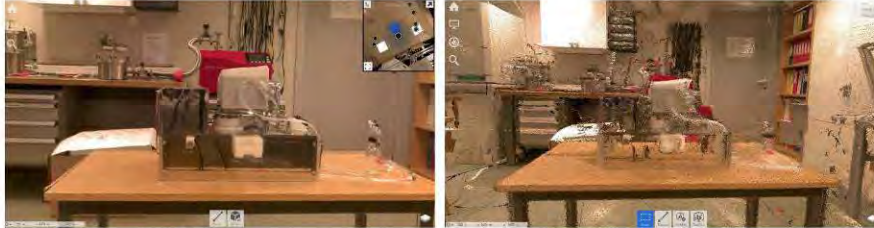


Details from the heating room 3D mesh



### Example: Bad scan of a small, shiny object

- Tried to scan a medical dispenser made of shiny metal and transparent plastic with a BLK360
- Lessons learned: The shiny surfaces should be powdered, but still the object is probably too small for the scanner
- The room itself looked better than the dispenser
- Alternatives: Take photos and use them as basis in the 3D modelling tool – or use a handheld scanner



The real thing to the left as the camera saw it and the scanner's "artistic" impression of the dispenser

### Example of handheld scanners

- Mostly for use at short distances
- Quality indicator while scanning
- Some requires a PC
- Shiny surfaces may have to be powdered



Artec LEO  
(Photo: Artec)



### 3D models from handheld scanning



High precision scan with detailed texturing

#### Artec LEO handheld scanner



- Measurements (done by hand and wrote down for late use in the 3D modelling tool)
- Blueprints/drawings (to take measurements from or use as background in the 3D modelling tool)
- Photos (use as background in the 3D modelling tool and to estimate sizes from + for textures)
- 3D models (import 3D models from another 3D system/CAD)
- Scanning (in field measuring using special SW and equipment resulting in a point cloud/mesh)
- Photo geometry (use photos as input to SW that creates a point cloud/mesh)
- 3D mesh (creation based on point clouds)

- For exact as-build-models
- Typically, small objects up to the size of a car
- Creates final 3D models with textures
- Polygon reduction may be needed to reduce model size
- Fast 3D model creation (Ca. 15 minutes per scan)



IFE's Jackal robot

Real, scanned pallet jack compared with the VRdose version



Sack trolley



Photo of the real thing



3D model from a scan with a handheld scanner

### 3D models from photogrammetry

- For as-build-models
- All types of objects
- Creates final 3D models with textures
- Polygon reduction may be needed to reduce model size
- For precise models it may take time

Measurements	(done by hand and wrote down for late use in the 3D modelling tool)
Blueprints/drawings	(to take measurements from or use as background in the 3D modelling tool)
Photos	(use as background in the 3D modelling tool and to estimate sizes from + for textures)
3D models	(import 3D mesh models from another 3D system/CAD)
Scanning	(to take measurements from a real world object and create a point cloud/mesh)
Photogrammetry	(use photos as input to SW that creates a point cloud/mesh)
3D mesh	(creation based on point clouds)



Photos taken with iPad and location info from GPS and Wi-Fi



3D mesh of polygons



3D mesh w/textures

### Photogrammetry of outdoor areas

- Use drone for taking photos – both vertical and oblique – from a height of 50-200 m
- Photo positions based on GPS and other more precise position tracking methods (f.ex. Inertial Navigation Systems)
- Good result depends on precise photo positioning
- Markers on the ground/building could improve the quality
- Large amount data, both photos and final 3D model
- Output can be a point cloud and 3D mesh with textures
- Example of professional software: Pix4D



Use of markers on the ground

Example of final point cloud =>



<= Example of photo positions and the final point cloud/mesh model

## Examples of 3D mesh creation using point cloud

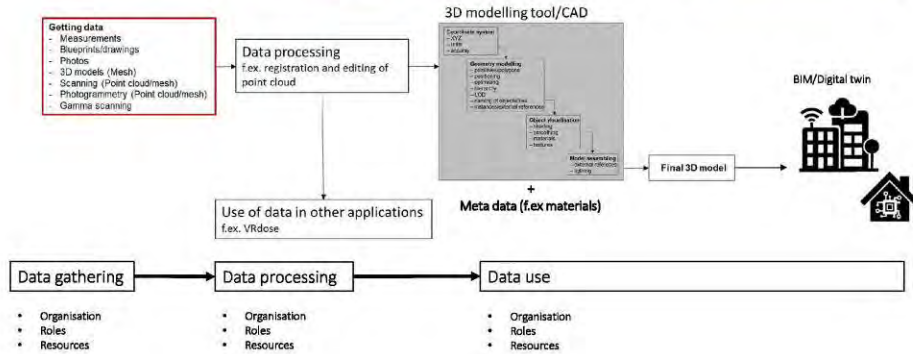


3D model of a boiler room based on a point cloud

- Measurements (dose by hand and write down for later use in the 3D modelling tool)
- Blueprint/drawings (to take measurements from or use as background in the 3D modelling tool)
- Photos (use as background in the 3D modelling tool and to estimate sizes from + for textures)
- 3D models (import 3D mesh models from another 3D system/CAD)
- Scanning (for field measuring using special SW and equipment resulting in a point cloud/mesh)
- Photogrammetry (use photos to create a point cloud/mesh)
- 3D mesh (creation based on point clouds)

- Make a 3D model (3D mesh) using point clouds
  - Quality depends on the software
  - Professional SW often use cloud processing
  - Works fine for large objects and areas
  - Poorly on small objects/details in big models
  - Some illogical results, f.ex. walls that are not totally flat
  - One big 3D mesh without any hierarchy, objects, naming etc.
- => Post-processing needed

## Summary



IFE



Thank you for the attention!



# Radiological Data System (RDS), a method for digital handling of radiological measurement data at nuclear sites

Presentation given at the NKS Data4decom workshop 2024-04-09 by Lars Peterson, Nutronic AB

[info@nutronic.se](mailto:info@nutronic.se)    [www.nutronic.se](http://www.nutronic.se)    +46-26-658850



### Nutronic INSTRUMENTATION

- In-house design & development of radiological smear test instruments
- Distribution and service on all types of radiological instruments

### Nutronic RP PERSONNEL SERVICES

- Strong expertise in providing staff for radiation protection (RP) in normal operation, outages & decommissioning

**Nutronic has a unique position to identify collaborative opportunities  
between instrumentation and operational RP services**



## Challenges in handling radiological data for decommissioning

- Variable and stringent regulatory requirements on documentation in decommissioning compared to normal operation
- Manual methods for data transfer still common, i.e. pen and paper
- Some instruments have memory cards or cable connection to transfer data but all manufacturers have their own system
- Only for raw measuring data, no methods for adding metadata on location, system numbers, project number, calibration status etc.
- No unified database for data from different instruments
- Challenging to combine different types of instrument data to use for decommissioning, especially free release work

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## Radiological Data System (RDS)



## Main concepts of RDS

- Replace pen/paper with a rugged handheld computer
- Unification for all instruments used by Radiation Protection Technicians (RPT:s) on a daily basis
- Frisking probe, dose rate meter, wipe test instrument
- Transfer of data via Bluetooth from instrument to handheld computer
- Transfer from computer to server with WiFi (self-contained, no external network needed) when within range
- Bar and QR codes, i.e scan room/system identifiers
- Store measurements together with pictures and notes in a database
- Tags for "everything", predefined tags or user defined
- Visual, audible and vibration alarm notification



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## Main benefits of RDS

- The handheld computer replaces other readout instruments, i.e. the same handheld device for all instruments/probes
- The app has both analogue and digital presentation and includes a histogram
- Significant improvement of data quality:  
Who, what, where, when, how much, directly from the instrument to the database
- Simplifies searching of data by tags, predefined and user-defined
- Possible to force daily pre-operational check with test source and zero test (i.e. background)
- Calibration expiry check before each use
- Saves all measurements in a database incl. calibration and pre-operational check status
- The server features a web interface that is easy to operate
- Data export to Excel files
- Possible to customise export to facility's common database or other systems
- Possible to connect server to LAN to give access to data to all LAN users

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## Considerations for system implementation

- Use of low-powered radio transmission (Bluetooth Low Energy, BLE)
- New way to operate/read out the instruments, some training needed (but the app is easy to use!)

## Development status today

- System showcased at WNE in Paris November 2023
- General release of the system planned for 2024
- First order for the floor monitor to Swedish customer for decom application. Currently in production.
- We are seeking cooperation with other manufacturers to integrate more instruments into RDS

## Hand-held computer



- Zebra, a well known rugged handheld computer for industrial use
- Available with or without cellular connectivity to comply with restrictions on radio transmitters
- Charged on a dock, no charging cables with flimsy connectors
- Industrial grade Bar-/QR-code scanner
- Camera for taking photos of measured objects

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## Database server

- Turnkey all-in-one solution with preinstalled software
- User-friendly touch screen interface
- Panel form factor, desk- or wall-mounted
- Can be used as a free standing system (data export to USB memory) or connected to an office network (online data export for all LAN users via web interface)
- Search filters can be applied to find relevant data by date, tags for specific identifiers such as rooms, systems, projects, or any combination of search criteria
- Export to Excel files
- Future safe - software updates for the app and database are very easily done

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## Floor monitor



- Integrated into Nutronic RDS system, i.e. includes database, calibration check, constancy check, etc.
- Logs values with up to 0,5s resolution
- The monitor is driven by motorised wheels at a preset constant speed corresponding to the required MDA
- Eliminates human-induced errors caused by varying or excessive speed
- Two high-efficiency scintillation detectors
- Powered by an off-the-shelf battery that is easily changed to allow uninterrupted operation
- Optional automatic mapping of the room by LIDAR

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## Dose rate meter



- Slim BT module to the well-known Automess AD dose rate meter
- Using Bluetooth Low Energy (BLE) mode, minimal added battery consumption
- Separate external BT dongle cable when used with probes like the teletector
- Built-in memory to log dose rate for up to 20 days



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## Frisking Probe

- Best-in-class efficiency and response uniformity
- 18 hours of continuous operation on full charge
- Automatic sleep mode to save battery
- Inductive charge on dock, no cable to connect
- Weight 680 gr (1.5 lb)
- Wireless data transfer by Bluetooth

## NT200 wipe test instrument



- Nutronic NT200, industrial grade alpha/beta counter with lab quality
- Integrated into Nutronic RDS system
- High detector efficiency and low background gives short measuring times
- Pass-through sample holder for optimized workflow
- Built-in printer
- Automatic detection of alpha pulses whilst counting beta (“auto-alpha mode”)
- Automatic background compensation by a separate background detector
- Easy to decontaminate

## Conclusions

- Out of the box complete system, hardware and software, no installation required
- RDS is useful in normal operation and decommissioning of nuclear sites
- Avoids manual handling of measurement data
- Enhances quality of radiological data with pictures and tags for “everything” (location, system number etc.)



Thank you for your attention!

Nutronic AB  
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*AI and Robotics for remote sensing and manipulation in decommissioning*  
 (Omar Zahra & Mustafa Ali Hadi Jarallah/IFE)

**IFE** | Data4Decom | 9 April 2024 | Omar Zahra  
Mustafa A.H Jarallah

## AI and Robotics for Remote Sensing and Manipulation in Decommissioning

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[Abdenour.benkrid@ife.no](mailto:Abdenour.benkrid@ife.no)



IFE: Institute for Energy Technology



Digital Systems -> Applied Physical Sciences

Renewable energy | Nuclear technology | Materials technology | Digitalization | Radiopharmacy and health | Oil and gas | Industry and environment | Safety and security

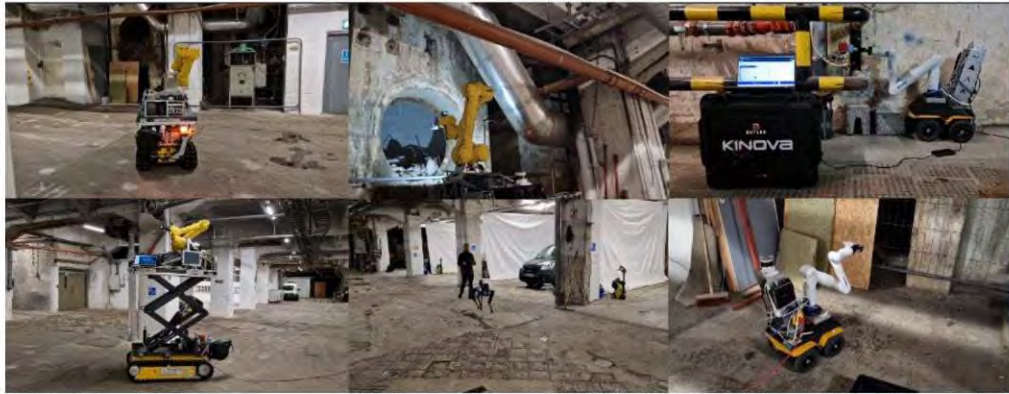
**HADRON**

**H**azard  
**A**ware  
**D**igitalisation &  
**R**obotics in  
**N**uclear & other domains

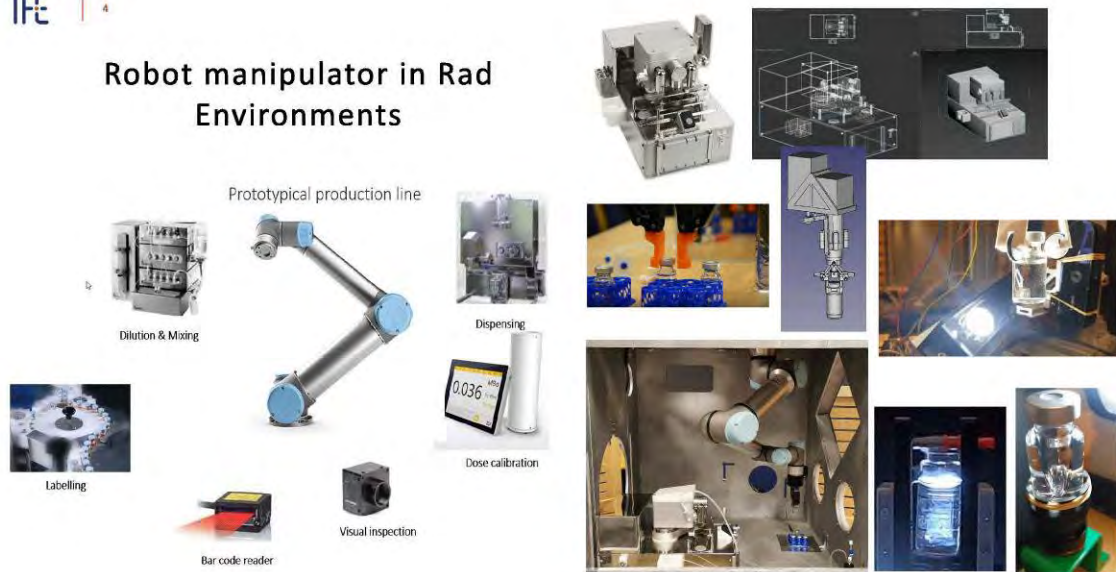


	<b>Nuclear Decom</b>
	<b>Maintenance &amp; decom</b> of industrial sites (Nuclear, Oil & Gas, ...)
	<b>Incident response</b> at nuclear & other potentially hazardous sites
	<b>Radiological, chemical or other labs</b>
	<b>Space applications</b> (radiation effects)
	<b>Fabrication, use or shipping of dangerous substances, ...</b>

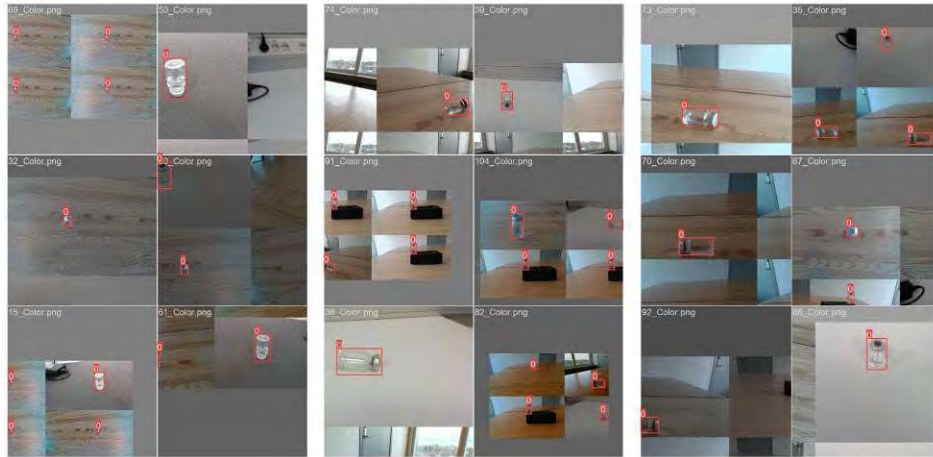
## Field Demonstrations



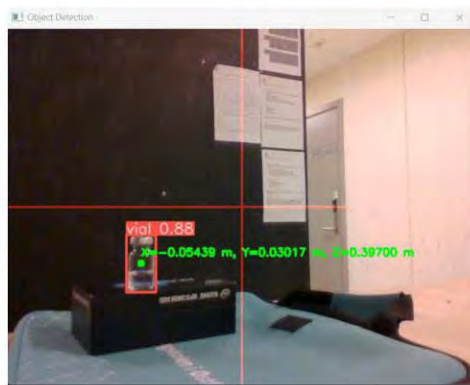
## Robot manipulator in Rad Environments



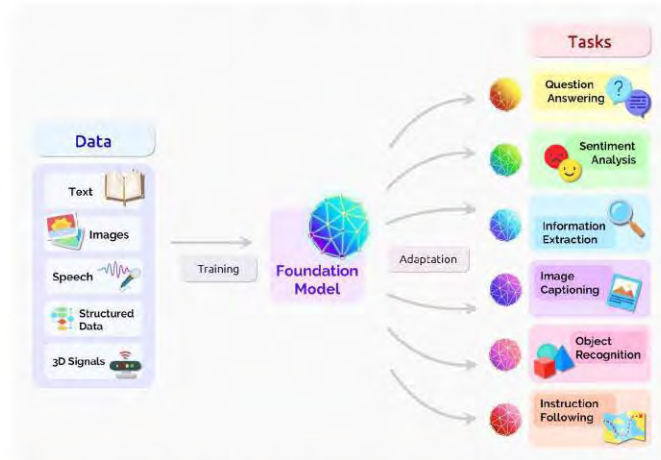
### Training batches



### Ready for grasping



## Foundational models

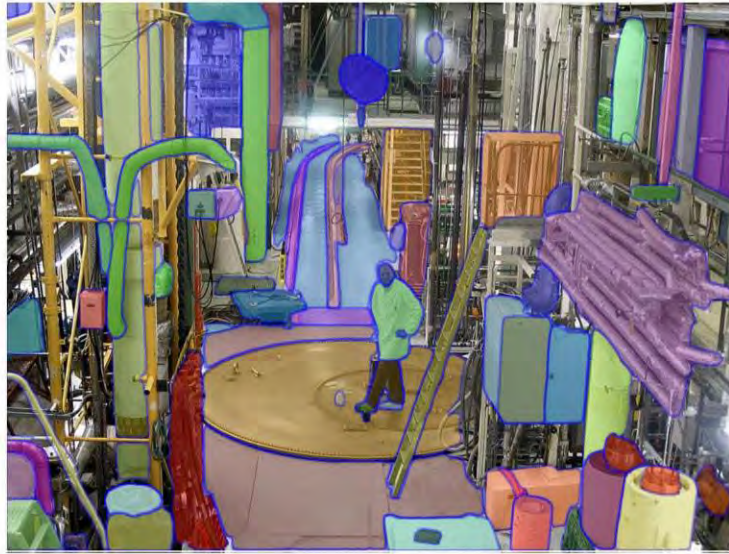


[On the Opportunities and Risks of Foundational Models. Bommesani et al. 2021](#)

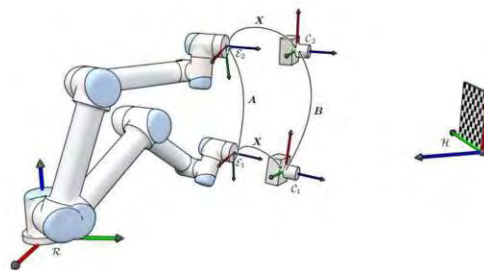
## Segment Anything Model – learning by prompting



- <https://github.com/facebookresearch/segment-anything>
- <https://github.com/facebookresearch/dinov2>



