



# Application of innovative, **digitalisation** and **robotics** based, solutions for **decommissioning** and life-cycle management of nuclear facilities

Institute for Energy Technology, Halden, Norway

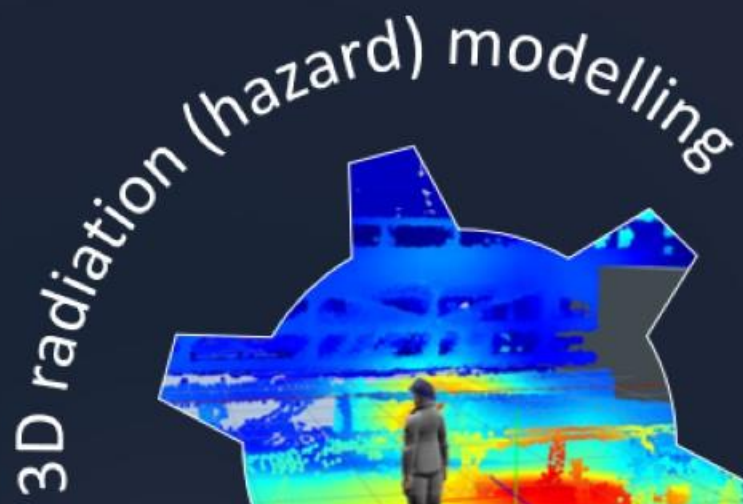
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# The market need

- Technologies like IoT, sensor technology and unmanned vehicles (UVs) etc. are overcoming the primary obstacle (acquisition of required input data) for enabling integrated digital systems supporting operations in environments with industrial hazards.
- Robots are becoming feasible alternatives to humans for working in environments with industrial hazards.

However, integrated hazard awareness ('intelligence') (preferably real-time) is required for complementing such systems, e.g. for feasibility and safety demonstration, training, mission control, radiation protection, safety monitoring and other purposes.

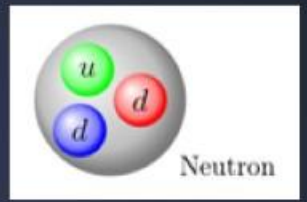
# Hazard Aware Digitalisation and RObotics in Nuclear and other domains



Robotics



Nuclear



# Core background



## Risk assessment

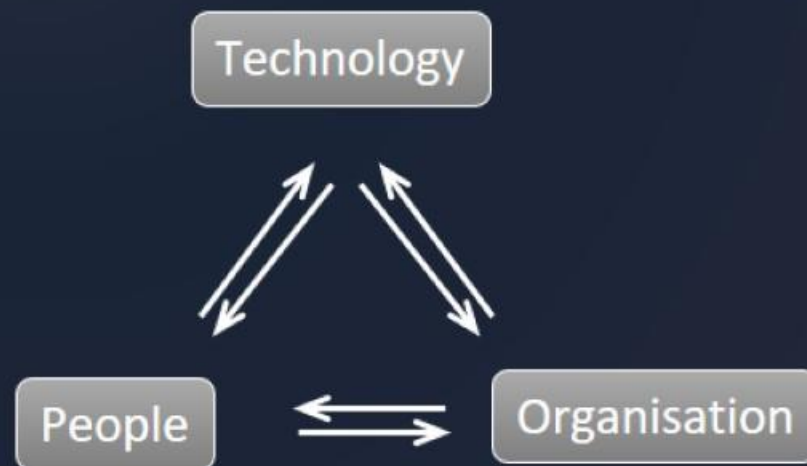
- Real time radiation transport
- Geostatistics
- Monte Carlo radiation transport
- Source deconvolution
- 3D gamma mapping
- Aerosol inhalation
- Internal and external radiation exposure of workers

## Non tech

- Workforce management – training
- Knowledge management
- Human and organisational factors

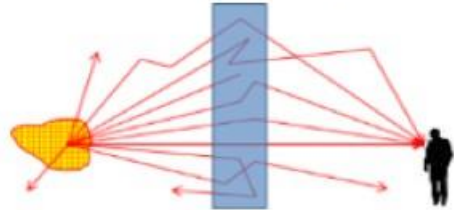


- 3D modelling
- Virtual and Augmented reality
- Advanced user interfaces
- Mobile and wearable devices
- Machine Learning (AI)



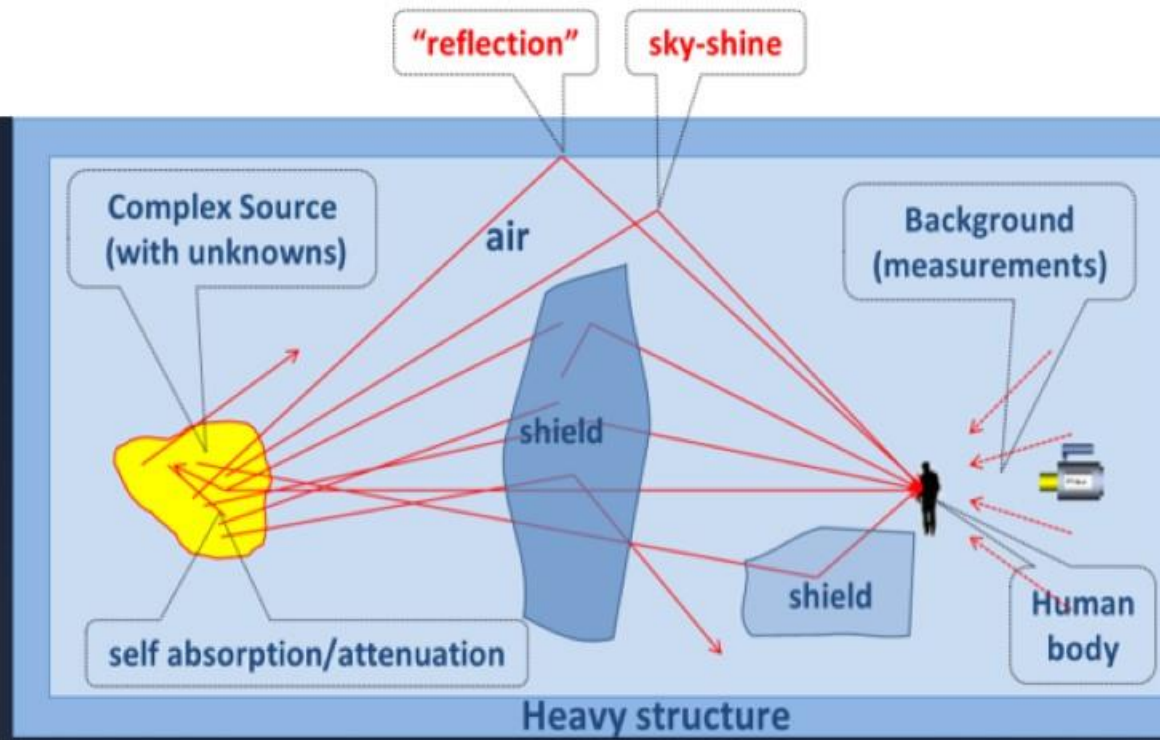
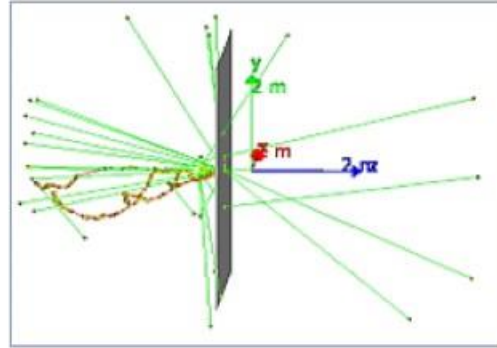
# Radiological hazard modelling

