

HADRON

Centre for

Hazard Aware Digitalisation and RObotics
in Nuclear and other domains

István Szőke

Institute for Energy Technology, Halden, Norway

Contact: Istvan.Szoke@ife.no

Starting point

IFE has become a key partner in national and international collaborative initiatives, where IFE brings in technology related to (radiological) **hazard awareness in digital and robotic systems** and expertise in application of the technology for **management of hazardous sites (decommissioning) and other areas.**

IFE's current portfolio

- 15 externally financed on-going projects
 - OECD Halden Reactor Project (2 running, 5 planned from 2021 on)
 - Industrial innov. projects (NFR): RoboDecom, LiveDecom, MEDPROT (~21 MNOT total)
 - Support projects (Ministry of Foreign Affairs) mainly with Russia and Ukraine 5-6 on-going (10,3 MNOT total)
 - EURATOM projects within large international consortia: 3 on-going/initiating SHARE, PLEIADES, PREDIS, one on waiting list (TITANS)
 - Support project(s) for NND: one on-going (Public information centre at NND), new projects are planned
 - The DigiDecom workshop and training series – annual events
- Strategic institute initiative(s)
 - Hazard-Intelligent Digitalisation and Robotics in Decommissioning

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.

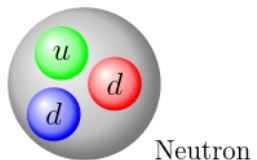
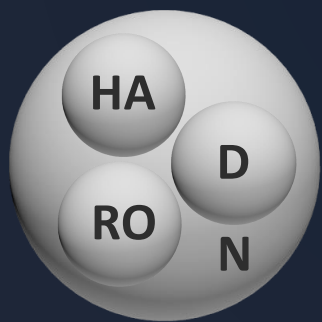
However, integrated hazard awareness ('intelligence') (preferably real-time) is required for complementing such systems, e.g. for feasibility and safety demonstration, training, mission control, safety monitoring and other purposes.

Vision

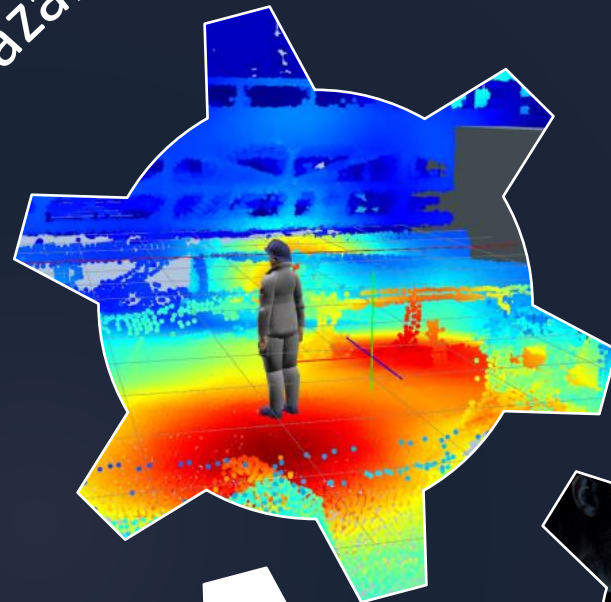
Become a known national/international **Centre** for: 'Hazard Aware Digitalisation and RObotics in Nuclear and other domains' (HADRON)

*HADRON will also support (and extend) IFE's existing **IAEA International Collaborating Centre** related to digitalisation for decommissioning*

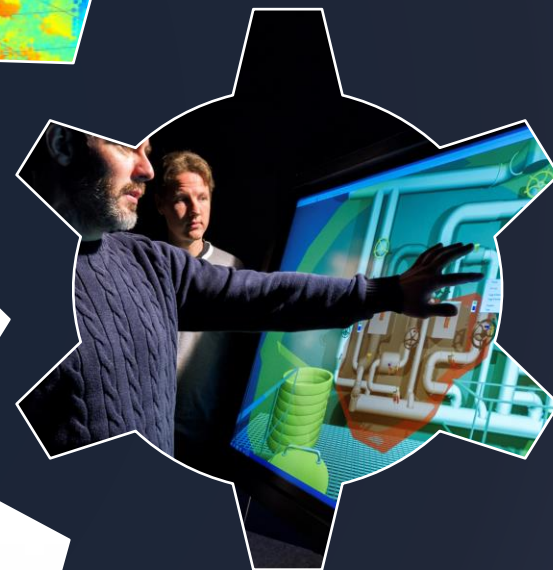
Hazard Aware Digitalisation and RObotics in Nuclear and other domains