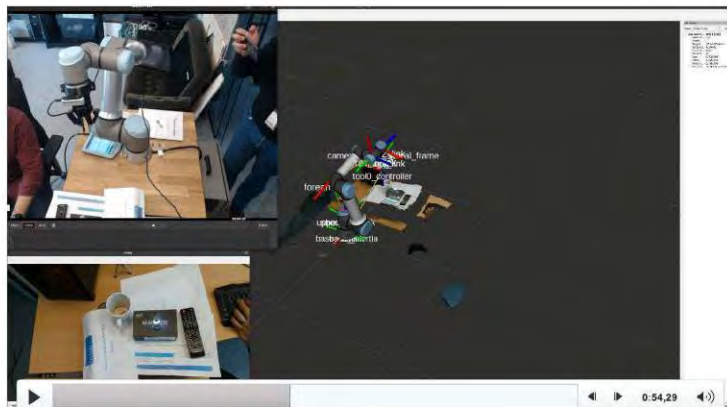
### Hand-eye calibration



### Object recognition and graspability



### The integrated solution




**Any Questions?**

## A3.2 Workshop session 2

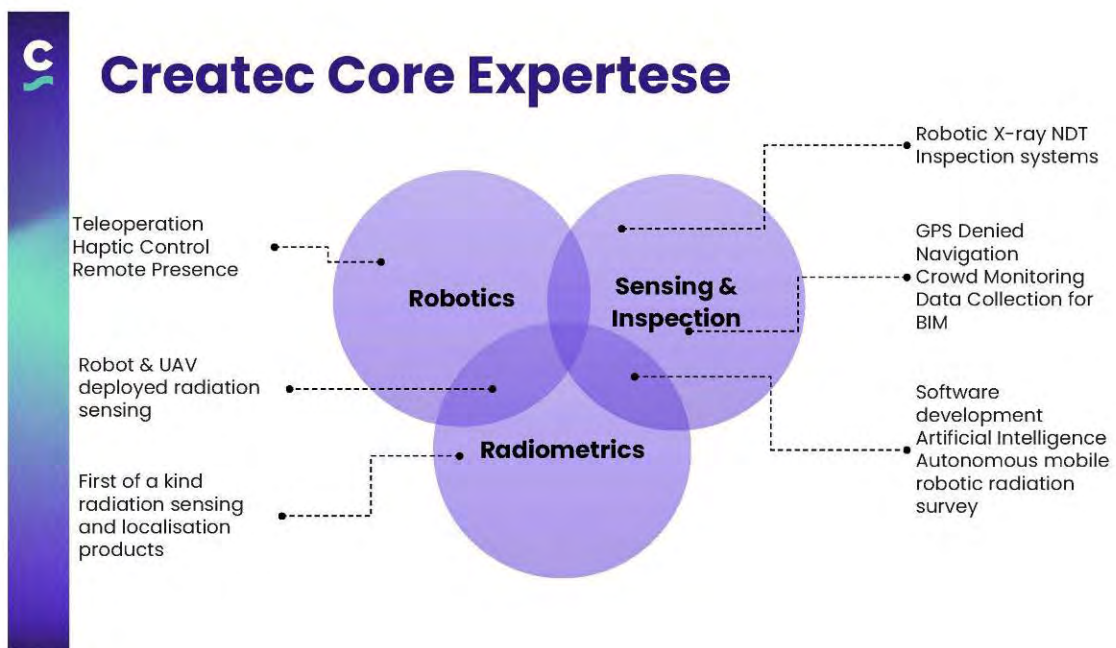

### *Radiation Imaging and Robotics in Hazardous Environments*

(Ross Fawkes/CREATEC)



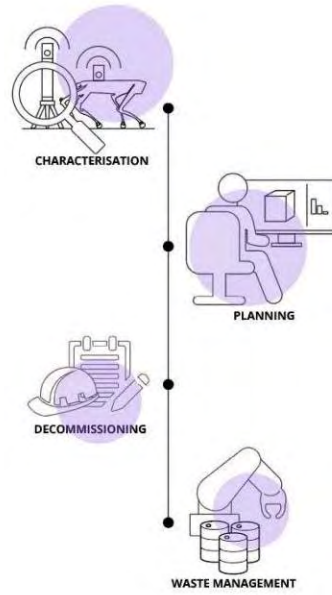
# Radiation Imaging and Robotics in Hazardous Environments

BostonDynamics  
GOLD SOLUTION  
PARTNER



# Benefits of Digital

-  **Cost-savings**
-  **Increase Operational Efficiency**
-  **Improve Site Safety**
-  **Make Confident Decisions**
-  **Reassurance for Regulatory Bodies**
-  **Intuitive Digital Twin Models**



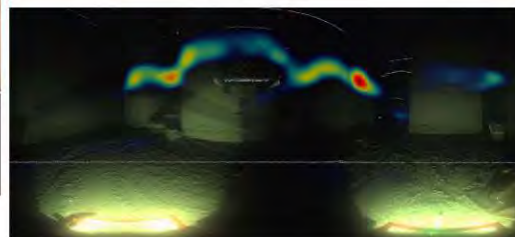
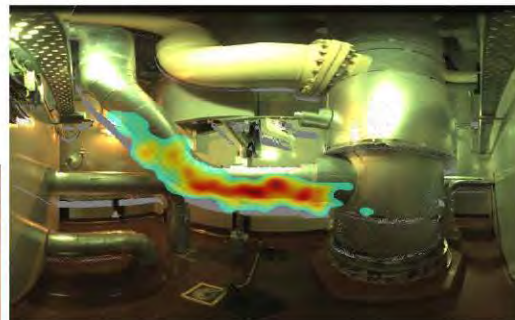
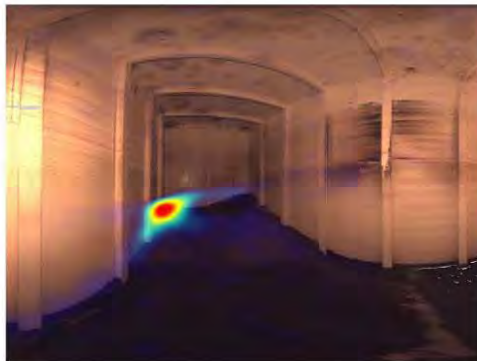
## N-Visage® NV3

First of a kind high gamma imager

- ❑ Market leading, patented technology inspired from medical sector.
- ❑ Deployed around the world: UK, Europe, USA, China and Japan.
- ❑ Produces rich panoramic Radiometric images
- ❑ Data can be further analysed using N-Visage Fusion
- ❑ Wide operational range: 50  $\mu\text{Sv/hr}$  – 2  $\text{Sv/hr}$
- ❑ Excellent background rejection – localising weaker sources



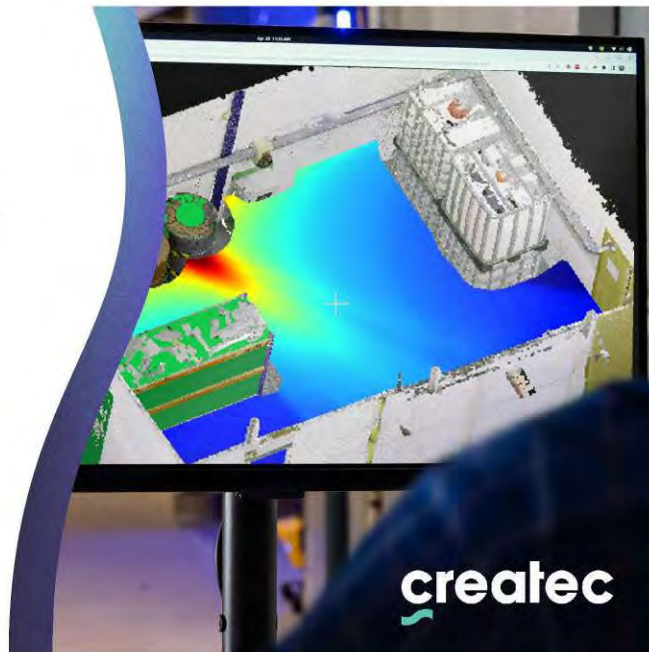
### Example: Radiometric overlays



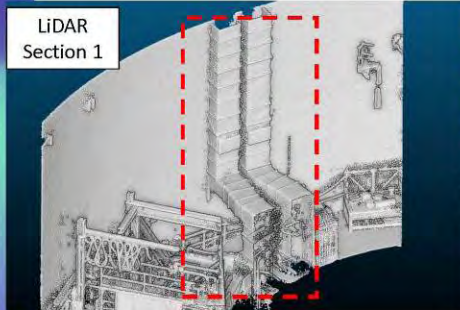
## NV Fusion

Drive deep insights from radiation analysis software

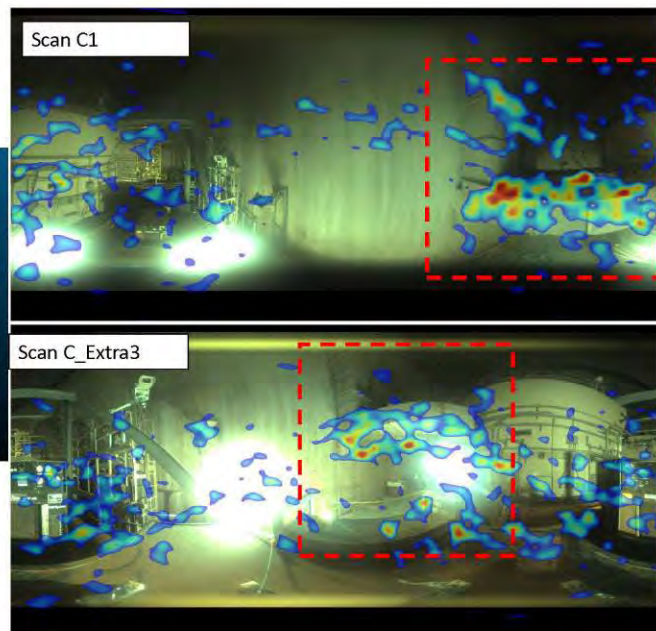
- ① Accurate source term information.
- ② Dose planes.
- ③ Model RP activities, such as shielding and moving sources.



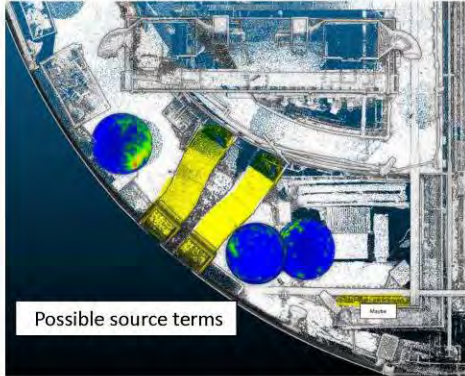
### Example: Radiometric overlays



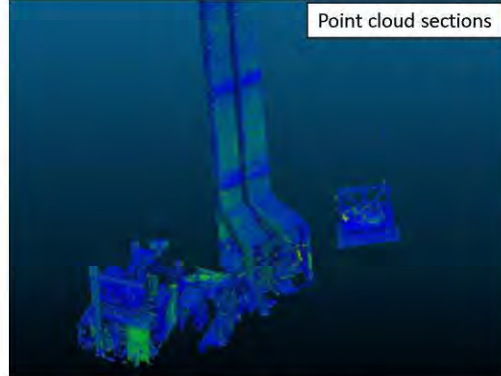
- Inspect scans for potential source locations



## Example: Expected sources

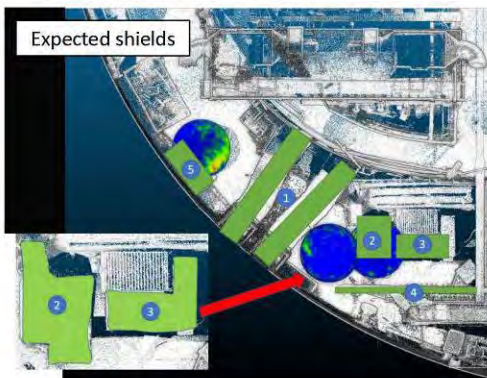


- ☐ Identify important source structures

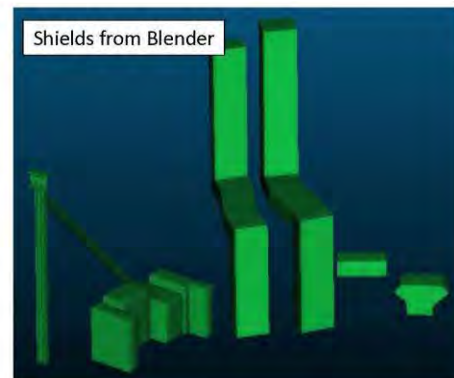


- ☐ Section for solving
- ☐ Start with fewer points

## Example: Expected shields



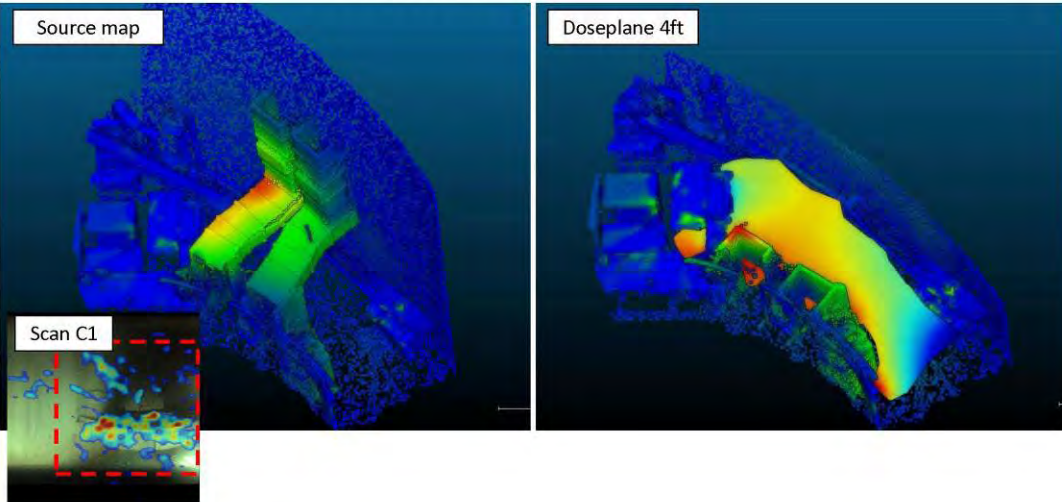
- ☐ Identify important attenuative objects



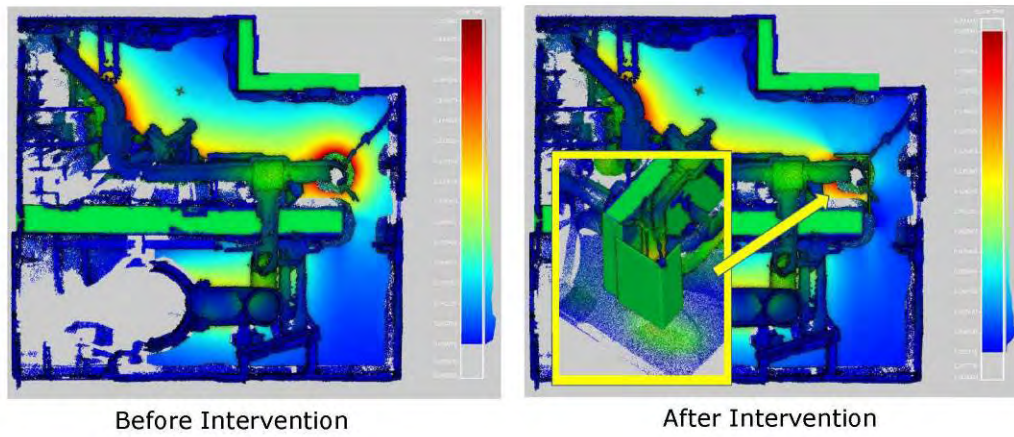
- ☐ Start with simple shapes



## Example: Fusion output – 3D solution



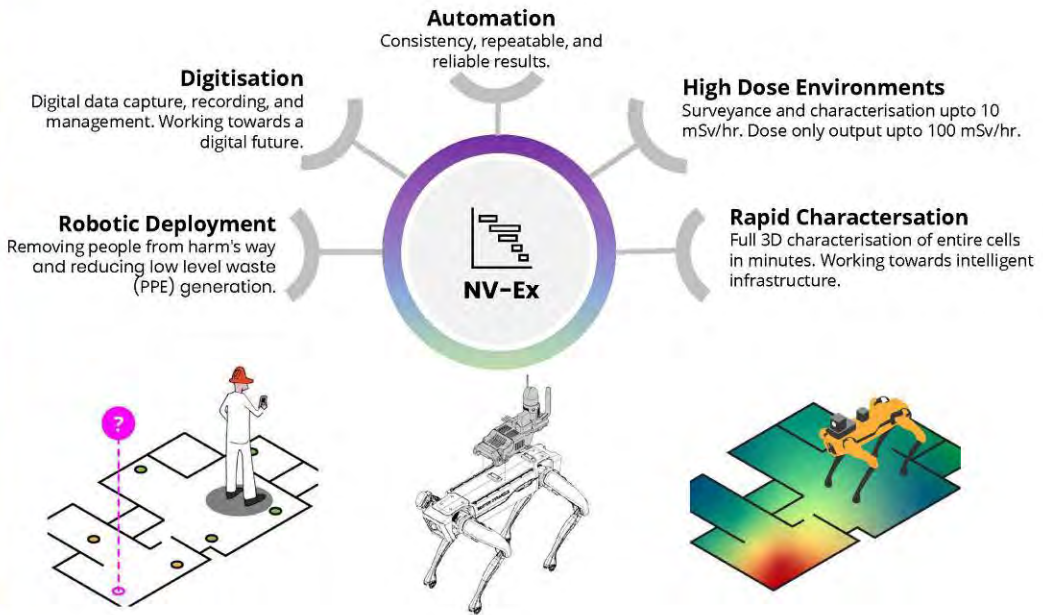
## Example: Interventions



# NV-Explore

## Real-time radiation sensor for mobile robots

- ① Seamlessly integrated for quick, cost effective and efficient deployment.
- ② Market-leading source location accuracy.
- ③ Instant on the ground insight into safety.



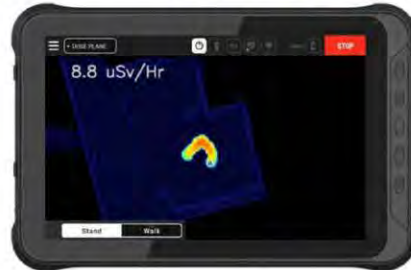


## Real-Time Radiation Mapping

Integrated with Spot

### Doseplane

- ❑ Top down 2d view.
- ❑ Highlights robot path.
- ❑ Real-time doserates in  $\mu\text{Sv/hr}$ .

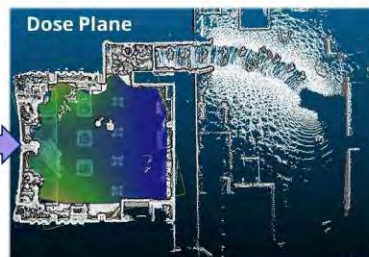
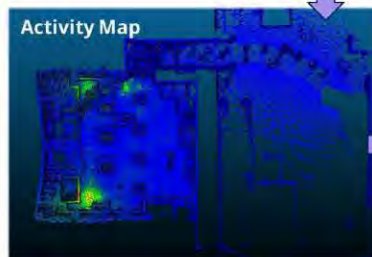
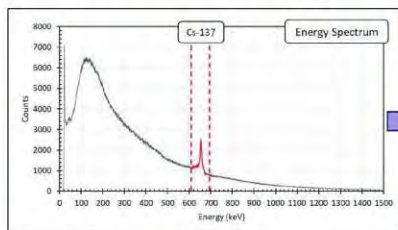


### Gamma Overlay

- ❑ Augmented reality overlay.
- ❑ Highlights gamma source terms in real-time.
- ❑ Integrated with Spot's front camera.



## Off-line Analysis



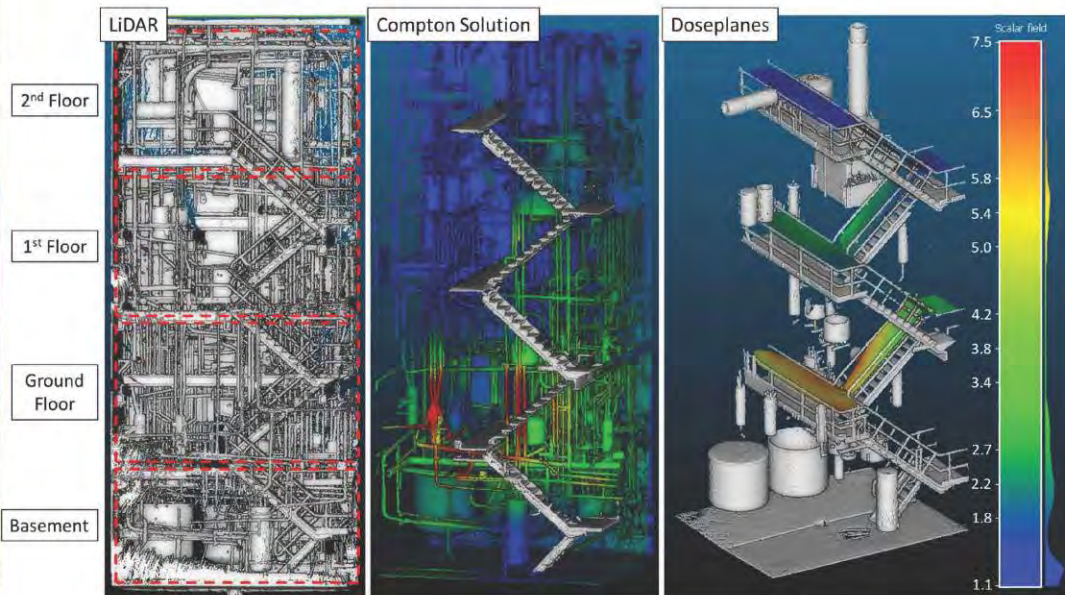
# Case Study Example:

DSRL (NRS) – Survey



## Key Takeaways

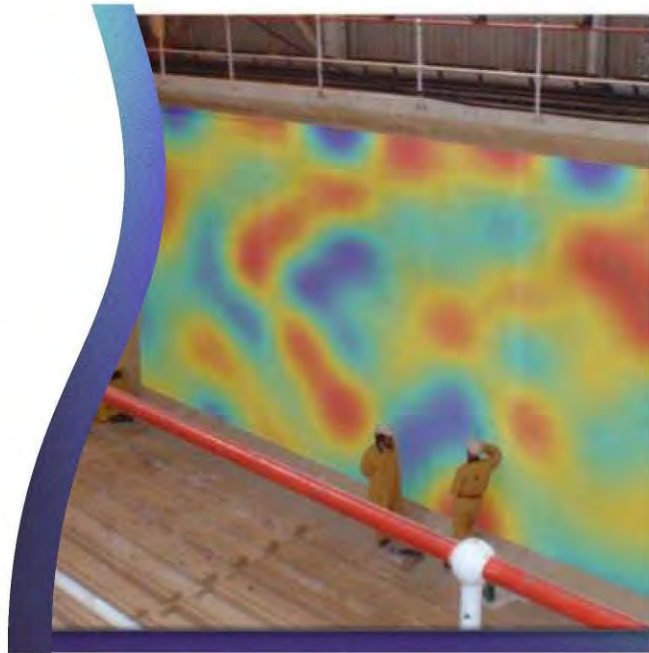
- ❑ Active deployment in Evaporator Cell, over 5 days on site
- ❑ First entry into cell in decades
- ❑ Full radiometric characterisation of cell:
  - Lidar mapping
  - 3D radiation mapping
  - Dose breadcrumbs using approved dosimeter
  - Multi-level doseplanes
- ❑ Spot Suit utilised for contamination control



## D:EEP

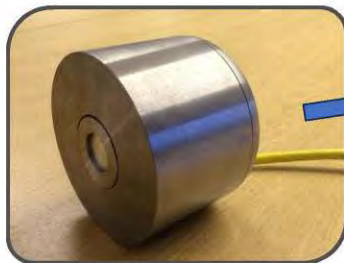
Non-destructive depth profiling of cementitious materials.