## Real-time (Point Kernel) radiation transport

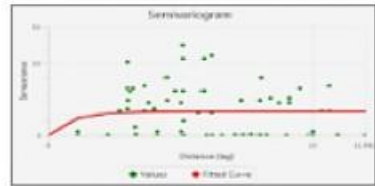


$$Dose = Const \times \sum \left( \underbrace{\frac{Ay_i}{4\pi d^2}}_{\text{conversion of units}} \times \underbrace{e^{-\mu_{en} \times t}}_{\Phi_i(natl)} \times \underbrace{E_i \cdot (\mu_{en}/\rho)_i}_{\Phi_i(att)} \times \underbrace{B_x(E_i, t)}_{\Psi_i(att)} \right) \cdot CF$$

## MC radiation transport (MCNP, GEANT4)



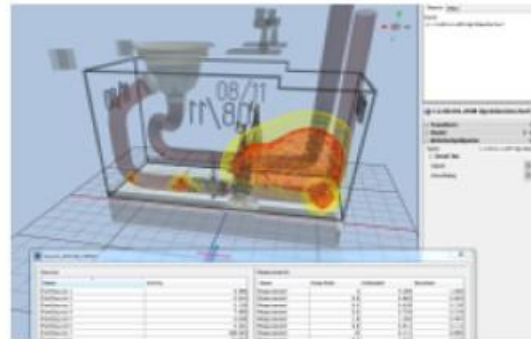
## Interpolation, Geostatistics



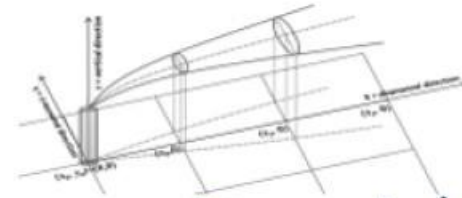
$$Z^*(\mathbf{u}) = m(\mathbf{u}) + \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_{\alpha}(\mathbf{u}) [Z(\mathbf{u}_{\alpha}) - m(\mathbf{u})]$$

$$= \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_{\alpha}(\mathbf{u}) Z(\mathbf{u}_{\alpha}) + \left[ 1 - \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_{\alpha}(\mathbf{u}) \right] m(\mathbf{u})$$

## Source deconvolution



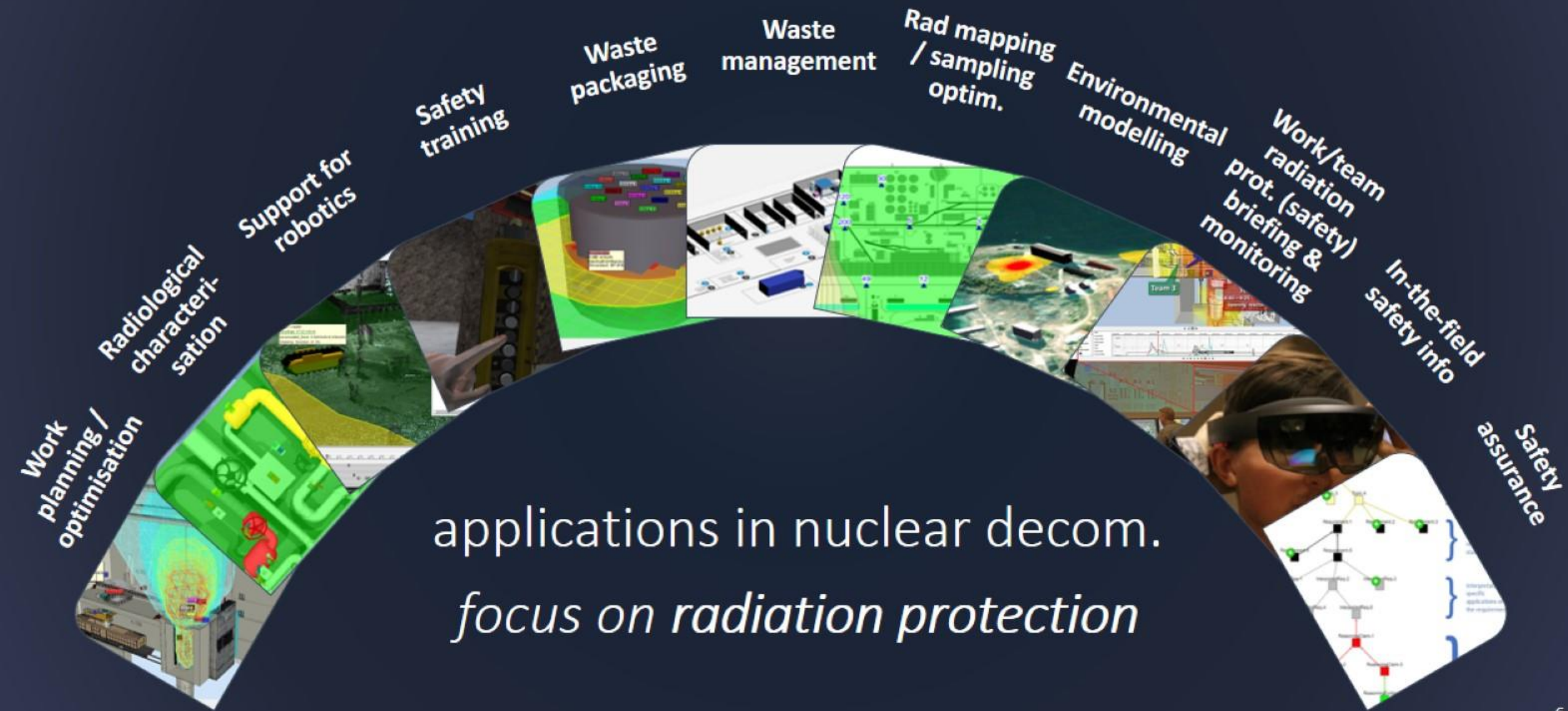
## Atmospheric dispersion



$$C(x, y, z) = \frac{Q(x)}{2\pi \cdot \sigma_y(x) \cdot \sigma_z(x) \cdot u_{10}} \exp\left[-\frac{y^2}{2\sigma_y(x)^2}\right] F(x, z)$$

$$C(x, y, z) = \frac{Q(x)}{\sqrt{2\pi} \cdot \sigma_y(x) \cdot A \cdot u_{10}} \exp\left[-\frac{y^2}{2\sigma_y(x)^2}\right]$$