3D hazard modelling



3D digital simulation



Robotics



Nuclear

HADRON mandate

Establish new **Centre** and **Lab** at IFE under the team HADRON

Primary objectives :

- Map existing expertise at IFE
- Build required complementary knowledge
- Find and evaluate new ideas
- Strengthen national and international relationships
- Strengthen project portfolio

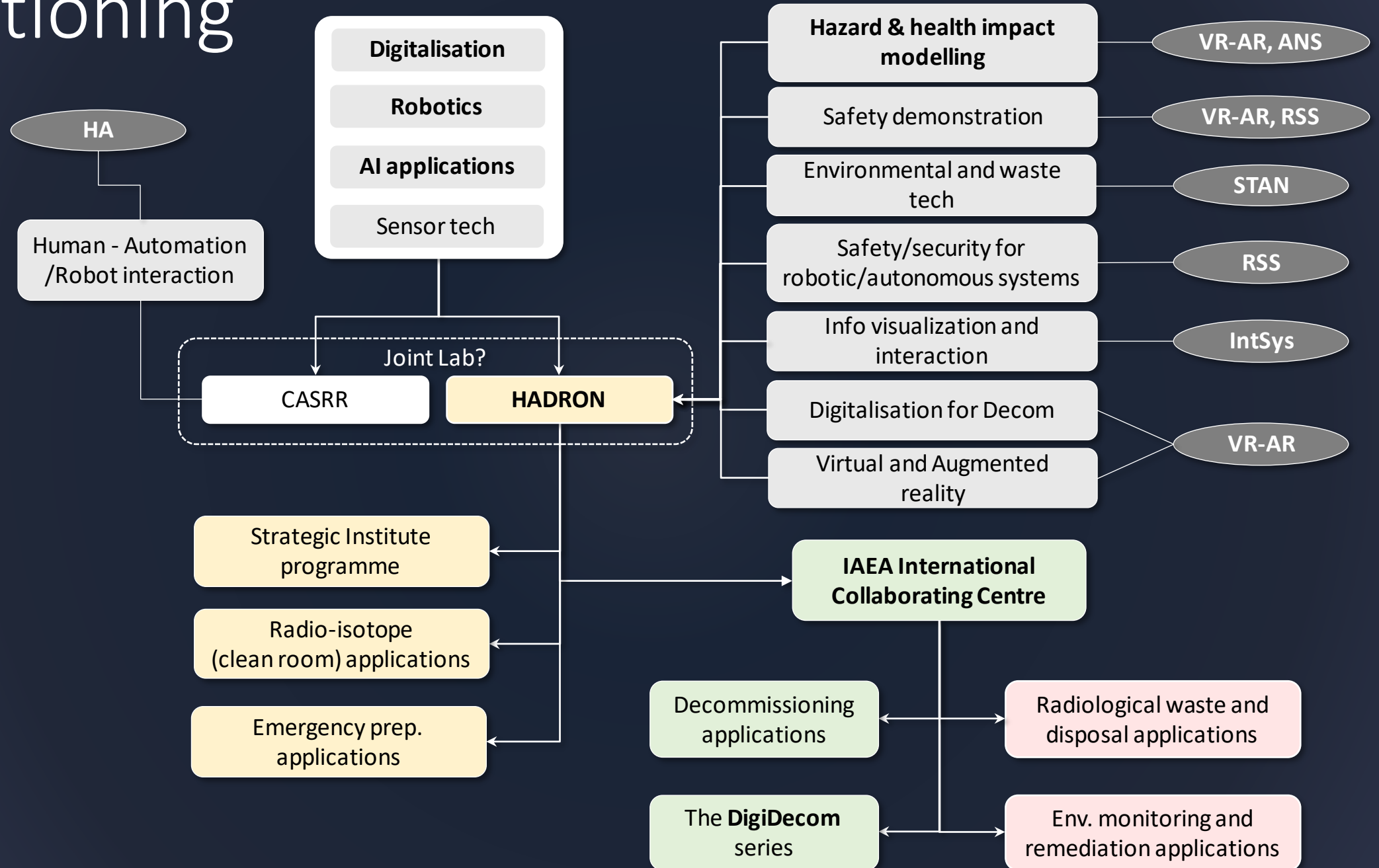
HADRON mandate (cont'd)