- ① In-situ measurements of surfaces in wet, or dry environments.
- ② High precision profiling on contamination ingress.
- ③ Rapid results vs conventional techniques.



## What is D:EEP?

### Deployment Hardware



Standalone Detector

- ❑ Needs detector and collimator
- ❑ Challenge is creating the deployment method

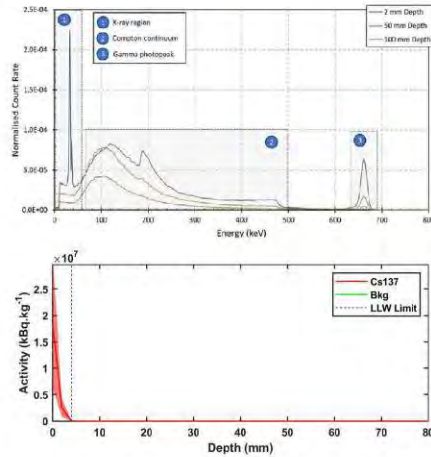


Single Axis Scanning Frame



## What is D:EEP?

### Software



- ❑ Characteristic spectral features vary as a function of depth.
- ❑ Geant4 used to generate theoretical response at depth.
- ❑ Models generated every 1 mm upto 150 mm depth.
- ❑ Measurement spectra compared to simulation to obtain best fit.
- ❑ Individual contributions used to generate depth profile.



## Case Study Example:

### Chapelcross Pond 1 Measurement



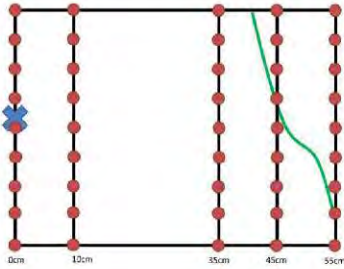
Pond 1 at Chapelcross Nuclear Facility. Pond had been decommissioned, emptied, and decontaminated in preparation for Care and Maintenance phase.



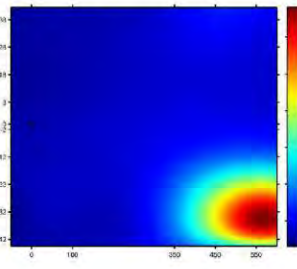
Single axis vertical scanning frame in use at Chapelcross Pond 1.

## Case Study Example: Chapelcross Pond 1 Measurement

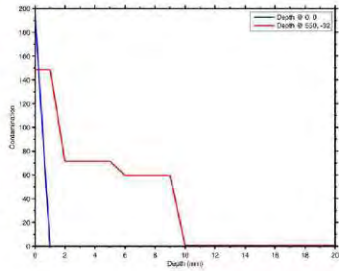
**Measurement Positions**



**Activity Distribution**



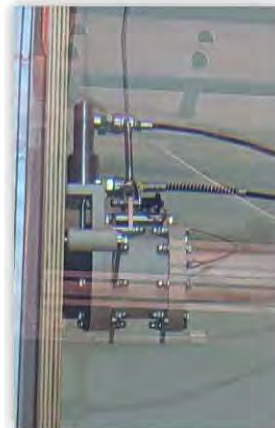
**Depth Profile**



## Case Study Example 2: EDF Dungeness Trial



Factory Acceptance Test of the D:EEP deployment mechanism at the Fortis test pond, Barrow, UK.



Detector housing deployed underwater showing the ability of the system to deploy the sensor flush against a wall



## Mobile Robotics



### Efficient

Streamline operations and improve efficiency by using mobile robotics to automate repetitive data collection and monitoring tasks.



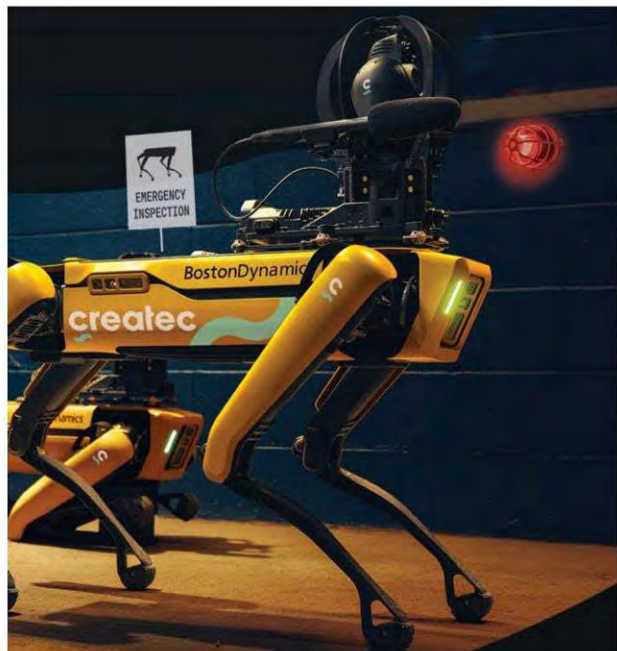
### Improve Site Safety

Removing people from hazardous or unknown environments. Use Spot® to understand and access areas which are dangerous for workers.



### Predictable

Proactively manage remote sites by gathering consistent data round the clock, finding failures before they prompt shut downs.





## Ancillary Data Collection



### Visual Inspection / Condition Monitoring

- ❑ high resolution photographs taken.
- ❑ video footage recorded.

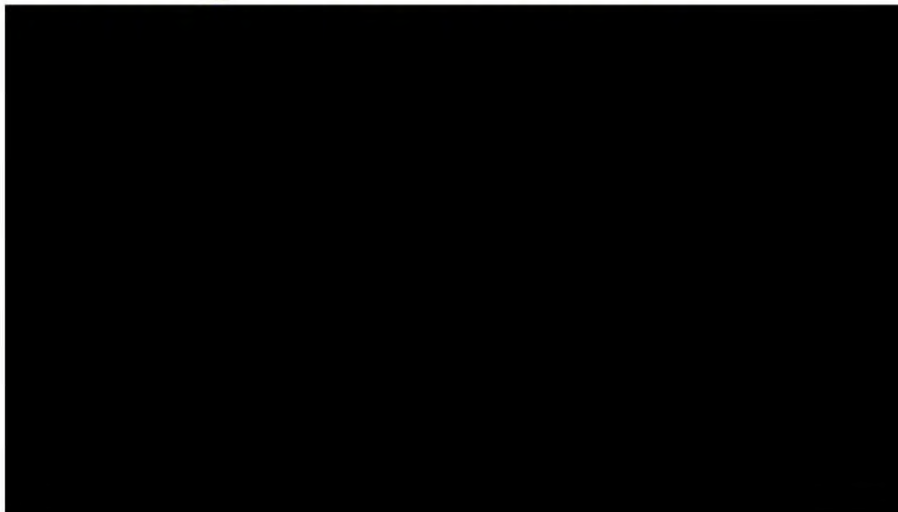


### Contamination Monitoring

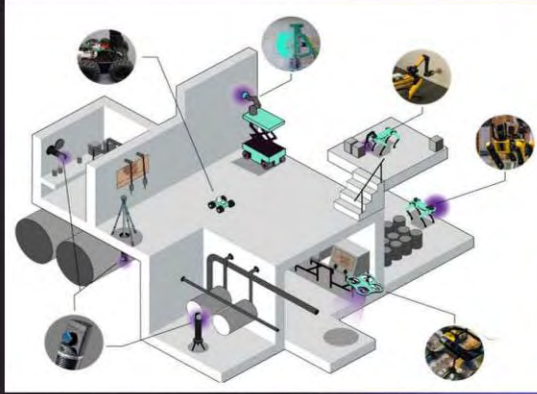
- ❑ Swabs of the environment taken remotely using Spot with Arm.



## Accessing the inaccessible



**createc**



**Any Questions**

Boston Dynamics  
GOLD SOLUTION  
PARTNER



*Use of site data in VRdose for decommissioning planning*  
(Joachim Bratteli/IFE)



09.04.2024

IFE-ÅPENT

## Data for decom planning

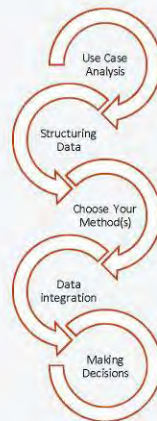
Integration of data to bridge the gap between the known and unknown while planning decom work operation

Joachim Bratteli – joachim.bratteli@ife.no  
BSc. Computer Sciences – Senior Engineer VR & AR



## The process of planning

IFE-ÅPENT # 3 | IFE



## 01 Use Case Analysis

Figure out if there are things that we do not know that gives a gap that needs to be bridged

### Use Case Analysis

This is where we gather information about the work operation that we plan. Main goal is to gather as much relevant knowledge and figure out if there are things that we do not know that gives a gap that needs to be bridged.



#### What do we know?

Normal work operation and maintenance work operation

Industrial hazards

Expected dose-rate during normal operation and maintenance work operation



#### What do we not know?

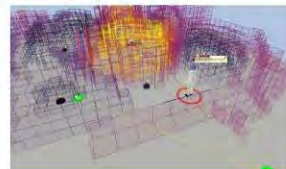
Work operation for decommissioning

Nearby work operations

Where and what are my sources?

What happens when we start cutting?

Competence needed



#### Bridging the gap

Define alternative work operations

Dose-rate simulations

Source deconvolution

Add competence

Radiation /shielding surveys

Photos: Mick Tully, Image Communication and Joachim Bratteli, IFE

## 02 Structuring Data

Putting existing data together ready for analysis.

### Going from non-structured to structured

We structure data needed for the use case. Detailed information about the work operation like the operation locations, what to bring, what to do, who can do it, how long it takes, etc. Based on the scope of the operation, necessary data about the environment as structural data and hazards is needed to perform adequate risk analysis. Finding if the data is sufficient is key.

		
<p><b>Work operation</b></p> <ul style="list-style-type: none"> <li>Location</li> <li>What to do</li> <li>Competence / Role</li> <li>Equipment</li> <li>Duration</li> </ul>	<p><b>Environment</b></p> <ul style="list-style-type: none"> <li>Structural</li> <li>Radiation and other industrial hazards.</li> </ul>	<p><b>Is it sufficient?</b></p> <ul style="list-style-type: none"> <li>Data analysis</li> <li>Environment modelling</li> <li>Extrapolate</li> <li>Characterization</li> </ul>

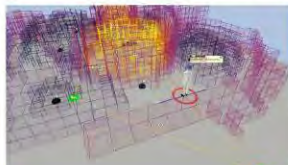
Photos: IFE - [creativecommons.org/licenses/by-sa/3.0/deed.en](https://creativecommons.org/licenses/by-sa/3.0/deed.en), no changes and Joachim Brattell, IFE

## 03 Choose Your Method

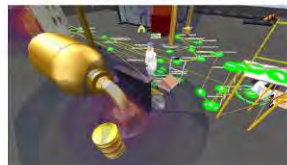
Interpolation / Extrapolation and/or Simulations are ways to calculate the possible radiation hazards in the area. In some cases gamma radiation is the dominant radiation hazard.

### Choose your method(s)

For analyzing the risks taken by the participants we need to choose the method that give sufficient input to do a good decision. Interpolation / extrapolation of dose-rate measurements could be enough for most use cases, like the work operations for gathering missing data. Simulations are required for operations where sources and/or shielding material largely change the radiation situation where work operations are performed.

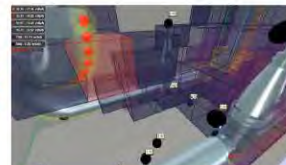


Interpolation / extrapolation



Simulation

Point Kernel (VRdose, Microshield, ...)  
Monte Carlo (MCNP, Geant4, ...)



Combinations

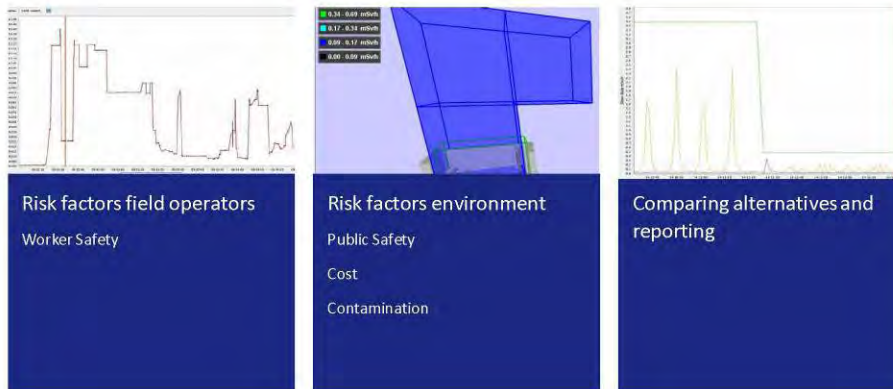
Photos: Joachim Bartsch, IFE

## 04 Data integration and filtering

Integrating input data and the results, showing possible hazards to be aware. Could we mitigate the hazards?

### Data integration and filtering

Integration of the data is needed to do adequate risk analysis on how alternative work operations affect the field operators and/or the environment.



Photos: Joachim Bartsch, IFE

## 05 Making Decisions

Decision makers align and prioritizes different work operations that is going on and decide if the plan is mature enough to put into life.

### Making decisions

Decision makers align and prioritizes different work operations that is going on. We could send this work operation to scheduling if the plan is mature enough.

#### Are we ready?

- Need more input?
- Are we doing the right things?
- Are we doing the things right?
- Scheduling?
- Are the risks to high?

#### Scheduling conflicts

Consider other operations that is ongoing for conflicts when it comes to resources

#### Issue work orders

- Gather more data
- Refine analysis



Ved IFE bygger vi bro mellom forskning, utdanning og industriell virksomhet

**Joachim Bratteli**

Bsc. Computer Sciences – Senior Engineer VR & AR

[ife.no](mailto:ife.no)

+47 938 72 721

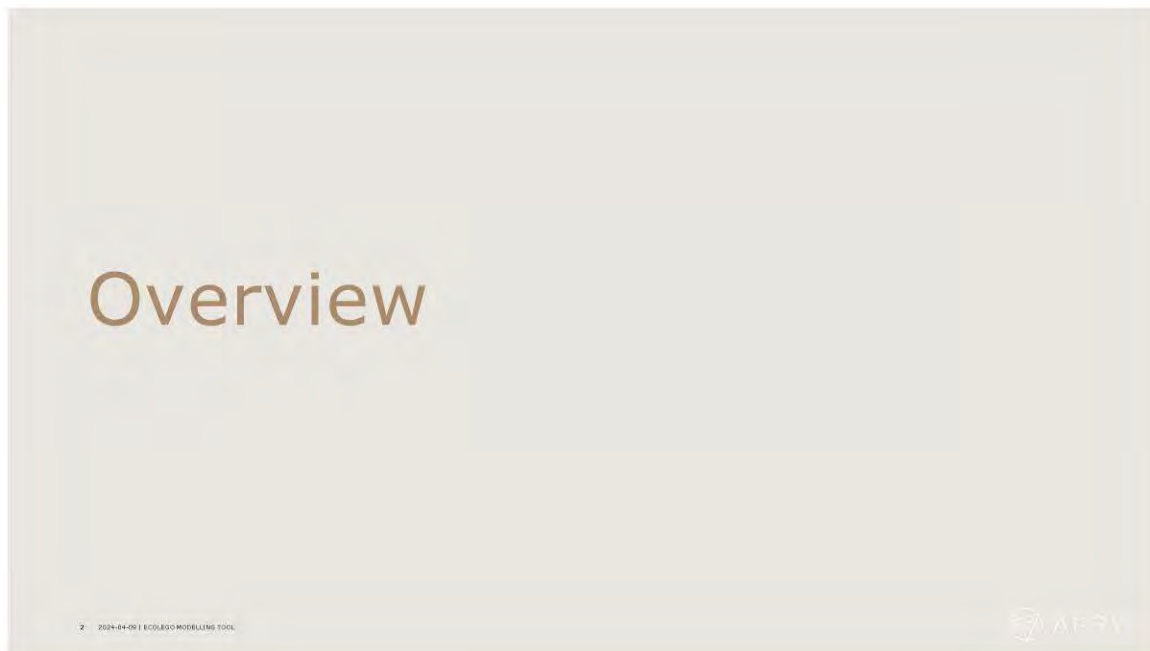
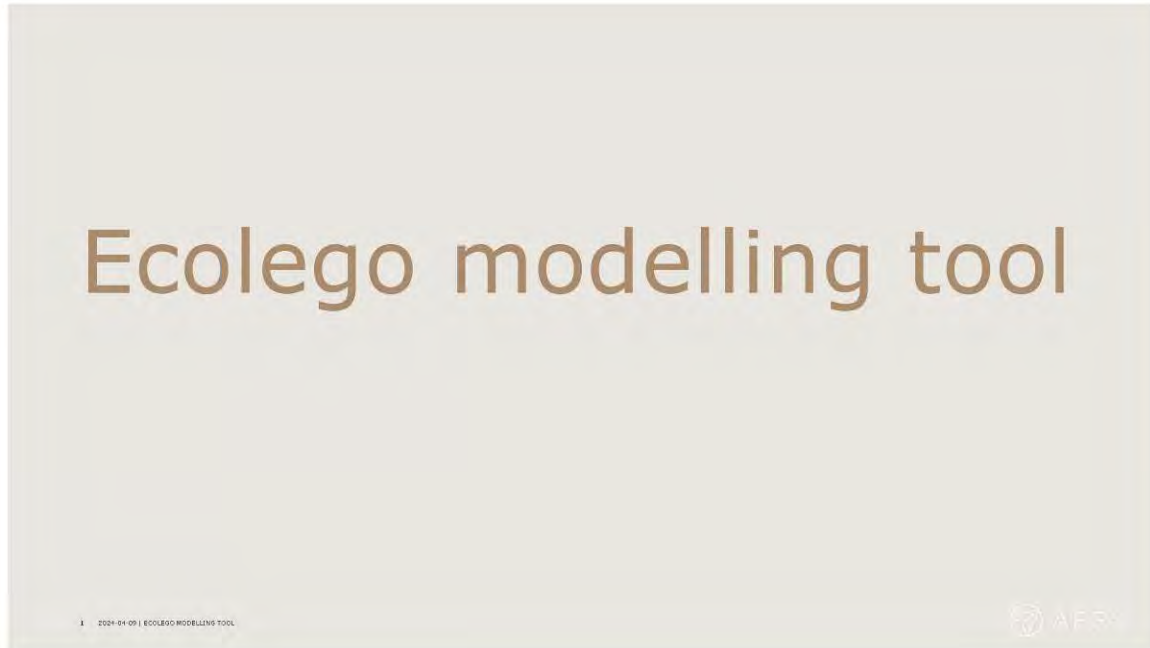
[Joachim.bratteli@ife.no](mailto:Joachim.bratteli@ife.no)

### A3.3 Workshop session 3

#### *AFRY Intelligent Scenario Modelling*

(Benedict Jaeschke/AFRY)

AFRY Intelligent Scenario Modeling is presented below but with its former name “Ecolego” which was still effective at the time of the workshop/presentation. The change of name took place during the period between the presentation and the publication of this report.



# What is ecolego?

Software for creating mathematical models of dynamic systems and performing simulations

- Risk assessments
- Sensitivity analysis
- Parameter optimization
- Databases
- Documentation
- Reporting



3 2024-04-05 | ECOLEGO MODELLING TOOL



## WHAT IS ECOLEGO?

# Key features

### Fast

Strong numerical solvers for continuous or event-driven processes

Allows simulation of thousands of compartments and species



### Flexible

- Interaction matrices
- Box and arrow diagrams
- Model browser
- Relationship diagrams
- Hierarchical models



### Risk assessment

- Monte Carlo simulations
- Probability distributions
- Parameter correlations
- State of the art sensitivity analysis methods



### Quality assurance

- Parameter databases
- Linking with Excel
- Documentation of QA process
- Model reviews



WHAT IS ECOLEGO?