# Examples of Hazard Aware Digitalisation and Robotics



# Long term decom support projects by IFE abroad



Fugen NPP (JAEA)  
(1995 - )



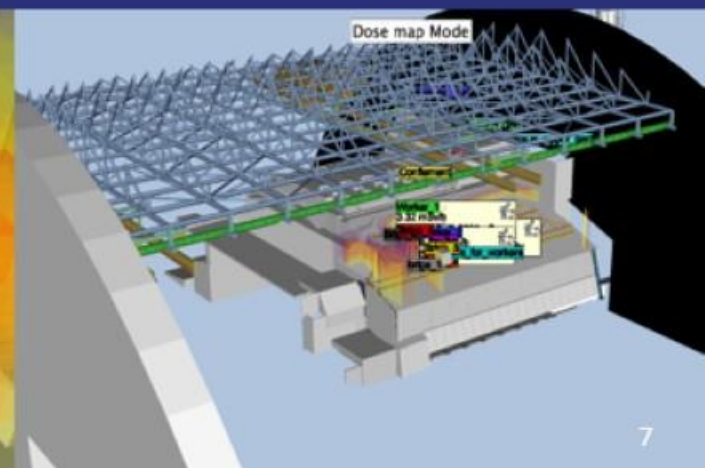
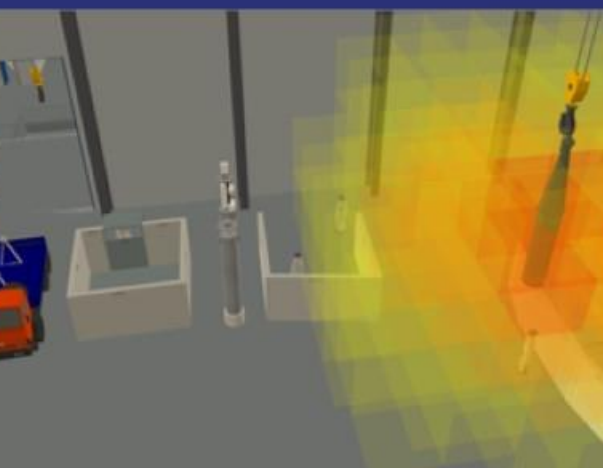
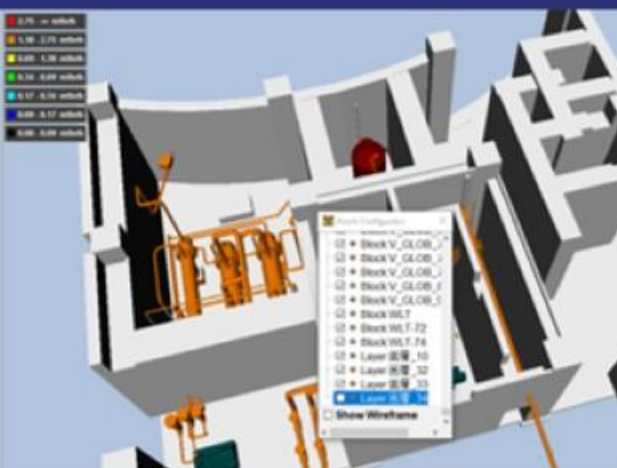
Leningrad NPP  
(1999-)



Andreeva bay, NW Russia  
(2011-)



Chernobyl NPP  
(2008 - )



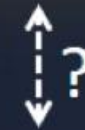
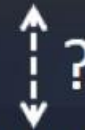
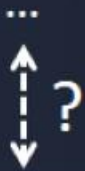
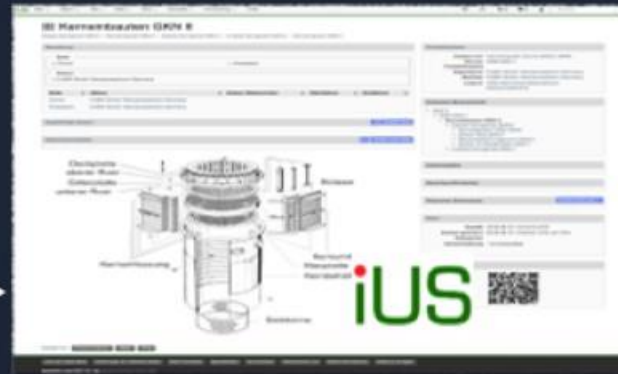
# Towards holistic support