# Applications



## RADIONUCLIDE TRANSPORT

Modelling the fate of radionuclides in a facility and the environment. For example, the release of radionuclides from a waste repository and their transport in the geosphere and the biosphere



## PHARMACOKINETIC MODELLING

Predicting the absorption, distribution, metabolism and excretion of synthetic or natural chemical substances in humans and other animal species



## CHEMICAL EXPOSURE ASSESSMENTS

Models to assess the exposure to chemicals in the environment taking into account their transfer and accumulation through different media, including human food chains



## CARBON SEQUESTRATION

Modelling the long-term behavior of carbon after its sequestration in geological formations

3 2024-04-06 | ECOLEGO MODELLING TOOL



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MODELLING

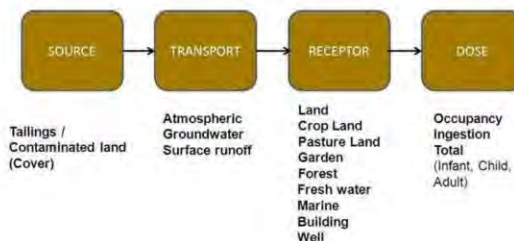
# NORMALYSA



Assessment of **radiological impacts** from contaminated lands and surface waste disposals on:

- Groundwaters
- Surface waters: rivers and lakes
- Adjacent lands: forests, croplands
- Coastal areas
- Humans

Focusses on Naturally Occuring Radioactive Material (NORM)



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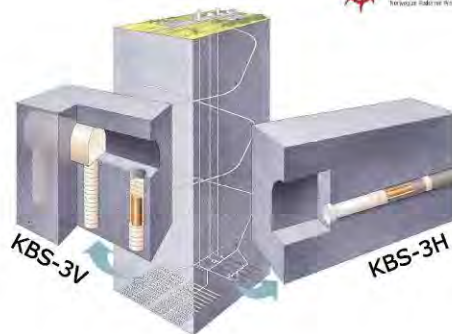
USE CASES

## Safety Assessment of Radioactive Waste Repositories



Modelling of:

- **Long-term** performance of engineered barriers
- **Radionuclide releases** to the geosphere
- **Transport of radionuclides** in the geosphere
- Radionuclide **transfer and accumulation** in the biosphere
- **Radiological impacts** on humans and the wildlife



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# Modelling

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## MODELLING

# Compartment Models

### Compartments

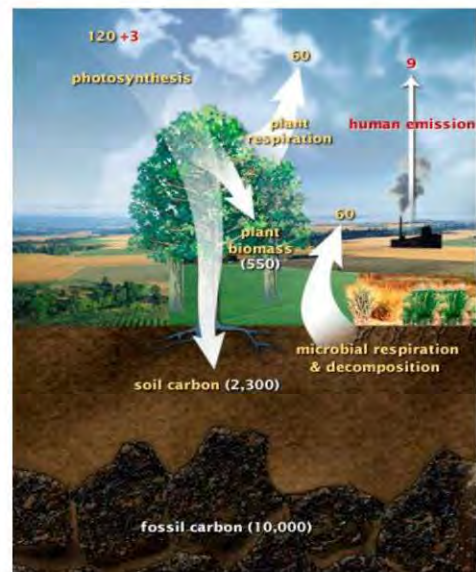
- Soil layer, tree, human organ, part of silo, savings account, country

### Model species

- Radionuclides, chemicals, water, money, people, goods

### Fluxes

- Transfer of species between compartments
- Linear, non-linear, discrete



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MODELLING

# Building Blocks

Expressions

- An algebraic equation

Parameters

- Constant data

Time series

- Lookup tables

Compartments

Transfers



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MODELLING

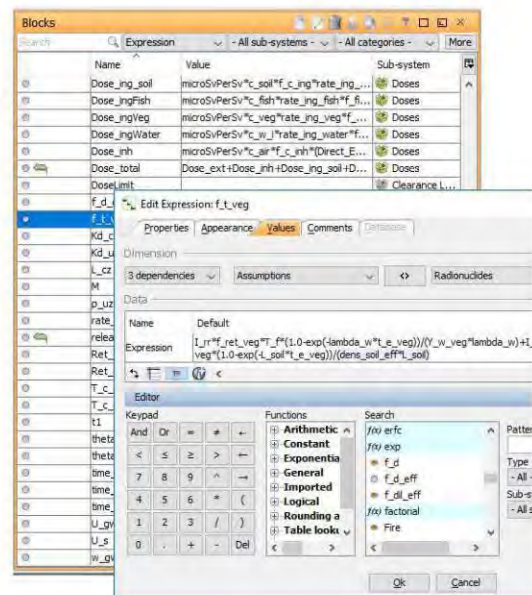
# Equations and Data

No required order for building.

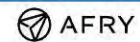
Users have access to all building blocks when editing equations.

Unit checking performed.

No limit on number of dependencies for blocks.



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MODELLING

# Browser

When a block is selected, all **available information is presented** in a web-page format.

**Makes it easy** for modellers, reviewers and customers to see "under the hood".

The **model can be navigated** by clicking hyperlinks.

## Metabolism in gut (Transfer)

ID: Man.Gut\_to\_MetabolitesGut  
 Full name: Metabolism in gut  
 Display name: Gut\_to\_MetabolitesGut  
 Category: Transfer  
 Description: Metabolism is described by a saturable process (Michaelis-Menten equation) or a first order reaction.  
 Sub-system: GI tract  
 Unit: mg d<sup>-1</sup>  
 Source: Amount in gut  
 Target: Amount of metabolites formed in the gut  
 Dimension: Materials

Equation		TC
$(V_{max}[Gut] Content_{MainCYP} C[Gut]) / (K_m[Gut] + C[Gut])$	unit <sub>min.per.day</sub>	No
$CL[Gut] Content_{MainCYP} C[Gut]$	unit <sub>min.per.day</sub>	

where

Name	Unit	Full name	Type	Sub-system
C	mg/L	Concentrations in compartments/organs	Expression	Man.GeneralOrg
CL	L/min	Clearance	Expression	Man.Metabolisr
Content <sub>MainCYP</sub>	unitless	Content of cytochrome P450 in compartments	Expression	Man.Metabolisr
K <sub>m</sub>	mg/L	Michaelis constant	Parameter	Man.Metabolisr
unit <sub>min.per.day</sub>	min d <sup>-1</sup>	Unit conversion from day to min	Parameter	

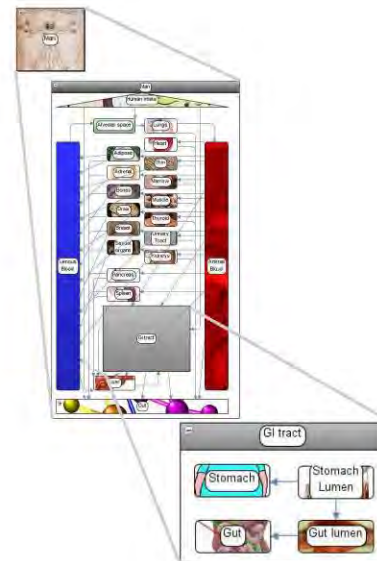


MODELLING

# Hierarchical Models

By arranging blocks into **subsystems**, the model becomes **easier to manage** and overview.

Subsystems can be used to **build model libraries**.



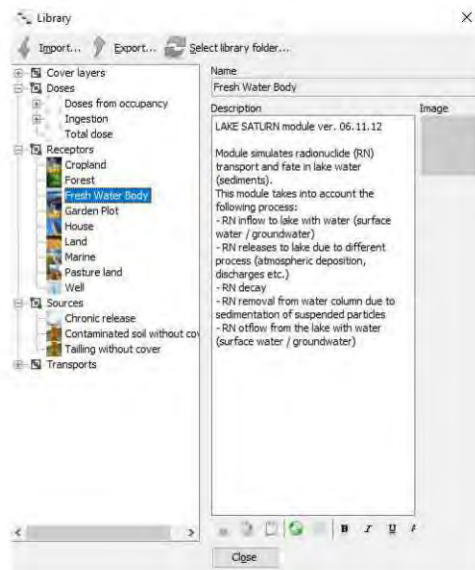
## MODELLING

# Build Model Library

- Organise model into a subsystem
- Define model inputs and outputs
- Enter in library



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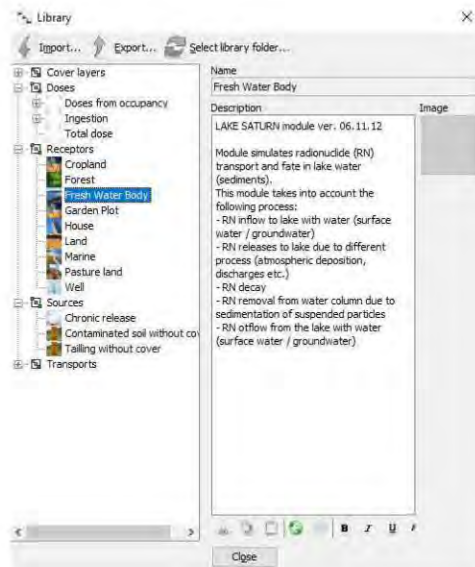


## MODELLING

# Use Library

- Fetch subsystems from library
- Connect them
- Quickly build a complex model for a specific scenario
- The model can be automatically updated when the library changes

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MODELLING

# Interaction Matrix

Models are defined by creating and connecting building blocks.

The interaction matrix is useful when there are **many connections** between building blocks.



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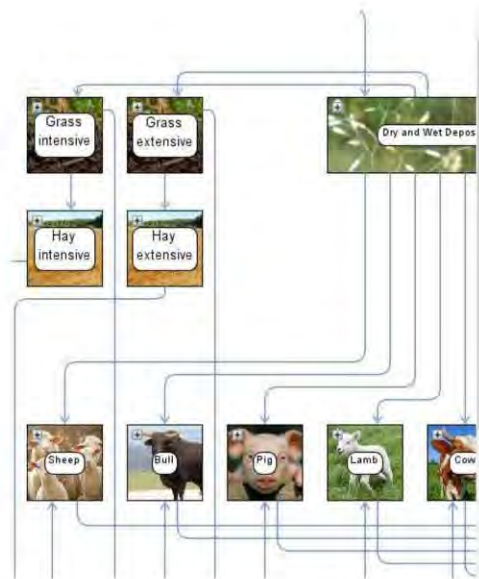
MODELLING

# Graph View

Box and arrow diagrams are **intuitive** for new users.

Can more easily represent the conceptual model.

Boxes can be arranged on a custom background to illustrate the relationship between the real and modelled system.



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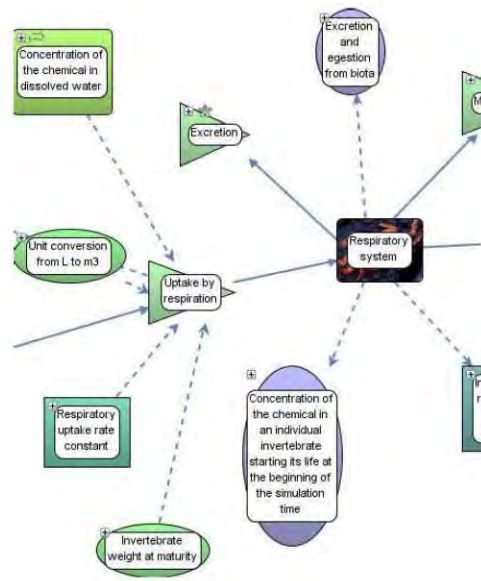


MODELLING

# Relationships View

Relationships between model building blocks can be generated.

All views are **interactive**.



## The Model-making Process (Example)

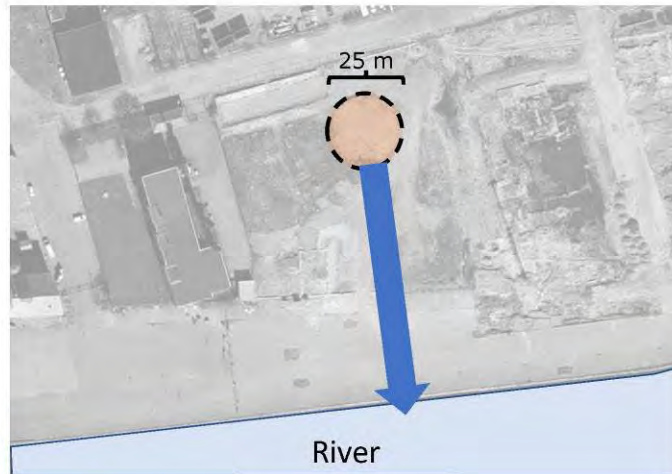
EXAMPLE  
Site



21 2024-04-09 | ECOLOGO MODELLING TOOL



EXAMPLE  
Site

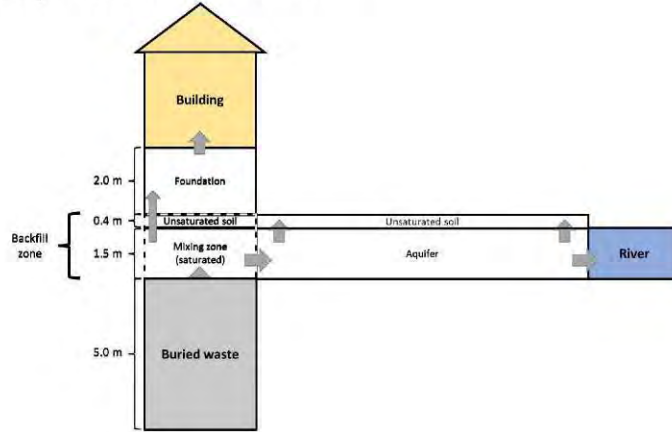


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EXAMPLE

# Conceptual Model

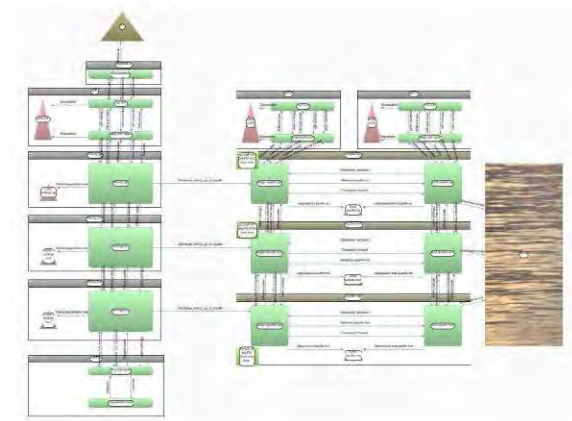


23 2024-04-05 | ECOLEGO MODELLING TOOL

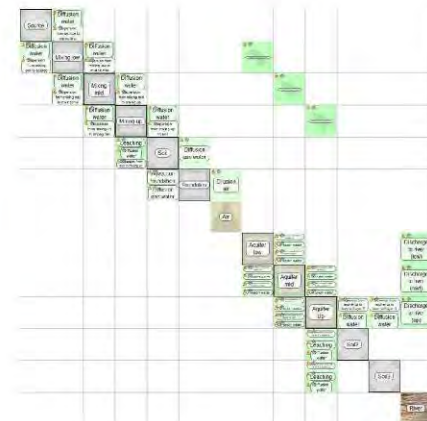


EXAMPLE

# Ecolego Model



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# Parameterisation

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## PARAMETERISATION

### Model parameters

Identify parameters that are appropriate to use generic data and those that require site data.

For example:

#### Site-specific parameters

- Meteorological data
- Population time on site
- Diet
- Groundwater flow
- Transfer coefficient (retention in ground)

#### Generic parameters

- Radionuclide half-life
- Dose coefficient
- Breathing rate

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PARAMETERISATION

# Lacking data...

Without site-data:

- Regional-data
- Analogues
- Generic data (with justification)



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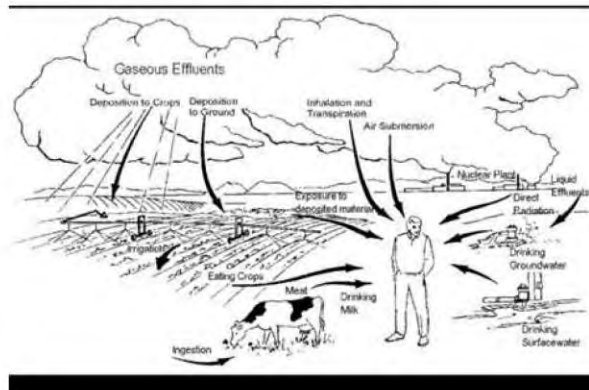


PARAMETERISATION

# Scenarios

Datasets for alternate cases

- Different exposure pathways
- "Less-likely" future scenarios



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# Importing data

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## IMPORT DATA

# Excel Import/Export

Simple and robust process for importing/exporting large datasets via Excel.

Multiple parameters/lookup tables are handled simultaneously, including associated dependencies.

Include data for deterministic and/or probabilistic values.

References and quality control features are included.

Values									
Parameter	Dependencies	Data	Observation	Reference	Reference	Export Info	Export Info	Export Info	Export Info
1	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...
11	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...
13	...	...	...	...	...	...	...	...	...
14	...	...	...	...	...	...	...	...	...
15	...	...	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...	...	...
17	...	...	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...	...	...
23	...	...	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...	...	...
25	...	...	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...	...	...
27	...	...	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...	...	...
29	...	...	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...	...	...
31	...	...	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...	...	...
33	...	...	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...	...	...
35	...	...	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...	...	...
37	...	...	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...	...	...
39	...	...	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...	...	...
41	...	...	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...	...	...
43	...	...	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...	...	...
45	...	...	...	...	...	...	...	...	...
46	...	...	...	...	...	...	...	...	...
47	...	...	...	...	...	...	...	...	...
48	...	...	...	...	...	...	...	...	...
49	...	...	...	...	...	...	...	...	...
50	...	...	...	...	...	...	...	...	...

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SIMULATION

# Probabilistic Simulation

Model inputs are often **uncertain** or poorly understood.

Thus, the **prediction** of the model will also be uncertain.

In **deterministic** simulations, “best estimates” are assigned to model parameters.

In a **probabilistic** simulation, model parameters are expressed using probability density functions.



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SIMULATION

# Probabilistic Simulation

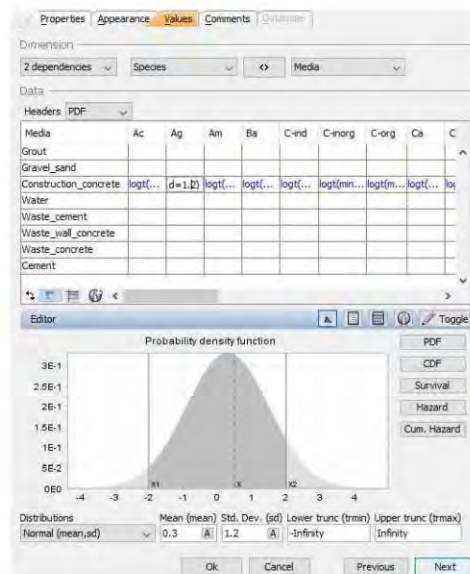
Assign **probability density functions** to uncertain parameters.

Parameter **correlations** can be considered.

Run **thousands of simulations** with randomized parameter samples.

Generate **statistics** (mean, std. dev, percentiles etc.).

Do basic **sensitivity analysis** (linear regression coefficients, first order sensitivity indices etc.).



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“Sensitivity analysis aims at determining how sensitive the model output is to changes in model inputs.”

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## Why Sensitivity Analysis?



### INPUT-OUTPUT RELATIONSHIPS

What is the relationship between the input parameters and the model output



### UNDERSTANDING MODEL BEHAVIOUR

Can communication of results be enhanced and make the model more understandable, credible?



### UNCERTAINTY CONTRIBUTION

How large fraction of the variation in the output is attributed to the variation in parameter x?



### MINIMIZING DATA COLLECTION

Which parameters can be fixed to nominal values without significant loss of information?

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# Data management and Quality Assurance

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## QUALITY ASSURANCE

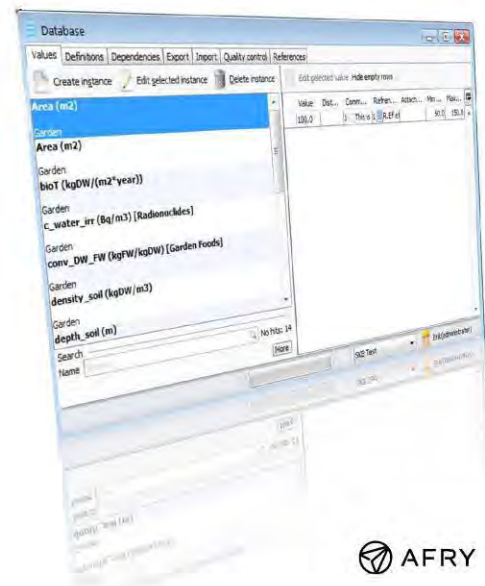
### Parameter Database

*Parameter database toolbox* allows a **shared parameter data server** to be set up.

Parameter data is filled in using a **database client** application (Ecolego not needed).

Database application has functionality for **quality assurance**.

Enforces **consistent naming** across models.



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# Model and Data Review

Comments can be used by model developers and reviewers to **communicate issues** discovered in models.

Reviewer comments can be **ranked** and marked as closed.



## Results and Reporting

SIMULATION

# Results

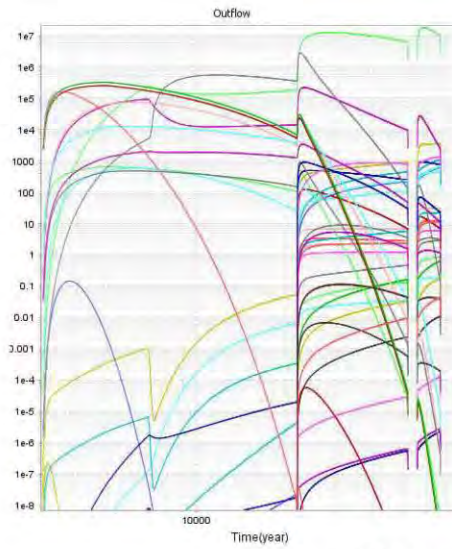
## TABLES

Many different ways to tabularize output data.  
Possible to export data to Excel or text files.

## CHARTS

Create plots of simulation outputs directly in Ecolego.

Plots are updated when new simulations have been run.



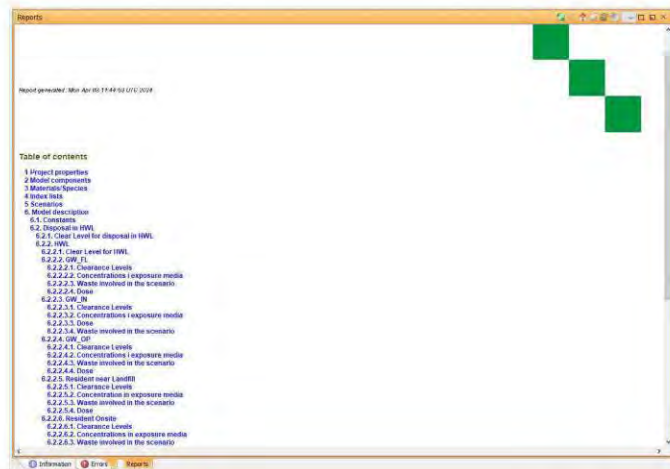
SIMULATION

# Report

Built-in report generator.

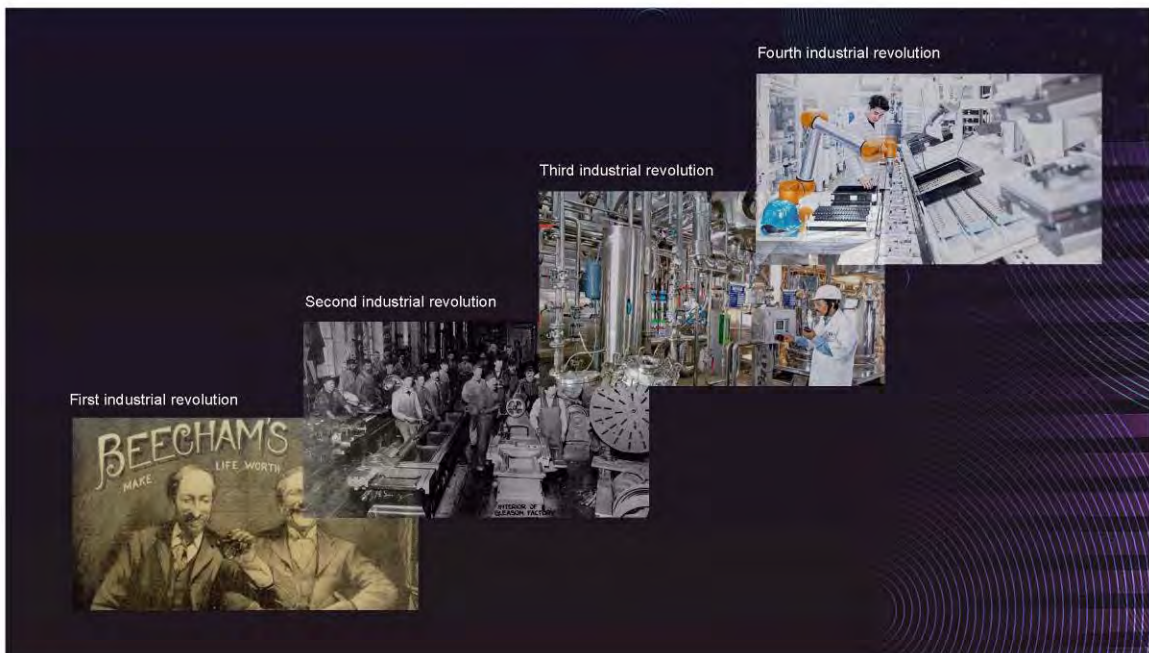
Includes details of:

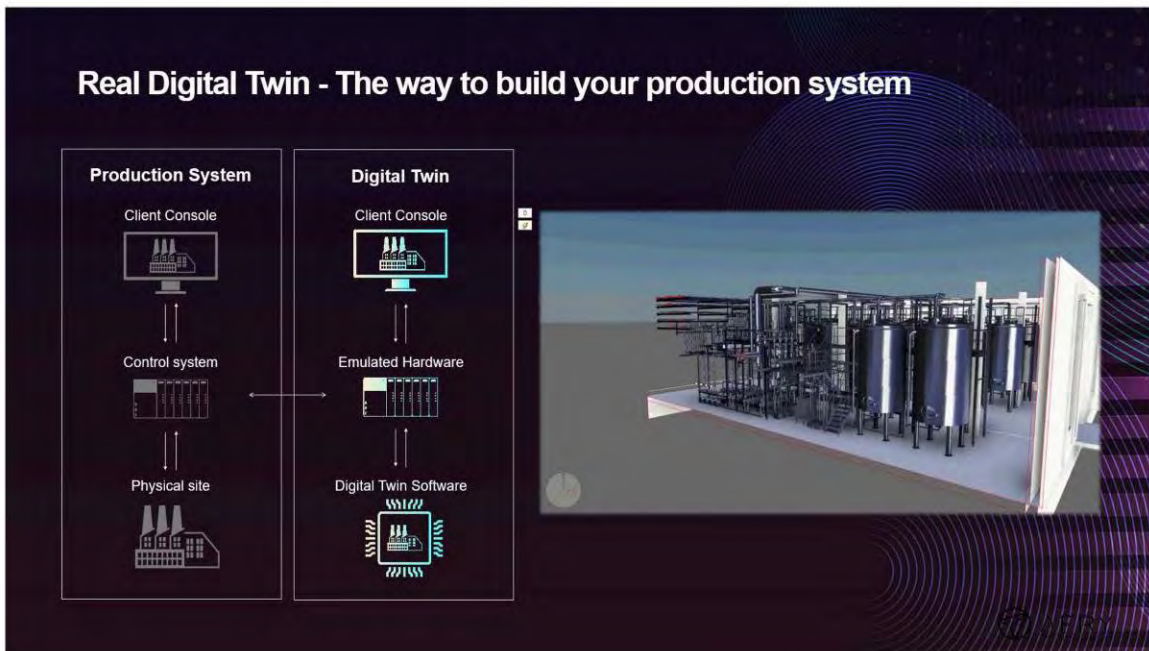
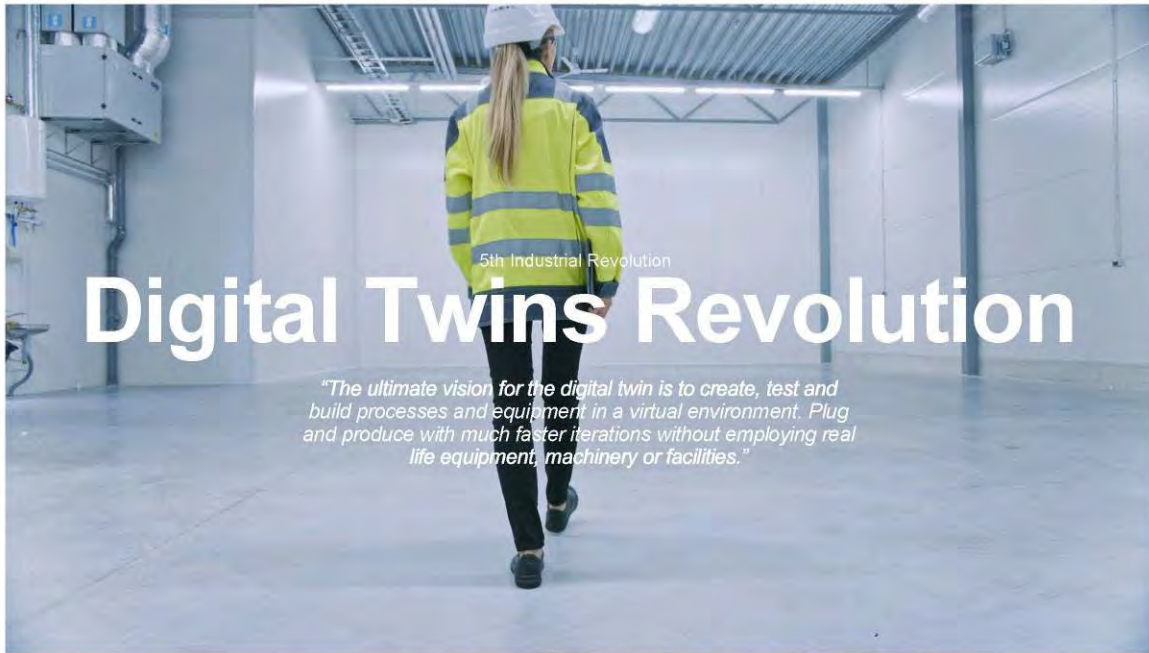
- Model components
- Parameters
- Simulation settings
- Results

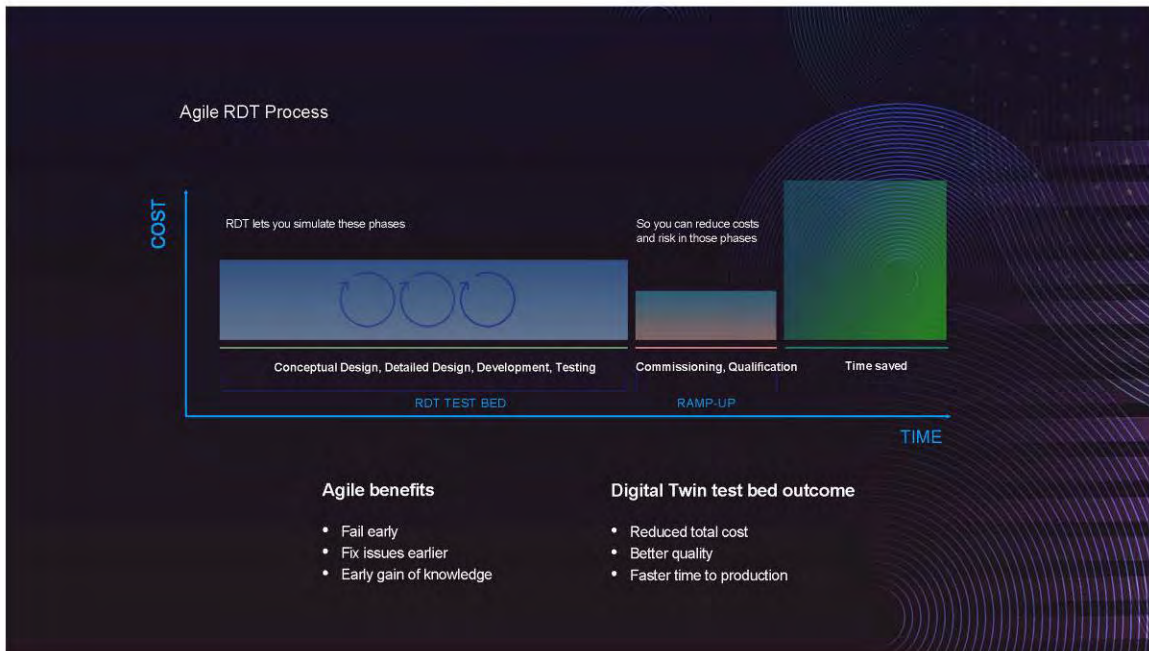




*Real Digital Twin*  
(Andreas Buhlin/AFRY)







# Substantial impacts

Up to  
**95%**

readiness before physical implementation



Up to  
**80%**

reduction of commissioning and ramp-up time



Up to  
**30%**

reduction of project development time



RDT process

**A.**

Analyze

**B.**

Scope

**C.**

Implement

#### Knowledge sharing

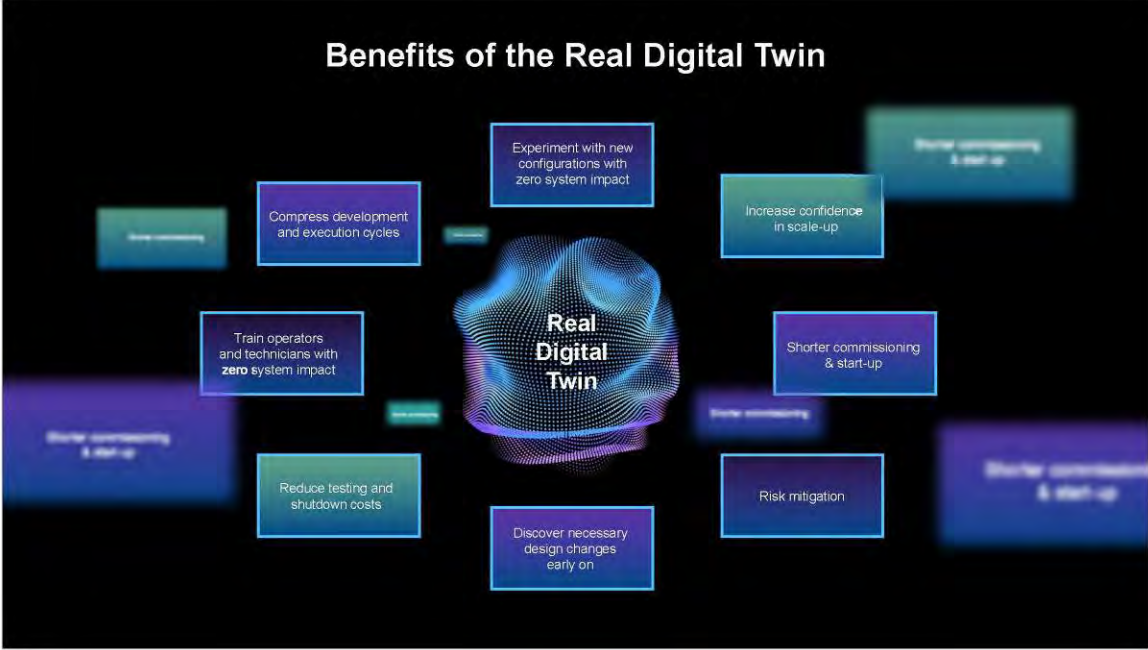
- RDT Way of Working
- Data collection
- Iterative approach

#### Level of simulation

- Test bed
- Virtual commissioning
- Operator training
- Optimization

#### Harness synergies

- Scale as you go
- Automatic generation
- Reusability
- Standardized interfaces



In conclusion:  
**With RDT you can develop faster at a much lower total cost.**



### A3.4 Workshop session 4


#### *Data gathering and use during Chernobyl decommissioning* (Fedir Lanskykh/ChNPP)




## “Data gathering and use during ChNPP decommissioning”

[April 2023]

**Fedir LANSKYKH**  
Leading engineer of the Engineering Center SSE ChNPP

Chernobyl NPP 



Power unit №1	1977 - 1996
Power unit №2	1978 - 1991
Power unit №3	1981 - 2000
Power unit №4	1983 - 1986

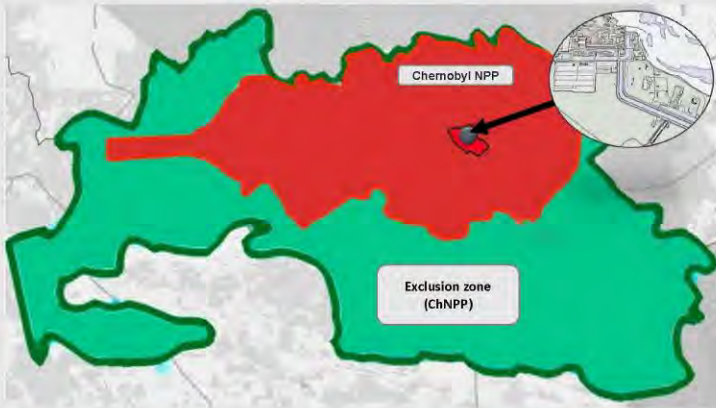
April 26, 1986 - severe accident at unit 4

December 15, 2000 - the final stop of the Chernobyl nuclear power plant.

On March 22, 2002 - the State Nuclear Regulation Committee of Ukraine issued to SSE ChNPP the License for performance of all types of activity on Chernobyl NPP shutdown and decommissioning.

**2**

The state specialized enterprise "Chornobyl NPP" is the operating organization (operator) of the nuclear installation - the Chornobyl nuclear power plant.



The main areas of activity of the ChNPP

- Decommissioning power units 1, 2, 3 of the Chornobyl NPP
- Transformation of the "Shelter" object into an environmentally safe system
- Management of spent nuclear fuel
- Management of radioactive waste

3

ANSWER

- indicators of operation of the nuclear installation
- emergency events - their characteristics and consequences
- data on facilities and areas of the nuclear installation
- data on the main indicators of the technical condition of buildings
- data on the main indicators of the technical condition of systems and equipment
- lists of systems and equipment
- data on the main indicators of the radiation state of buildings, systems and equipment
- data on nuclear fuel
- data on volumes and main characteristics of radioactive materials and radioactive waste
- data on flammable, explosive, chemically active substances and materials
- data on soil, surface and groundwater pollution


QUESTION




What data is required?

4

**Data collection**




- According to the results of engineering and radiation surveys
- According to the indications of sensors, observation and control systems
- From archival sources
- According to the results of scientific research
- From design and construction documentation



**5**

**Processing and use of data**




**Data processing is performed in different ways - it depends on the purposes of use**

information search

data structuring

receiving new information



systematization

receiving new information

changing the form of information presentation

- Making decisions on the implementation of established tasks and challenges
- Saving information

**6**

**Thank you for  
attention!**



State Specialised Enterprise  
"Chornobyl Nuclear Power Plant"

**Characterization of Radioactive Contamination under Post-Accidental Conditions at Unit 4 of Chernobyl NPP**  
(Maxim Saveliev/ISP NPP)



DATA4DECOM Collecting data for use in decommissioning

**Characterization of Radioactive Contamination under Post-Accidental Conditions at Unit 4 of Chernobyl NPP**

Institute for Safety Problems of Nuclear Power Plants  
National Academy of Science of Ukraine

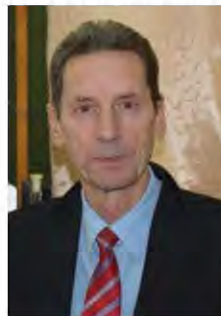


Institute for Safety Problems of Nuclear Power Plants – National Academy of Science of Ukraine

**Characterization of Radioactive Contamination under Post-Accidental Conditions at Unit 4 of Chernobyl NPP**



**Maxim Saveliev, Ph.D.**  
Senior Researcher at the  
Institute for Safety  
Problems of Nuclear Power  
Plants of National Academy  
of Science of Ukraine



**Viktor Krasnov**  
Head of Division for Nuclear and  
Radiation Safety at the  
Institute for Safety Problems of  
Nuclear Power Plants of National  
Academy of Science of Ukraine



**Maksym Pantin,**  
Ph.D. student  
at the Institute of Mathematical  
Machines and Systems Problems  
of National Academy of Science  
of Ukraine

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## Chornobyl - worst nuclear accident

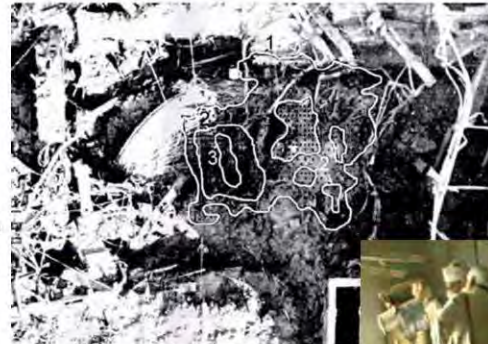


- April 26th, 1986 - steam explosions and melting of the reactor core (height 7 m, diameter 11.8 m, 190 t of nuclear fuel)
- Top biological plate with mass of 2000 t the explosion threw it up and it became at an angle of 15 to the vertical
- Bottom biological plate moved down to 4 m.
- More than tens of thousand peta-becquerels released into the environment

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## Post-accident measurements and assessments



Remote measurements using "Gamma-visor" -> from 1 to 3 TBq/m<sup>2</sup>



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## Post-accident measurements and assessments

- The use of helicopters (Ми-8Т and Ка-27М) with NaI(Tl) collimated sensor for radiation mapping from the height of 200m. More then 2000 measurements  
→ Success.
- The “Needle” experiment of use of helicopter to measure the gamma and temperature from the reactor remote sensors (operated by wire): deployed sensor fell unfortunately not into reactor but into empty north fuel pool as it was confirmed later in 1989  
→ Failure.
- The “Buoy” program - conus shape complex system with multiply sensors deployed by helicopters and later by DEMAG crane.  
→ Success.