Project planning, costing ... systems

3D scanners  
Hazard sensors  
Other analyses  
codes

Documents →

Semantic info systems

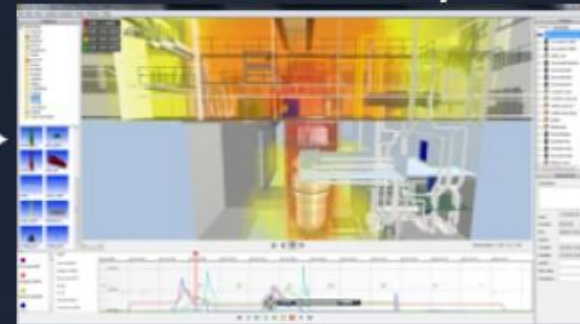


3D sim. supported work planning/training

VRdose family



**CAD model**

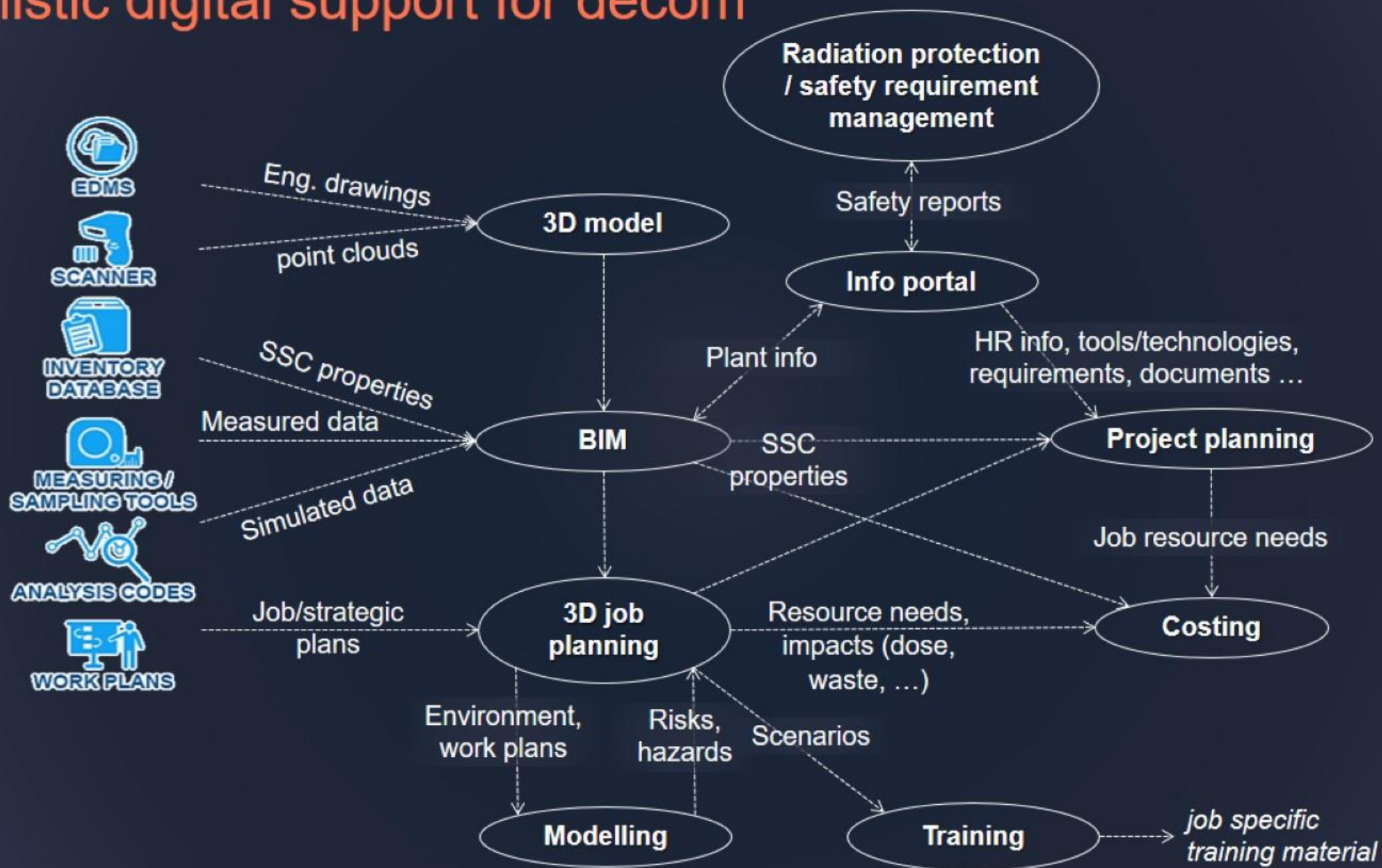


MCNP

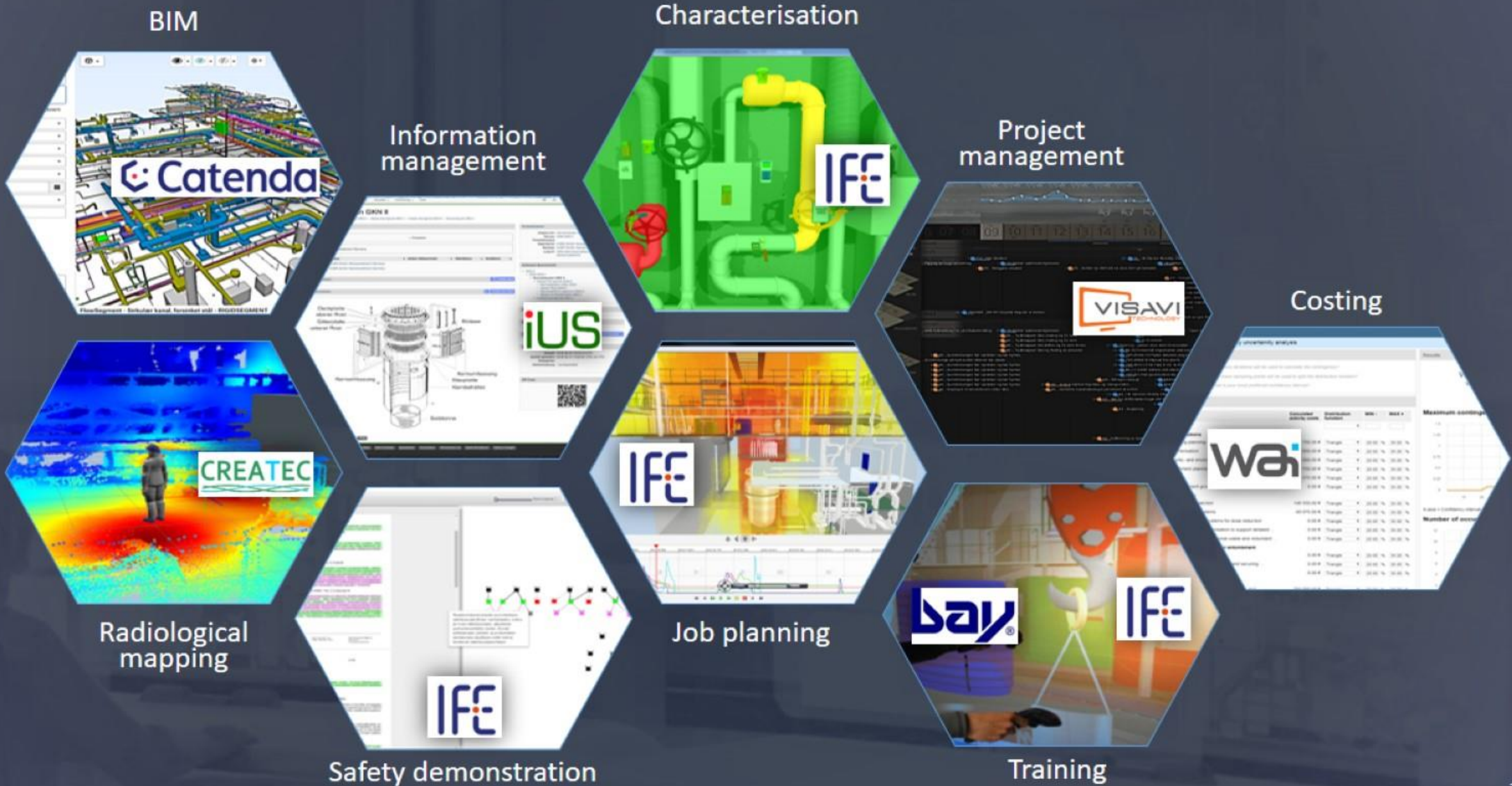
- Radiological input data
- Custom importers from historical database(s)
- Linked documents