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## The Shelter Object – construction

- Resolution of the Central Committee of the CPSU and the Council of Ministers of the USSR 634-188 of 05/29/86 - The Ministry of Medium Industry of the USSR was entrusted with "the work of burying the 4th power Unit of the Chernobyl Nuclear Power Plant and the structures related to it."
- The object was named "Shelter of the 4th Unit of the Chernobyl Nuclear Power Plant"
- Subsequent construction lasted for **206 days**, from June to late November of the same year: Erection by existing civil engineering technology with (adapted/ distant) human intervention: "Shelter Object (SO)" = "Sarcophagus"



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# The Shelter Object

11-04  
262

Утвердил  
Легвов Б.А.  
28 Октября 1986г.

ОТЧЕТ  
о состоянии физических параметров "Укрытия"  
к моменту завершения основных строительно-монтажных работ

Approved by  
V.A. Legasov  
October 28, 1986

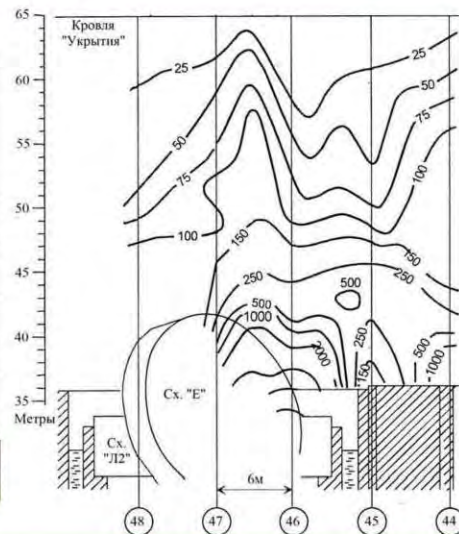
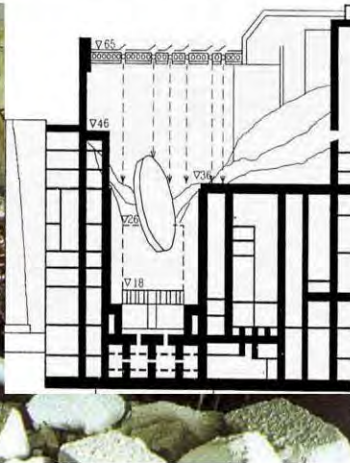


The Report on the state of the physical values of the Shelter Object on completion of the construction.

Conclusions:

- No changes in geometry and state of the fuel
- All radiation values are inline with calculated in the Design.

# Gamma field intensity





## Human intervention

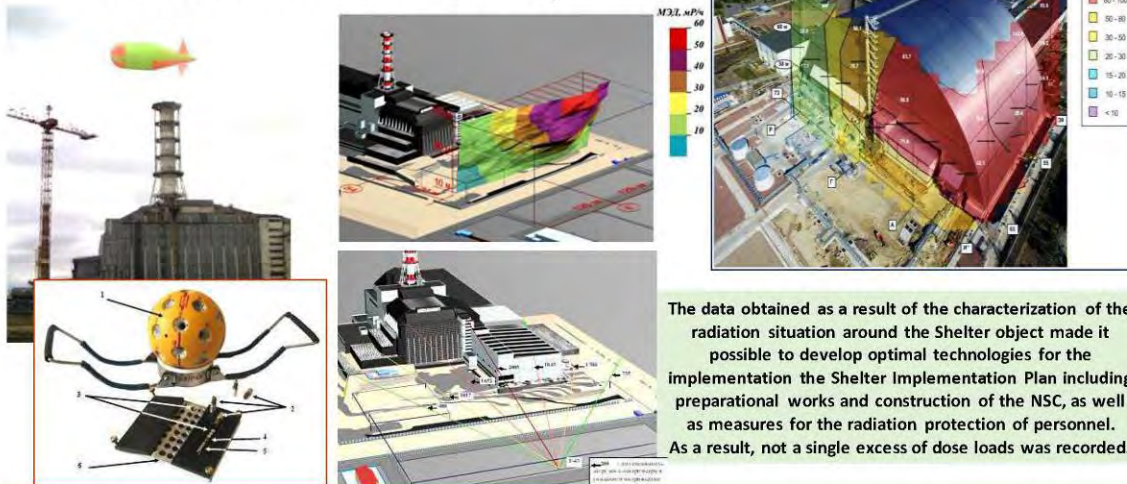
In memory of **Arthur Korneev** who passed away October 28, 2022



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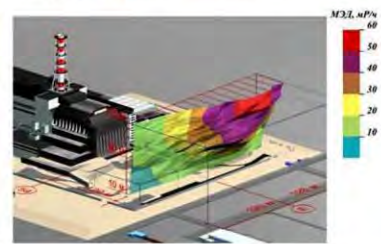
## Gamma fields intensity



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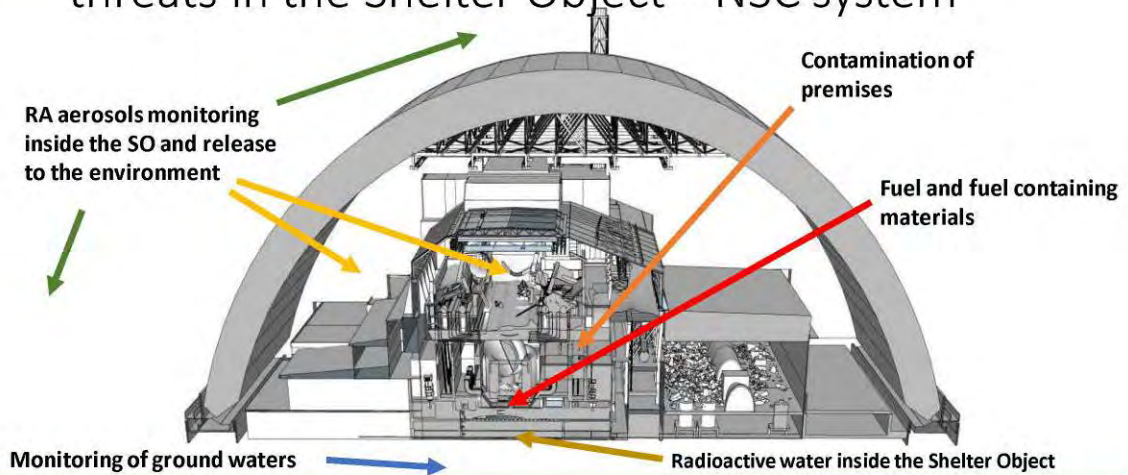
## Gamma fields intensity



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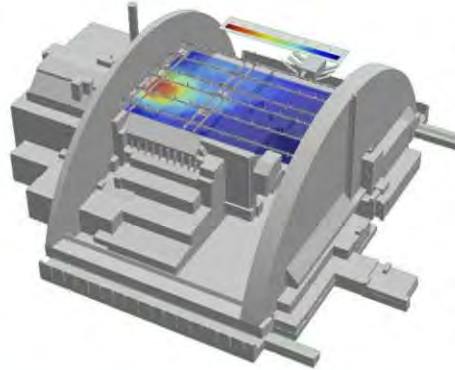


## Localization and characterization of radiation threats in the Shelter Object – NSC system



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## Gamma fields intensity at the NSC-SO system

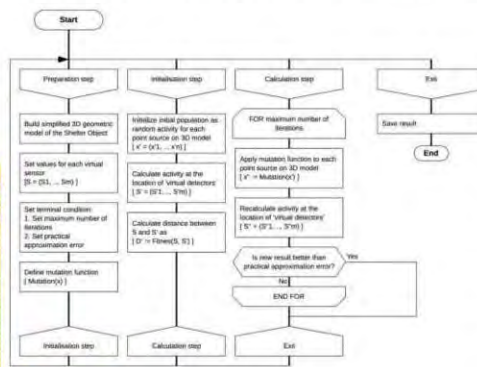
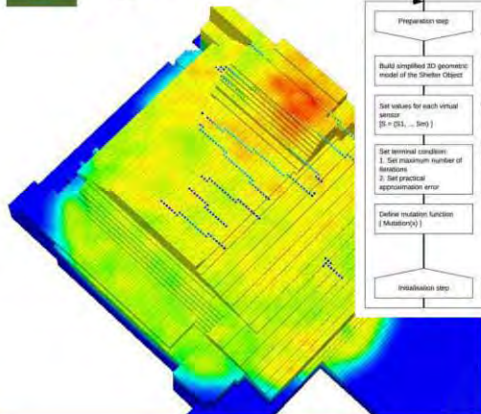


M. V. Saveliev et al.  
 Measuring the equivalent dose rate over the Shelter object after completion of the New Safe Confinement / M. V. Saveliev, V. A. Krasnov, A. P. Levchenko, A. E. Novikov, A. Y. Evstigneev, M. A. Pantin // Nuclear power and the environment № 4 (19) 2020, pp 50-56, December 2020

## Gamma fields intensity at the NSC-SO system

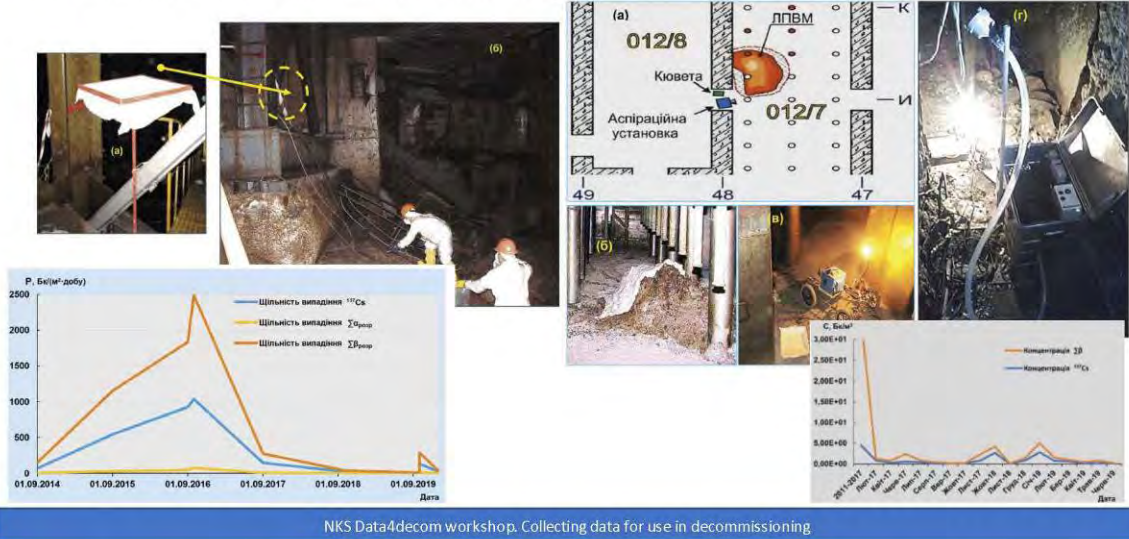


algorithms



Saveliev, M.; Pantin, M.; Skiter, I.; Scott, T.B.; Martin, P.G. Implementation of Novel Evolutionary Algorithm for 3-Dimensional Radiation Mapping and Gamma-Field Reconstruction within the Chernobyl Sarcophagus. Algorithms 2023, 16, 204. <https://doi.org/10.3390/a16040204>

## RA aerosols monitoring



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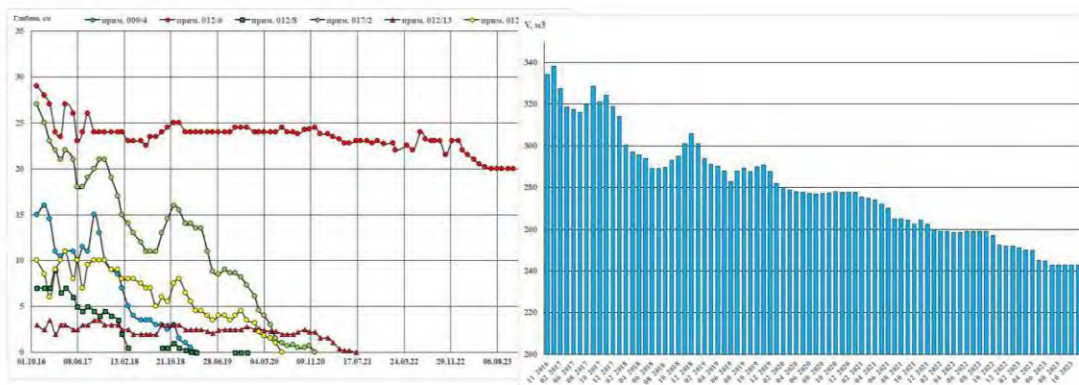
## Water inside the Shelter Object



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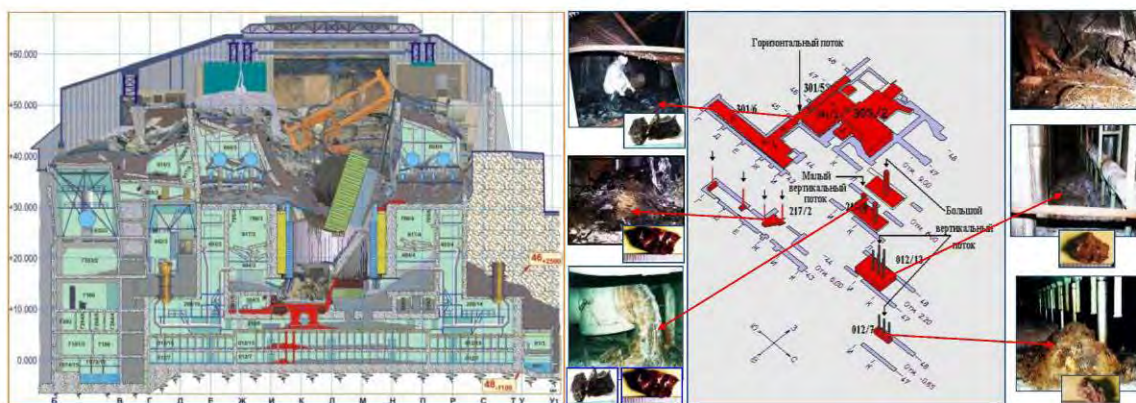
## Water inside the Shelter Object



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## Fuel Containing Materials (FCM)

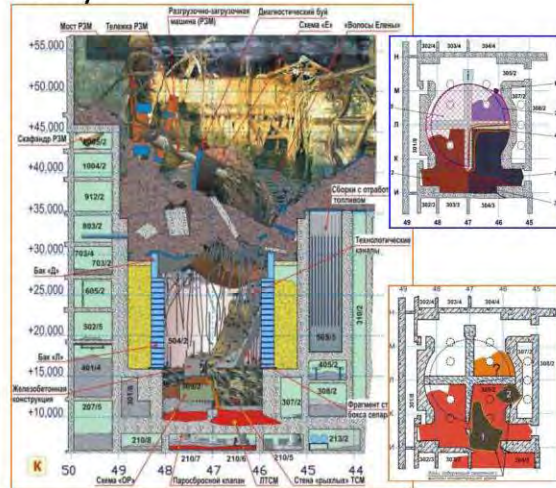
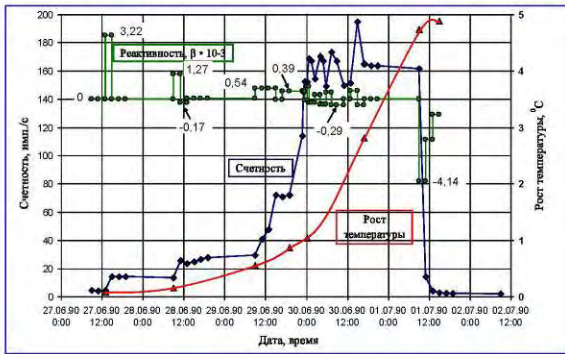


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# Corium below reactor cavity

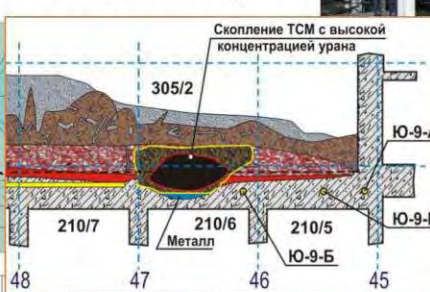
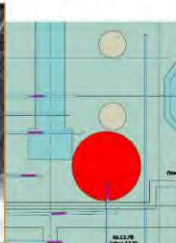
In June 1990 at premise 305/2 the neutron count rates and the temperature increased. The event came to an end after approx. 2 days.



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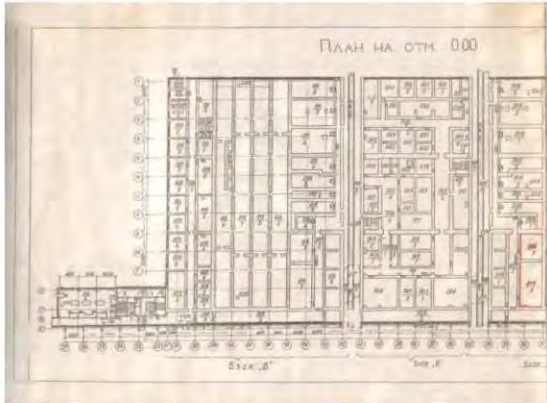
# Corium below reactor cavity



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## Digital Twining and BIM

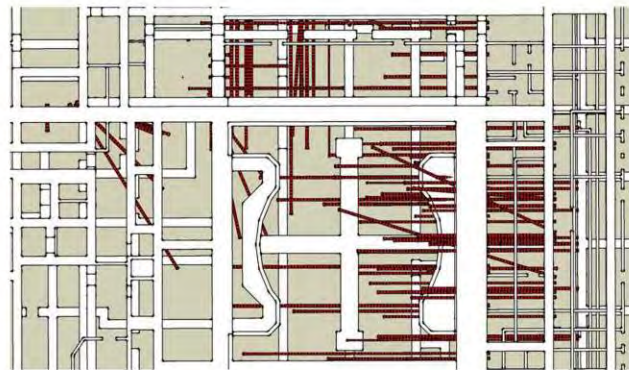
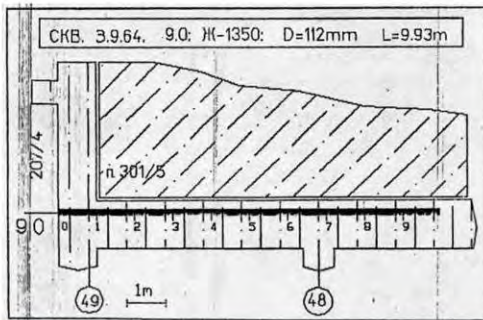


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## Building Information Modeling

### Boreholes



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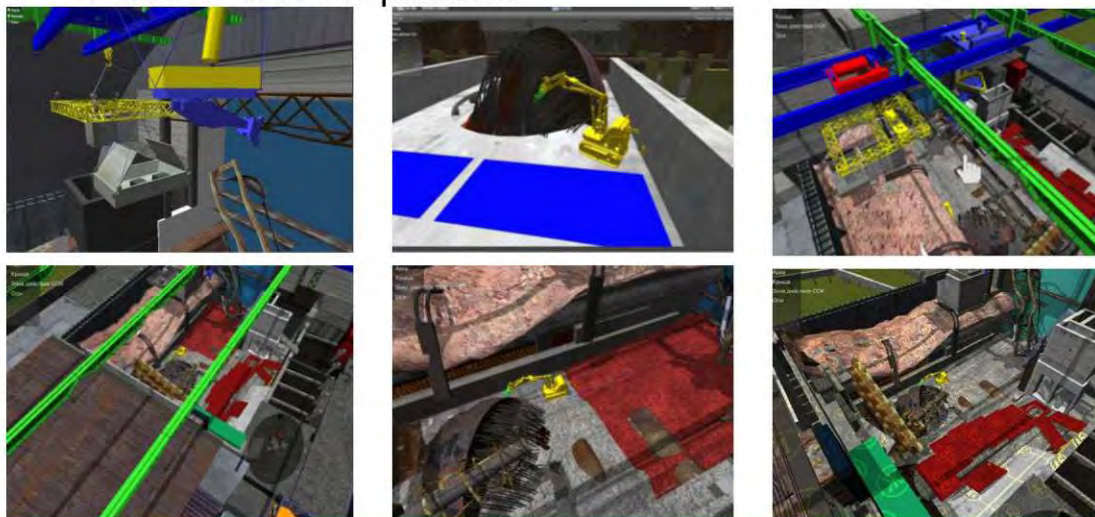
## Digital Twins for Decommissioning



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## Future development



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# Robotics



## Robotics

- Video and Radiation Surveillance
- Air Sampling
- Concrete and FCM sampling
- Mobile dust suppression systems
- Air purifier machines
- Magnet hold robot for movement on vertical steel walls
- FCM protective coating systems
- Collection and containerization of radioactive materials

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# Robotics

Figure 1 shows the general view of the quadruped robotic platform GO1 equipped with the set of CdZnTe detectors, processed by Raspberry Pi single board computer and NVIDIA Jetson Nano for processing information from the 3D camera ZED2 and plot (plotting) radiation map on the 3D model. Technically, LIDAR can be connected to improve the 3D model captured by the stereo camera.

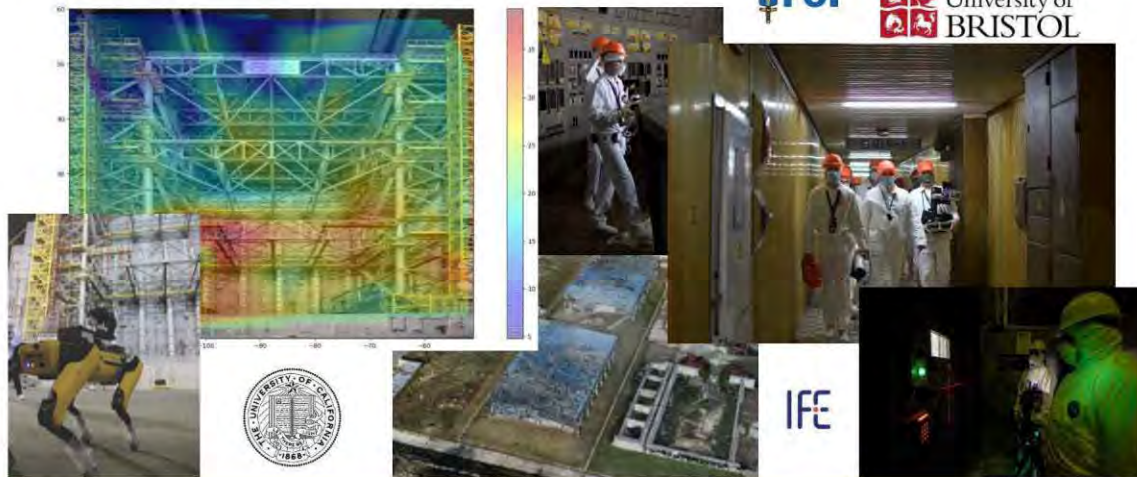
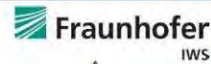


Figure 2 shows a general view of the GO1 four-legged robotic platform during operation at the Chernobyl NPP, equipped with a "BDMG-09" detection unit connected to a Raspberry Pi single-board computer for reading and storing data from the detector. The expectation is that it is possible to connect the LIDAR to the NVIDIA Jetson Nano to create 3D models and map radiation data.

NKS Data4decom workshop. Collecting data for use in decommissioning



## International collaboration



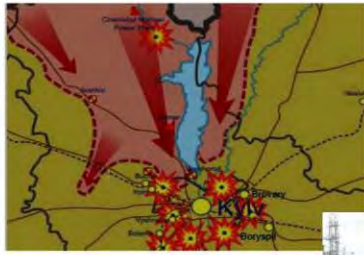
NKS Data4decom workshop. Collecting data for use in decommissioning



## References

- Many publications done in Russian and Ukrainian and some in English for ex:
  - Scientific Journal “Nuclear Power and the Environment” ISSN 2311-8253 DOI 10.31717/2311-8253
  - ПРОБЛЕМИ БЕЗПЕКИ АЕС І ЧОРНОБИЛЯ. DOI:10.31717/1813-3584 ISSN: 1813-3584
- Two comprehensive overviews in English are given in the publication on the right →
- The Shelter Object in Conditions of the New Safe Confinement / V. O. Krasnov, A. V. Nosovskyi, S. A. Paskevych, V. M. Rudko ; edited by A. V. Nosovskyi. — Chornobyl : ISP NPP, NAS of Ukraine, 2021. — 320 p. ISBN 978–966–02–9701–2
- The international projects to develop and support Short and Long Term Measures at ChNPP Unit 4 site, N. Molitor, Z. Drace, I. Stange-Wiehr

NKS Data4decom workshop. Collecting data for use in decommissioning



Thank you  
for your attention!  
Questions?

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*Integrated digital support concept for nuclear – new approach to data*  
 (István Szőke/IFE)





Institute for Energy Technology

Integrated digital support concept for nuclear – new approach to data

**Contact:**  
 István Szőke [Istvan.Szoke@ife.no](mailto:Istvan.Szoke@ife.no)



IAEA  
 International Atomic Energy Agency  
 Institute for Energy Technology (IFE)  
 IAEA Collaborating Centre



HALDEN PROJECT  
**HTO**




NUCLEAR RESEARCH CENTRE

**HADRON**

**DECOM**  
 decommissioning and repurposing

**IFE Institute for Energy Technology**

- safe operation of **nuclear** power plants
- development of **radiopharmaceuticals** for cancer treatment
- forward-thinking **energy** systems

**Digital Systems**





Renewable energy



Nuclear technology



Materials technology



Digitalization



Radiopharmacy and health



Oil and gas



Industry and environment



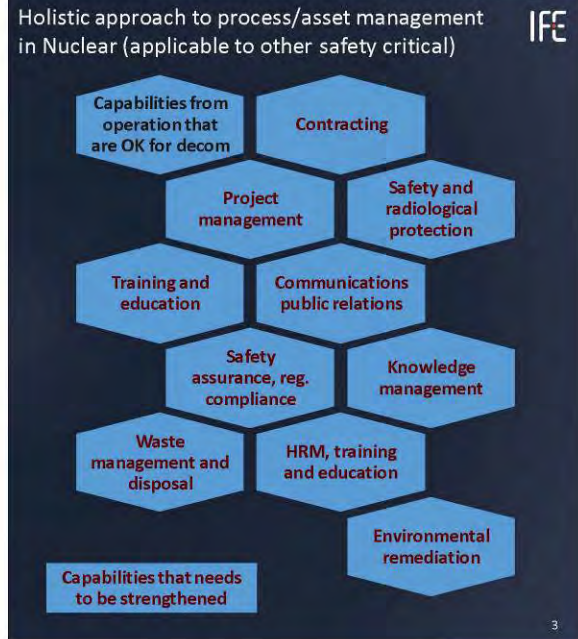
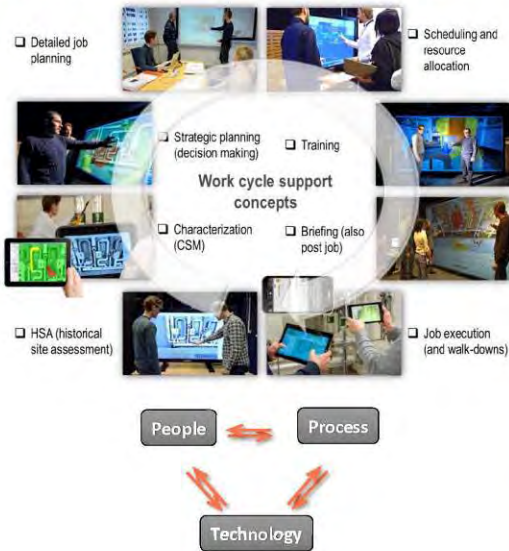
Safety and security

**HADRON DigiDECOM**

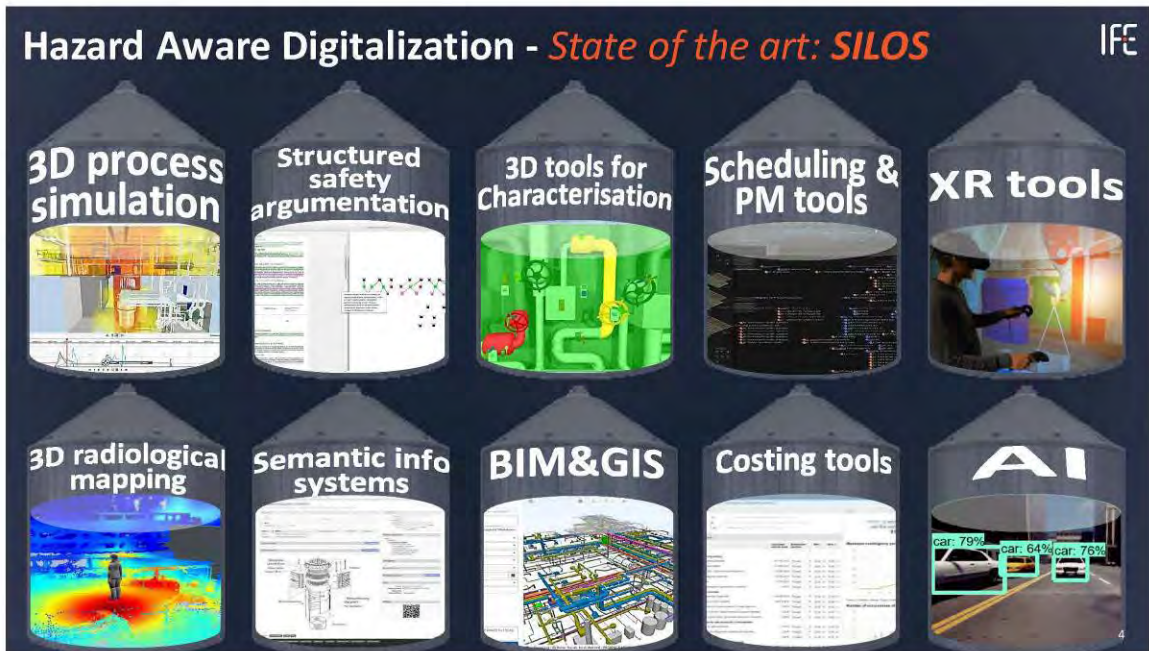
AI, data & robotics for sustainable decom & life cycle in nuclear & other industries  
 Nuclear physics & chemistry / fuels & materials competence for ensuring safety at nuclear sites

2

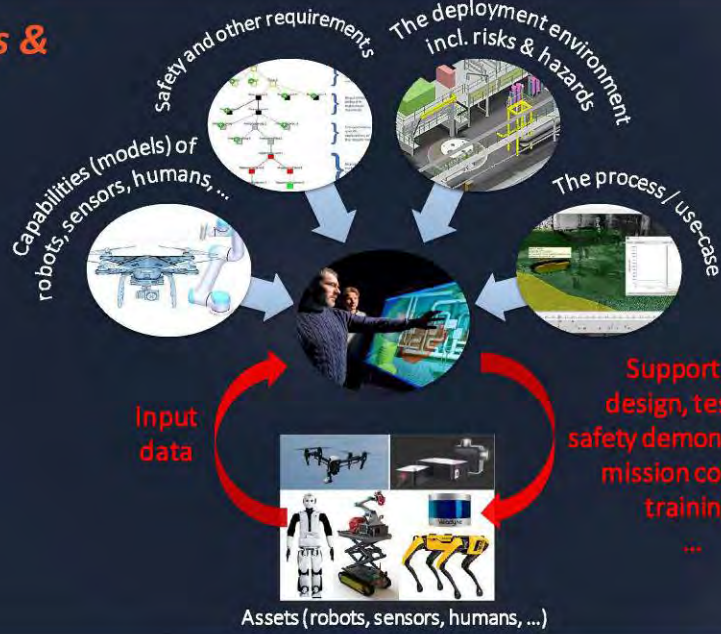
# HADRON Concept



# Hazard Aware Digitalization - State of the art: SILOS



# Digital Twins & Robots



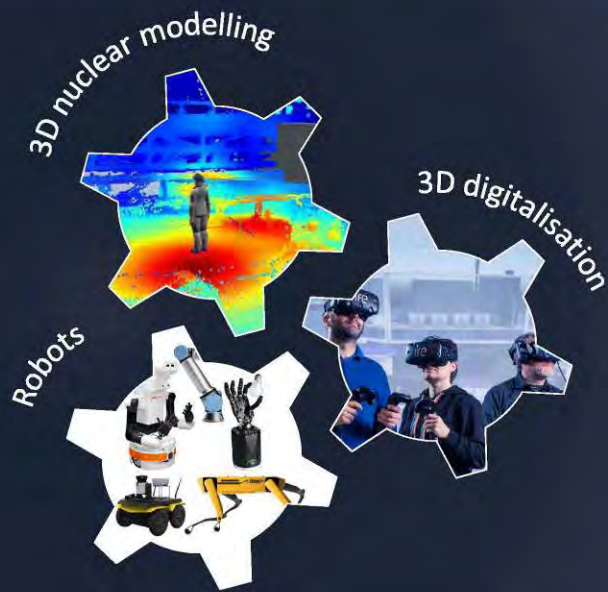
# HADRON ecosystem

	3D scanning & BIM modelling		3D hazard modelling
	3D hazard mapping		(AI) robot health / hardening modelling / monitoring
	Mission planning, robot behaviour specification		(Comp. vision) Recognition of hazards & risks
	Campaign planning / Process optimization		Training & briefing (for procedures with robots)
	Info management (BIM)		Safety assurance & demonstration
	Recognition of the environment and positioning		Mission control (and supervision)

# HADRON

Supported by **Digi**DECOM  
Halden VR Centre

...  
**H**azard  
**A**ware  
**D**igitalisation &  
**RO**botics in  
**N**uclear & other  
domains



IFE

# HADRON Technology

Supported by **Digi**DECOM  
Halden VR Centre

Robots with  
sensors

Physics and AI powered Digital Twin

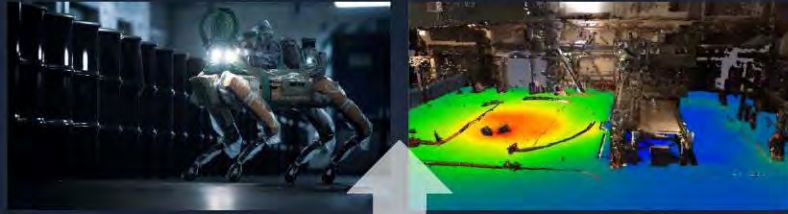


**Safe, efficient (optimized), sustainable process**

- + improved
- **Education** for the new generation
- **Public info / trust**
- **Knowledge** preservation

8

Mobile robot based scanning / survey



Digital Twin based integrated support system



IAEA  
International Atomic Energy Agency

Institute for Energy Technology (IFE)

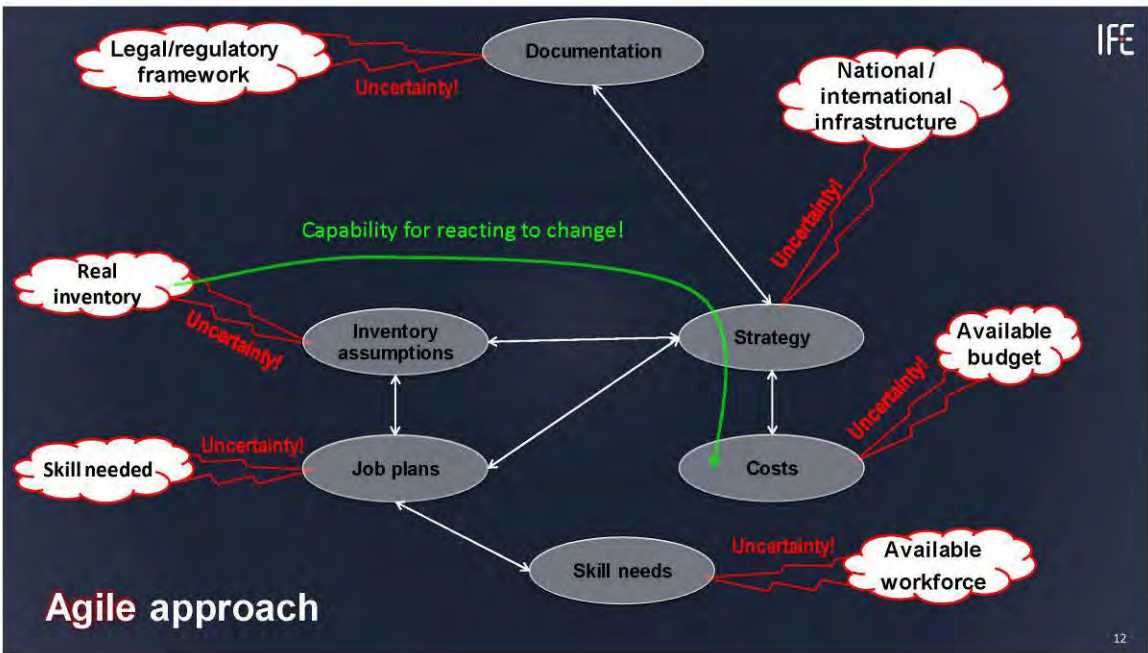
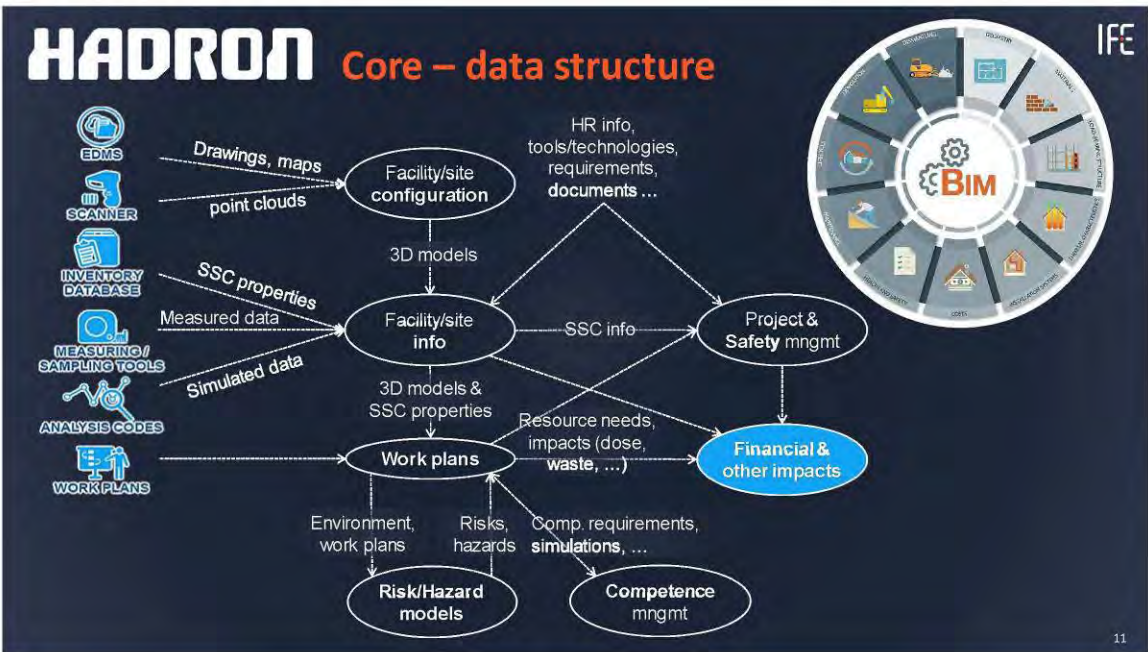
IAEA Collaborating Centre

since 2018

The first in  
nuclear decom

- Applied research, and
- International knowledge exchange to promote a *Holistic approach to digitalisation & robotics for Sustainable Nuclear Decommissioning*





# PLEIADES: Platform based on Emerging and Interoperable Applications IFE for enhanced Decommissioning process ES

**PLEIADES**  
Smarter Plant Decommissioning

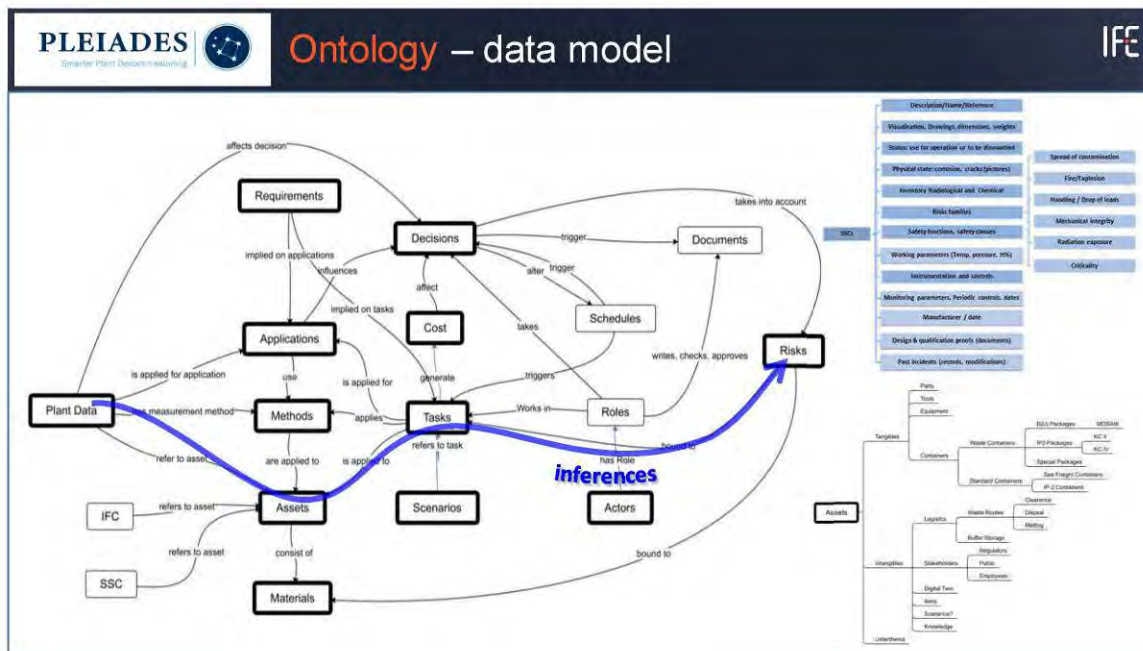


Demonstrate a modular software ecosystem based on interconnection of front-line support tools through a decommissioning specific ontology building upon open BIM (IFC).



This project has received funding from the EURATOM Research & Training Programme 2014-2018 under the Grant Agreement n° 899990. The content of this document reflects only the author's view. The European Commission is not responsible for any use that may be made of the information it contains.