# Holistic digital support for decom

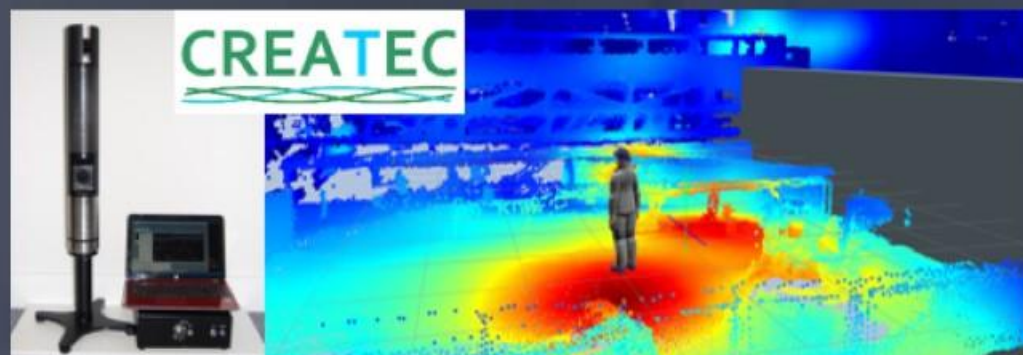


# Prototyping integration of digital capabilities for decom



# BUT how can we get the data?

- New cheap tech for 3D data



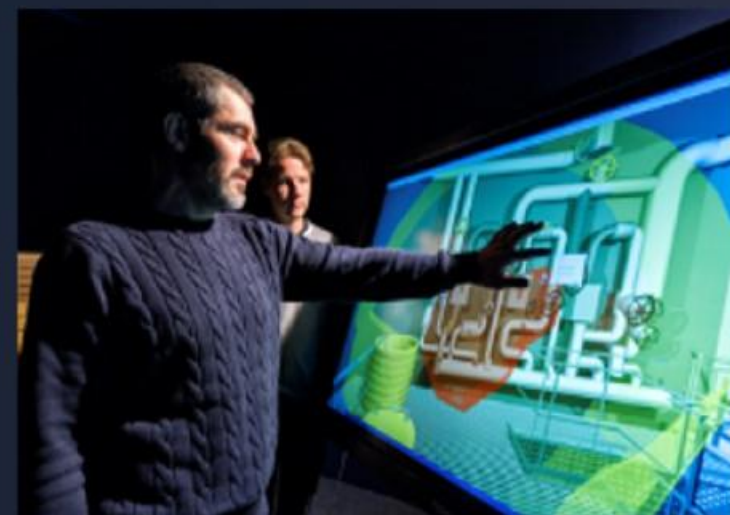
- New tech integrating 3D data acquisition into rad. characterisation champagnes

- New tech for deploying sensors/samplers – remote/robotic/autonomous systems



# Strategic research programmes (SIS)

- DecomSIS: Competence building at IFE within nuclear decom.
- HaLeDi: Acquisition of 3D data for digital support

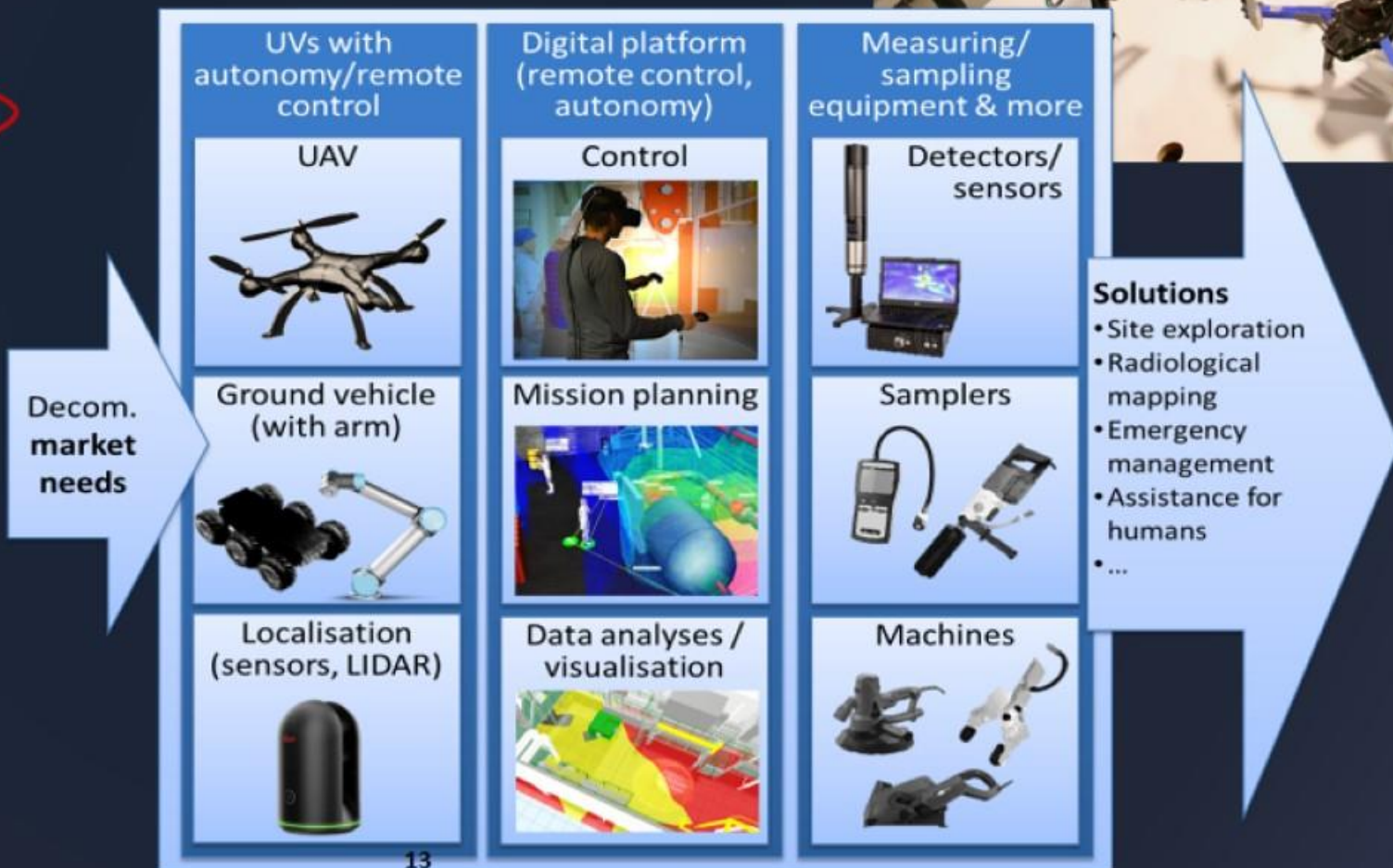


3D simulating based support platform



# RoboDecom – Robotics for decommissioning

- Integrate standard / emerging equipment in a **modular design**
- Integrate digital, sensor and robotic tech
- Enable high autonomy
- Prove safety/security
- Validate in the field and prove efficiency
- Full scope support: design, training, control, ...
- Guidance for application to specific needs



# RoboDecom prototypes

Prototype 1

Hazard sensor



UGV system



3D sim based digital platform



Sensor and Avoid  
Path planning  
Wireless com.

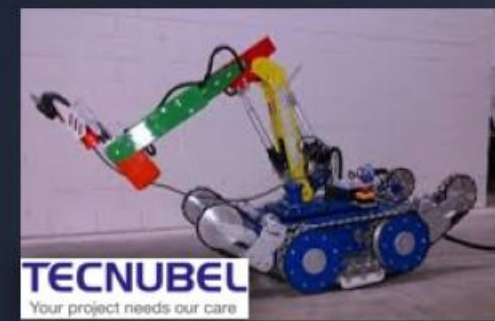


Digital support platform

UAV system



Prototype 2



Support for: design  
(especially modular  
systems), feasibility  
testing, control, training,  
demonstration, ...

Digital twin of the facility/site



Input data

Robots with sensors



Digital twins of robots





Spatial Computing and  
Augmented Reality for  
Hazard Mapping and  
Visualisation



Automated Assessment  
of Field Worker  
Performance using VR  
and AR-based Simulator  
Training



Enabling Robotic and  
Remote Operations

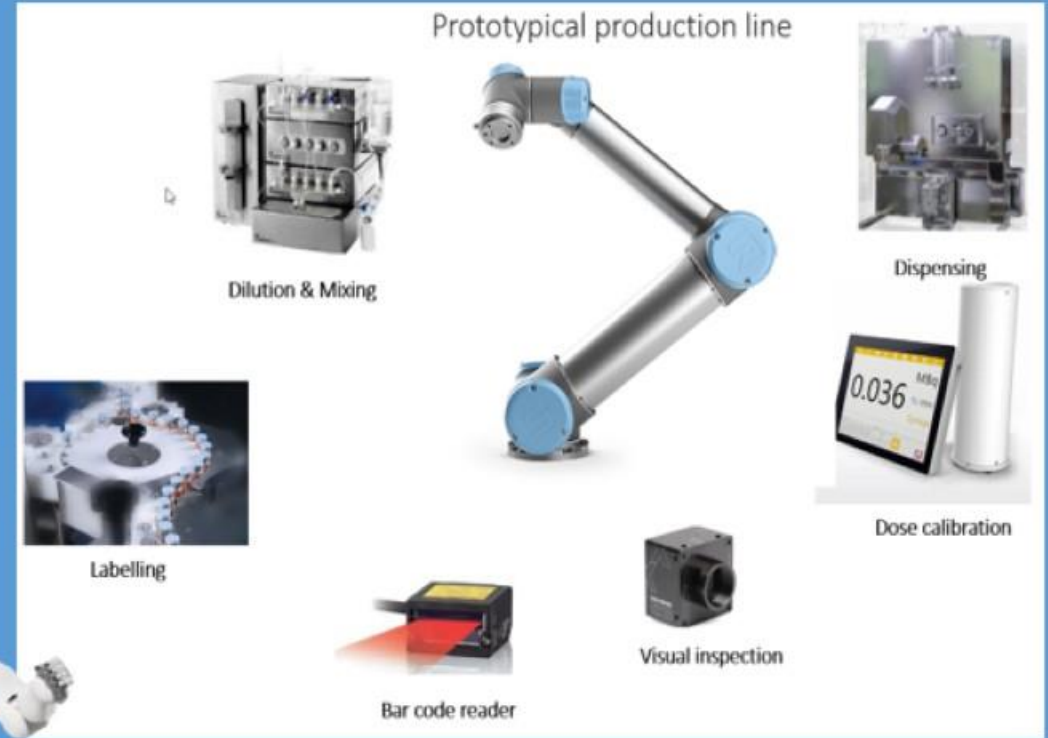


Higley collaborative international research under OECD-NEA  
umbrella between more than 100 organisations.



# The MedProt project

Sub-project:  
Automated manufacturing  
and dispensing of  
radiopharmaceuticals





# SMARTES - emergency management

To create an innovative cyber-physical system supporting first responders in complex emergency scenarios