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### Data types

- 3D BIM models
- 3D CAD models
- chemical inventory data
- costing data (cost estimations, actual project costs)
- data related to project progress
- data related to waste acceptance criteria (WAC)
- data related to waste management (input material, output material, quantities)
- data required for planning geometrical/3D data
- historical site assessment data
- neutron flux
- physical inventory data
- point clouds
- radiological inventory data
- risk and uncertainty related data
- task scheduling data
- ...

### Requirements - User to PLEIADES

### Requirements - PLEIADES to the user

### Expectations and KPIs

### Expectations

### Needs

#### 3D/BIM based inventory management with focus on risks (e.g. radiological)

- **Connect** radiological and other inventory info to SSCs
- **Aggregate** data from multiple sources
- **Update** inventory (new data, change to facility/site)
- **Export** for providing data to third parties
- **Inform communication** between all stakeholders

#### Scenario simulation for analysis/optimisation of work plans

- **ALARA** evaluation of work plans
- Planning of **protection**
- Testing & comparison of **alternatives** in terms safety, cost, ...
- **Sensitivity** analysis
- **Benchmarking** across a spectrum of similar parameter specs

	Relational	Document-oriented	Graph
<b>Advantages</b>	<ul style="list-style-type: none"> <li>Standardized language.</li> <li>Reliability.</li> </ul>	<ul style="list-style-type: none"> <li>Large amount of data structures.</li> <li>Flexible structure.</li> </ul>	<ul style="list-style-type: none"> <li>Fast relationship-based search.</li> <li>Semantic queries.</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>Rigid structure.</li> <li>Not intended to store large files.</li> </ul>	<ul style="list-style-type: none"> <li>Slow search.</li> <li>Data consistency not guaranteed.</li> </ul>	<ul style="list-style-type: none"> <li>High connectivity is required.</li> <li>Simple analytics.</li> </ul>
<b>Examples</b>	MySQL, IBM Db2, SAP HANA, MariaDB...	MongoDB, DynamoDB, MarkLogic, CouchDB...	Neo4j, ArangoDB, DGraph, OrientDB...

Structured data

Distributed File System	Object Storage
Files in Hierarchical Directories	Objects in Flat Buckets
POSIX File Operations	REST API
Random writes anywhere in file	Atomically replace full objects

Type of Storage	Possible product
Local File Storage	Filesystem (NTFS, FAT, EXT4, XFS)
Distributed File System	Hadoop Distributed File system (HDFS, JuiceFS)
Object Storage	Minio.io, Amazon AWS, Azure Blob Storage

Unstructured data

#### Safety and risk management

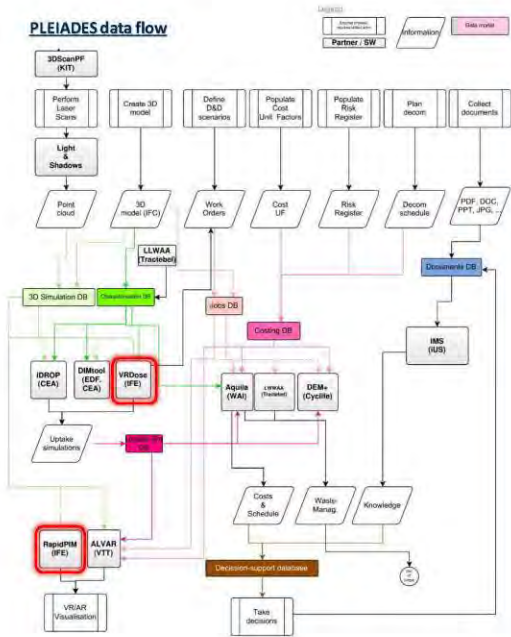
- Safety **demonstration**
- Support for **safety inspections**
- **Uncertainty** management

#### Waste route planning

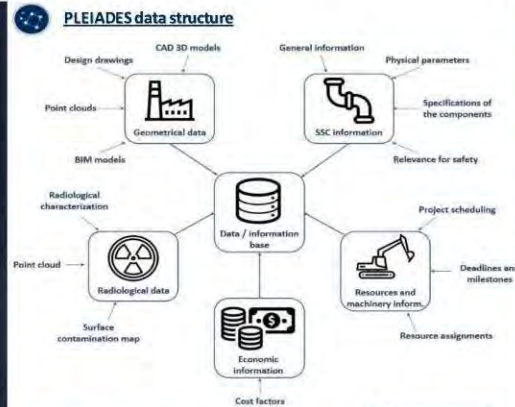
#### Monitoring

- **Costs** in comparison with plans
- **Tracing** waste items from initial to final location
- **Quality** control

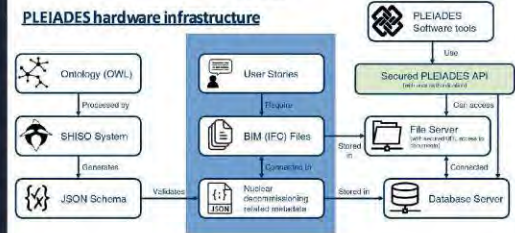
### PLEIADES data flow

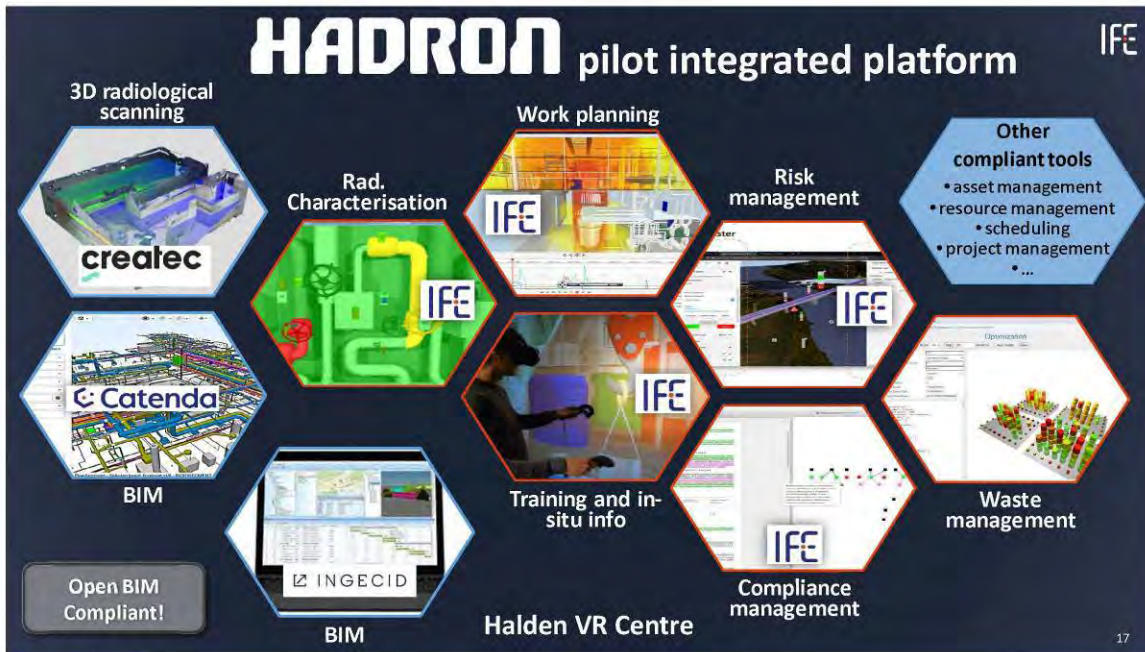


### PLEIADES data structure

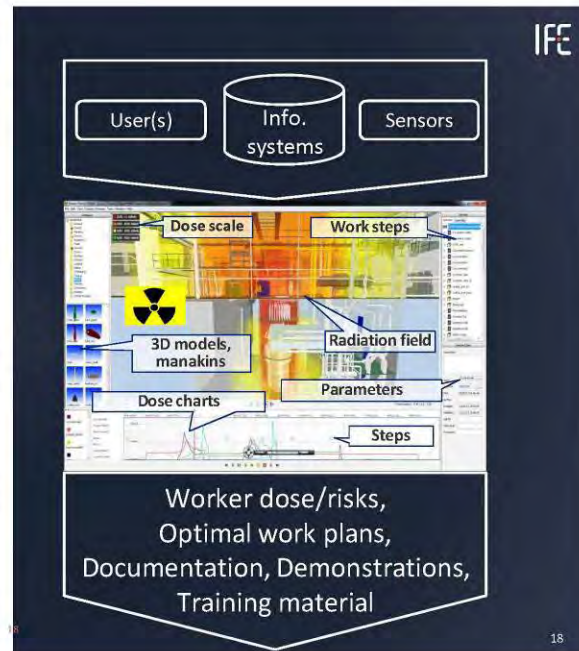
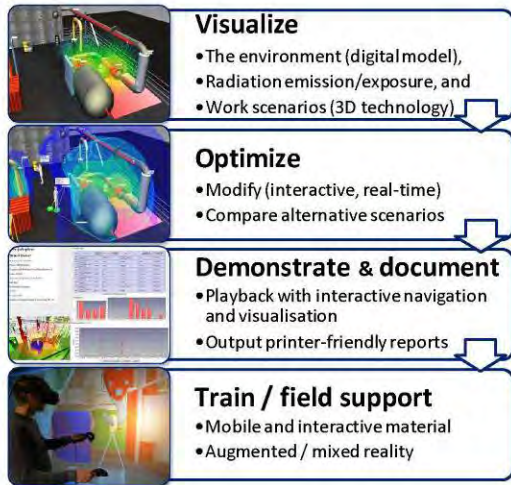


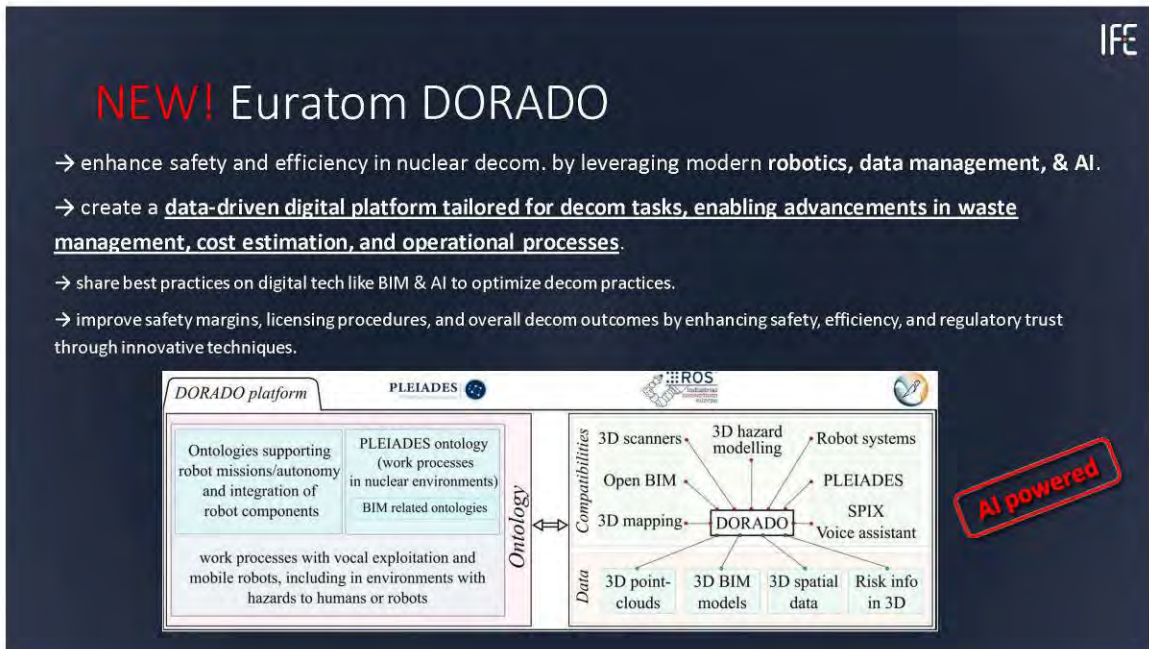
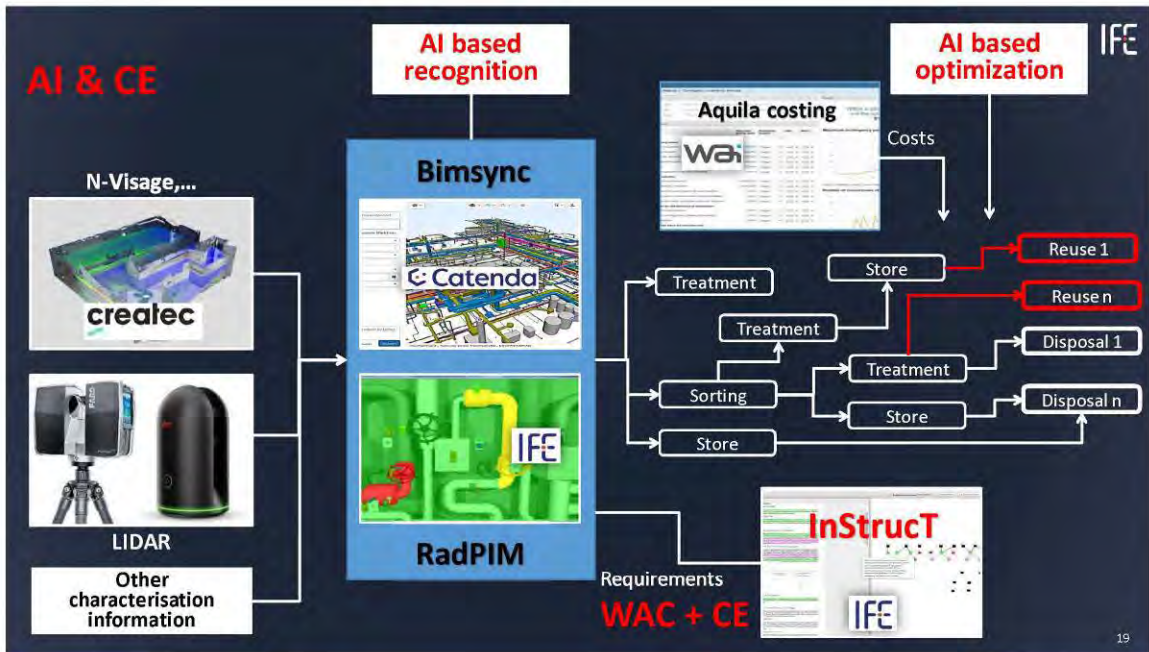
### PLEIADES hardware infrastructure





## IFE VRdose™ family

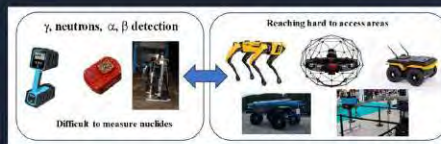
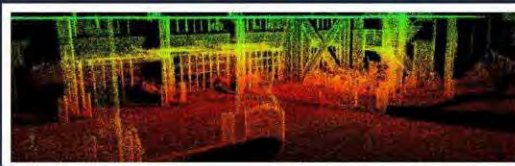




# NEW! Euratom XS-ABILITY

Revolutionize D&D operations by utilizing **modular robotic platforms** with a variety of **sensors** to **minimize human intervention in harsh environments**.

- enhance data security, reduce time & costs, and ensure high-quality results in compliance with regulation
- reduce operator dose 5 times, provide real-time rad. monitoring, half cleaning time, decrease investigation time 10-fold, streamline procedures, lower costs 30%, and enable automatic analysis of large contaminated areas



## Norwegian Nuclear Research Centre

**Academia**

**Research & Application Sector**



**RT3: Nuclear simulations** →  
Use of physics and AI powered Digital Twins!



# Integration of rad. physics & AI models

IFE

**Real-time (Point Kernel) radiation transport**

*Point Kernel Method (PKM) for radiation transport*

$$Dose = Constant \times \sum_{i,j} \left( \frac{A_{ij}}{4\pi r_{ij}^2} \times e^{-\mu_{eff}(r_{ij})} \times R_{ij}(E_{source}, r_{ij}) \times R_{ij}(E_{det}, t) \right)$$

*Integration of Monte Carlo (MC) and Point Kernel (PKM) methods*

**Source deconvolution**

**MC radiation transport (MCNP, GEANT4)**

**NEW!**

**AI techniques**

**Interpolation, Geostatistics**

$$\mathcal{Z}^*(\mathbf{u}) = m(\mathbf{u}) + \sum_{i=1}^n \lambda_i(\mathbf{u}) [\mathcal{Z}(\mathbf{u}_i) - m(\mathbf{u})]$$

$$= \sum_{i=1}^n \lambda_i(\mathbf{u}) \mathcal{Z}(\mathbf{u}_i) + \left[ 1 - \sum_{i=1}^n \lambda_i(\mathbf{u}) \right] m(\mathbf{u})$$

**Atmospheric dispersion**

$$C(x,y,z) = \frac{Q(x)}{2\pi \cdot \sigma_y(x) \cdot \sigma_z(x)} \cdot \exp\left[-\frac{y^2}{2\sigma_y(x)^2}\right] \cdot F(x,z)$$

$$C(x,y,z) = \frac{Q(x)}{\sqrt{2\pi} \cdot \sigma_y(x) \cdot A \cdot u_{eff}} \cdot \exp\left[-\frac{z^2}{2\sigma_z(x)^2}\right]$$

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Supported by **DigiDECOM**

# HADRON widely applicable

IFE

Responsible **decom** and management of wastes from our nuclear heritage

Maintenance & decom of industrial sites (Nuclear, Oil & Gas, ...)

Medical applications of nuclear technology

Commissioning and sustainable green lifecycle management of **SMRs** and other **new reactors** types

**HADRON**

Various other applications e.g. space, chemical labs & factories, mines, ...

Incident response at nuclear & other potentially hazardous sites

24

**IFE**  
NND  
GRIMSRUD  
SKOLT  
Innovation  
HALDEN KOMMUNE  
vipo  
SAFECLEAN  
NORSK KERNKRAFT  
HALDEN

# DECOM Cluster

decommissioning and repurposing  
Supported by **DigiDECOM**

Knowledge Exchange  
Incubator  
Benchmarks  
Joint R&I  
Competence building  
Pilots

**DECOM**  
decommissioning and repurposing

Will you join ?

Cluster manager: [stian.melhus@smartinnovationnorway.com](mailto:stian.melhus@smartinnovationnorway.com)  
Head of Education: [linda.sund@smartinnovationnorway.com](mailto:linda.sund@smartinnovationnorway.com)  
Head of Research: [Istvan.Szoke@ife.no](mailto:Istvan.Szoke@ife.no)

25



# NORWEGIAN NUCLEAR

ASSOCIATION

**NEW!**

Will you join ?

26

# Nordic nuclear collaboration



Discussing with: LUT, Danish Decom, Equinor, Vattenfall, Forsmarks K. AB, Ringhals AB, NORSAR, UIS, GE Healthcare, Thor Medical, Ringerikskraft, Tinfos, Fortum, Uniper (OKG), Swedish Atomic Forum, Petroleum Safety Authority Norway, DSA (observer), SSM(observer), STUK, SIS, ...

# XR powered simulation centre



# DigiDECOM

Since 2017

AI, data & robotics in the nuclear  
and other safety-critical environments



IFE

- A community of practice
- A conference
- A competence building platform
- A research-based business catalyser

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# DigiDECOM

AI, data & robotics for hazardous environments



IFE

**DigiDECOM 2024**  
Halden, Norway  
Nov. 12-15

**Will you join ?**



30

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Title	Data4decom
Author(s)	Niels-Kristian Mark <sup>3</sup> , Jere Luukkanen <sup>1</sup> , Wilma Falk <sup>2</sup> , Micaela Hamberg <sup>2</sup> , Link Hauge Lindskog <sup>3</sup>
Affiliation(s)	<sup>3</sup> IFE, <sup>1</sup> Fortum, <sup>2</sup> AFRY
ISBN	978-87-7893-586-1
Date	December 2024
Project	NKS-R / Data4decom AFT/NKS-R (23)137/4
No. of pages	167
No. of tables	1
No. of illustrations	225
No. of references	12
Abstract max. 2000 characters	<p>Safely decommissioning a nuclear site is a complex, long-term technological and organizational challenge due to its intricate nature, the necessity for knowledge transfer to future generations, and the presence of contamination.</p> <p>When planning, training, and executing the dismantling process, having information about the actual design and the current state of the plant is paramount for performing the work safely, efficiently, and at acceptable economic costs.</p> <p>Safe work hinges on thorough planning, which should be based on detailed data about the materials, environment, proper procedures, and the plant's history. This holds true for both operating, maintaining and decommissioning a nuclear site.</p> <p>Due to safety concerns, the nuclear industry tends to be conservative, favouring the continued use of well-known procedures and technology, even when it would be apparent in comparable industries to adopt a more modern approach.</p> <p>Exploring and implementing new methods can be time-consuming and costly. However, obtaining accurate data through effective methods and proper organization is crucial.</p> <p>In planning a work scenario, access to input data that describes the environment is needed. This includes not only</p>

radiological data but also information about the physical environment.

The project invited stakeholders in the Nordic nuclear professional environment to share their experiences and best practices from data collection in their decommissioning processes. This included the advantages and disadvantages of their chosen approaches, as well as the time and costs involved in obtaining and preparing the data for use in decommissioning.

Additionally, the project organized an online workshop on 9th April 2024 and conducted a literature review to find publications about the same issues. The collected material has been published in the current NKS report.

In conclusion, the choice of the right tool, method, and organization is essential for success in all aspects of safely decommissioning a nuclear site.

**Key words**                      Safe nuclear decommissioning, planning, data gathering, stakeholder experiences, best practices.