1. Unmanned Robotics & Sensing



2. Digital twin & Hazard simulation



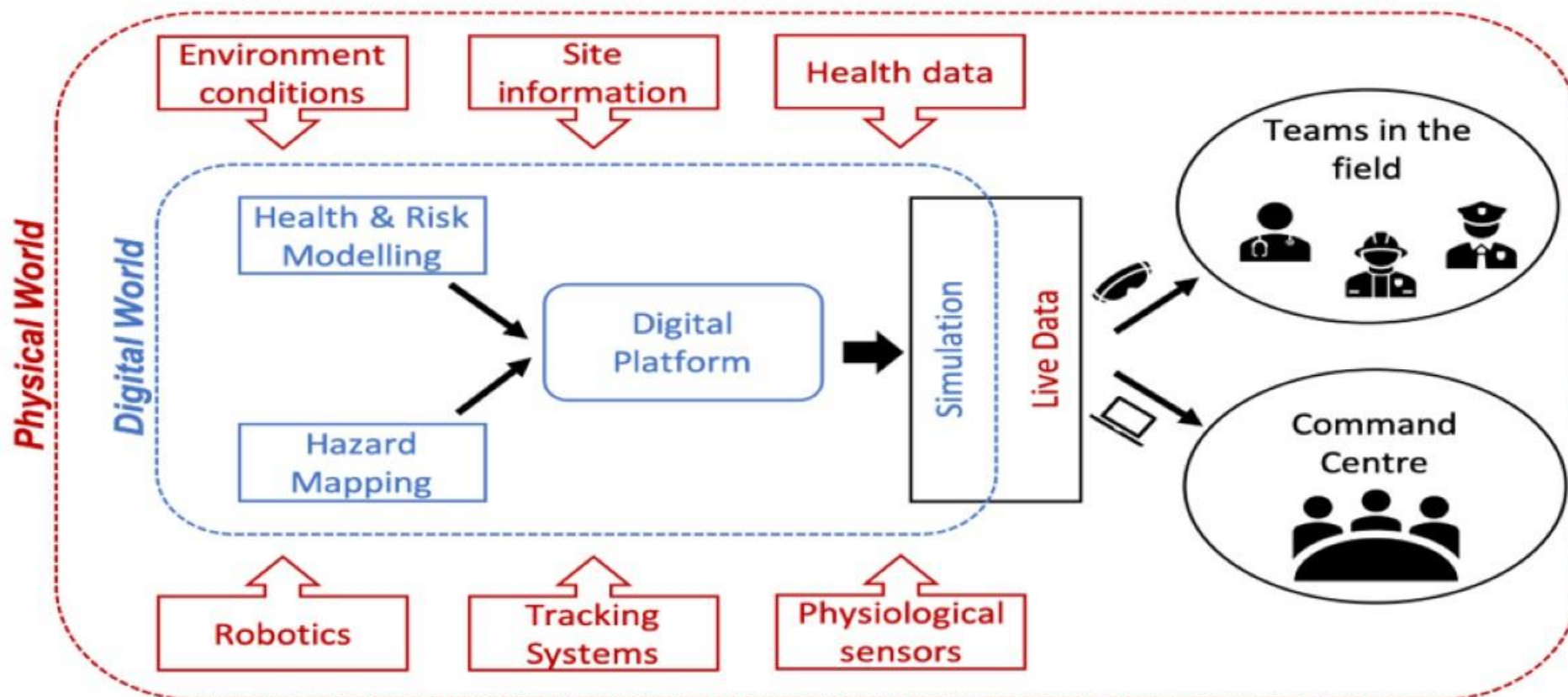
3. Acceptance



4. Decision making

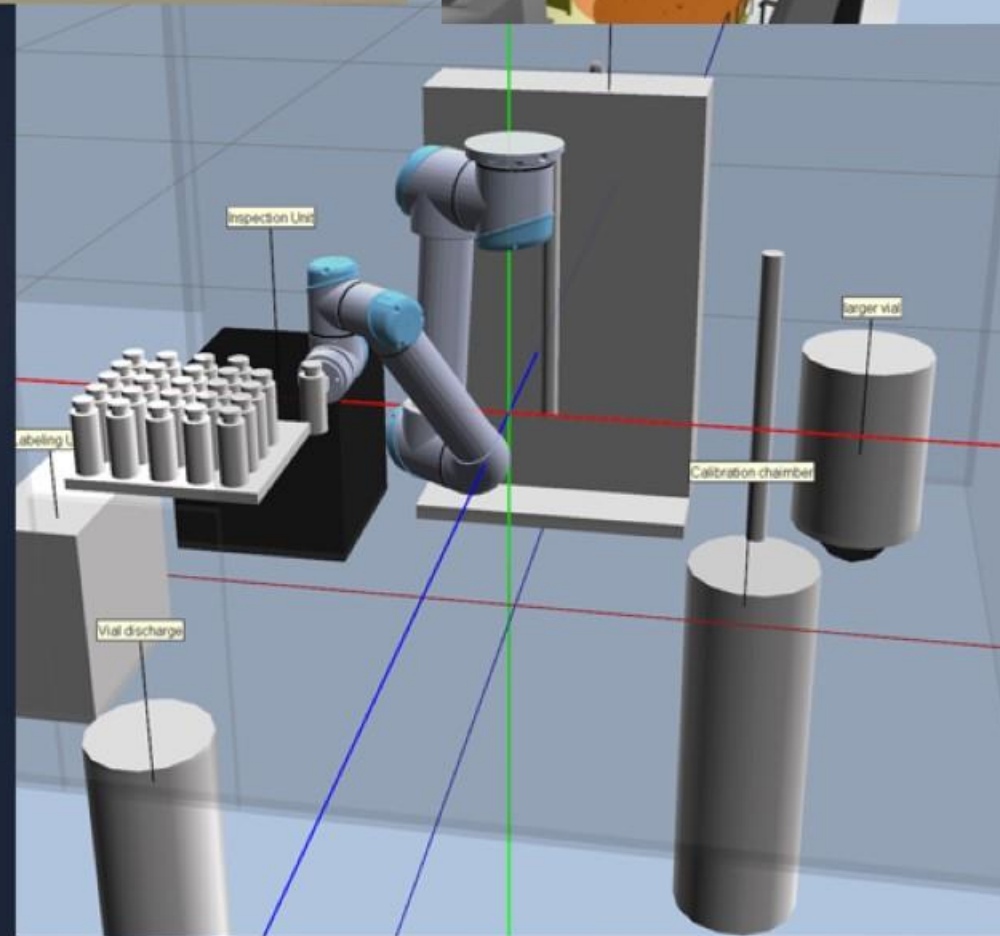
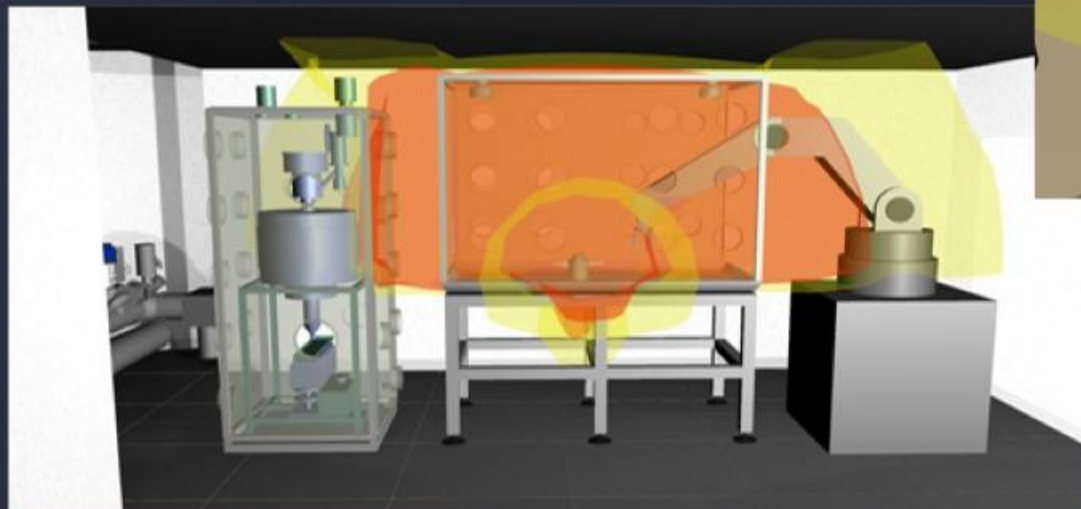


5. Training



H2020 proposal

# Digital twins for robotics



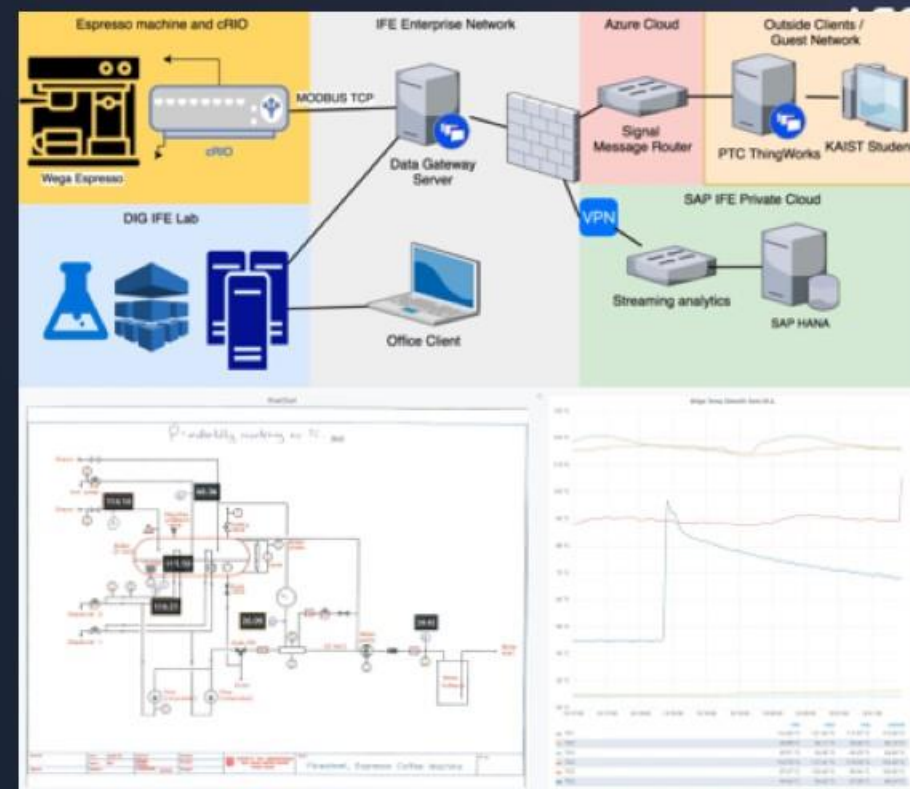
# Machine learning and AI



Rust

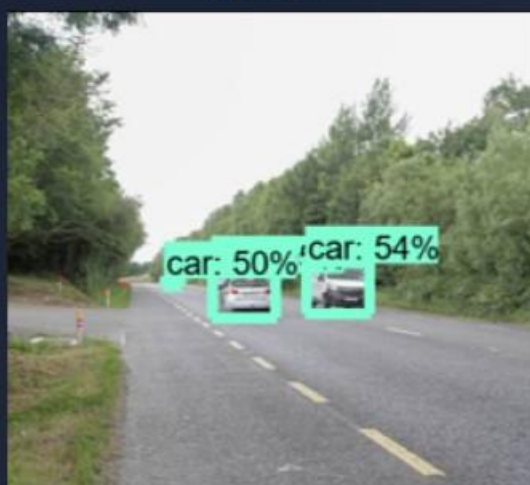
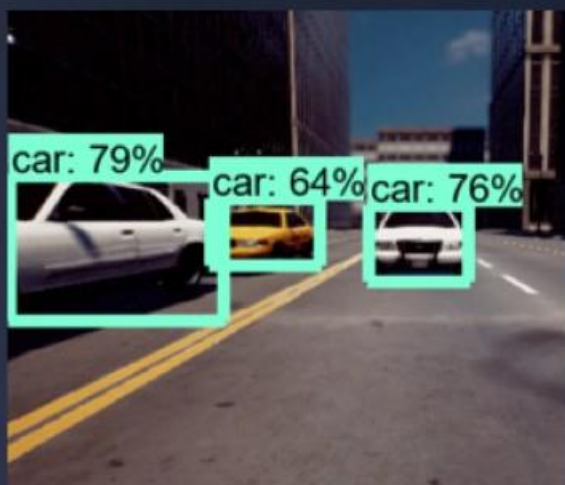


Clean



Virtual

Real



Potholes and cracks



# IFE - International Collaborating Centre of the IAEA

## IFE – the first IAEA collaborating centre in the field of nuclear decommissioning

The IAEA and Norway's Institute for Energy Technology will work together on digital innovation and transformation of decommissioning.



# DigiDecom 2017 2018 2019 2021-March



[www.ife.no/digidecom2017](http://www.ife.no/digidecom2017)

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[www.ife.no/digidecom2019](http://www.ife.no/digidecom2019)

[www.ife.no/digidecom-elinder-2020](http://www.ife.no/digidecom-elinder-2020)

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# Training course 2020 Norway

**IFE** Institute for Energy Technology **iUS** Institut für Umwelttechnologien und Strahlenschutz GmbH

**ELINDER** European Learning Initiatives for Nuclear Decommissioning and Environmental Remediation

**enen**

## DigiDecom ELINDER 2020

Innovative Course on Nuclear Decommissioning  
Date TBD 2020, Halden Norway



Learn how to take advantage of exciting key technologies like virtual & mixed reality, robotics, AI and serious gaming for safe and efficient disposal of our nuclear heritage.

### Learn about

- Current practices and lessons learned from real-life projects
- Innovative methods for safety assurance, radiological protection and knowledge management
- New trends for application of **digitalization, robotics, machine learning** and **AI**

### Using

- VR** immersive - interactive presence
- Serious gaming & simulation based story telling
- Augmented Reality** based examples
- Digital twins** of traditional/emerging equipment

### Through

- Examples** from real-life projects
- Friendly group competitions and prizes
- Learning by doing – **practical exercises** in VR
- Possibility for using data and examples from you

Hosted by IFE, a designated **IAEA Collaborating Centre**.

Targetted for professionals and newcomers with background in the nuclear and interests in digital innovation.

[Elinder2020@digidecom.eu](mailto:Elinder2020@digidecom.eu) [www.ife.no/digidecom-elinder-2020](http://www.ife.no/digidecom-elinder-2020)

Price: 2000 EUR incl. all lectures, eLearning package, facility visits, exam and certificate, as well as social events.

EU students qualify for applying for support through the ENEN+ project (see details on-line).

**Argonne** NATIONAL LABORATORY

**FIU** Applied Research Center

**SOGIN** **apollo+** nuclear

**VISAVI**

**createc** **Catenda**

**IAEA** Making Future.

**Norsk nukleær dekommisjonering**



[www.ife.no/digidecom-elinder-2020](http://www.ife.no/digidecom-elinder-2020)

# DigiDecom 2021



## DigiDecom 2021 International Workshop on Roadmap for Decommissioning Innovation

Digital transformation and other game changing trends  
2021 March, Halden, Norway



The workshop aims at bringing together a multidisciplinary international community for open and highly interactive exchanges about experience from earlier applications, as well as opportunities for future applications of new technologies and methods.



DigiDecom 2020 will also host the SHARE consortium, assisting the European Commission in development of a roadmap for decommissioning research. [www.Share-h2020.eu](http://www.Share-h2020.eu)



### Facilitate finding a roadmap for innovation

- Innovation needs based on experience from completed, on-going and up-coming decommissioning projects
- Future landscape and foreseen innovation needs



### Connect the dots together

- Connect emerging techniques with industry needs
- Integrate existing and emerging technologies like digital twins, robotics, AI, mixed reality, serious gaming, ...



### Identify barriers and facilitators

- Technology, organizational and other barriers to overcome to succeed with digital transformation
- Assets that can facilitate innovative applications.



### Facilitate partnerships

- Connect providers of innovation with those who will apply it and those who regulate it
- Connect people working on, or in need of similar things

All interested in presenting, discussing or hearing about the above topics are welcome!

[www.ife.no/DigiDecom2020](http://www.ife.no/DigiDecom2020)  
Contact: [digidecom@ife.no](mailto:digidecom@ife.no)

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