- Understand how existing expertise at IFE (e.g. machine learning, VR-AR, ...) can be applied
 - Establishing a group of experts with basic understanding of nuclear decom, radiological dosimetry, hazard impact, emergency response ...
- Build complementary knowledge: Robotics (middleware), Building Information Modelling (BIM), LIDAR, sensor and avoid, path planning, wireless com., image/object recognition ...
- Extend hardware testbed → establish new lab
 - Prototype solutions relevant for on-going projects and new opportunities (e.g. those identified in POC-Jackal) with partners – hands on learning with partners

HADRON mandate (cont'd)

- Strengthen national and international relationships
 - Extended collab. with project partners (SintefR, SintefM, nLink, HALODI, BergenRob, MaritimeRob, CREATEC, TECNUBEL, Magics, iUS, ...) to new areas
 - in Robotics: FIU, NTNU cybernetics group, NNL, INESC TEC, JAEA, KAERI, ...
 - in Hazard modelling: CER Hungary, ...
 - in Sensors: CER (space tech), ENVI-TECH, AITEX, ...
 - in Emergency response: HVL, AKUT, NTNU, PUI, YAS, ISPNPP, JAEA, APC, HB, ...
 - in Safety and human aspects: UoY, NTNU-SR (NSR), ...
- Strengthen project portfolio
some new proposal initiatives are:
 - H2020: The SMARTES proposal will be submitted in August 2020
 - Hazard-Intelligent Digitalisation and Robotics for emergency first response – NFR
 - Hazard-Intelligent Digitalisation and Robotics in clean rooms (HALODI)
 - Research infrastructure – NFR
 - Proposals for joint application from SINTEF ...

Positioning

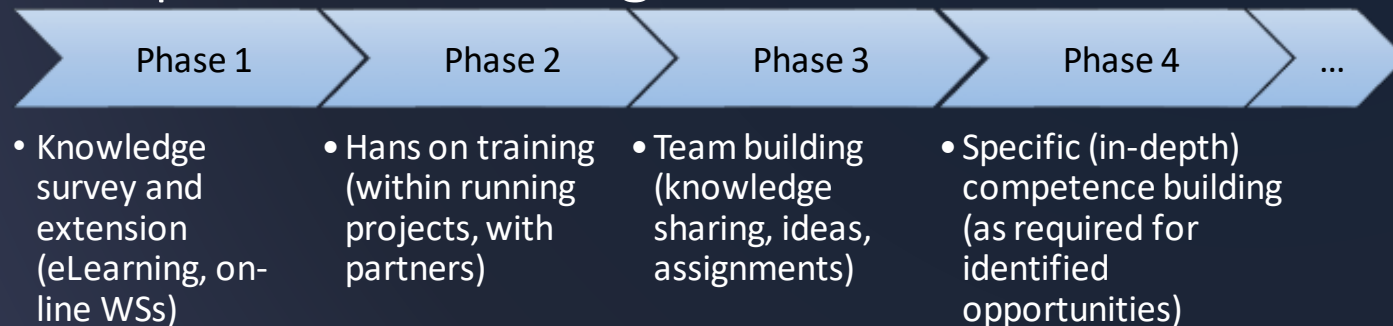


Roadmap

HADRON
Known international centre for Hazard Aware Digitalisation and Robotics
in Nuclear and other domains



Competence building



Proficient agile cross-sector team

Target market and opportunity

Any industry where operations in environments with industrial hazards are involved are potential market segments due to the clear trend for higher adoption of robotics, automation and digitalisation.

Some concrete areas are:

- Decommissioning of nuclear and other industrial installations, e.g. oil platforms
- Operation and maintenance of nuclear and other industrial facilities
- Production of radiopharmaceuticals
- First response and remediation after accidents involving industrial hazards (e.g. CBRN)
- *Results will be applicable to more 'common' situations too*

Business case – HADRON

When? Who? Where? How?

When is it necessary?

What is the tech read for?

Where is it worth it (provide superior capabilities)?

What is it proven for?

Side benefits worth considering

- Humans: motivation - new exciting work and useful skills for existing staff and newcomers
- Organisation: higher efficiency and reusable capabilities in numerous other domains
- Regulation: Strengthening safety requirements due to possibility for removing humans from harms-way

Background



Hazard modelling

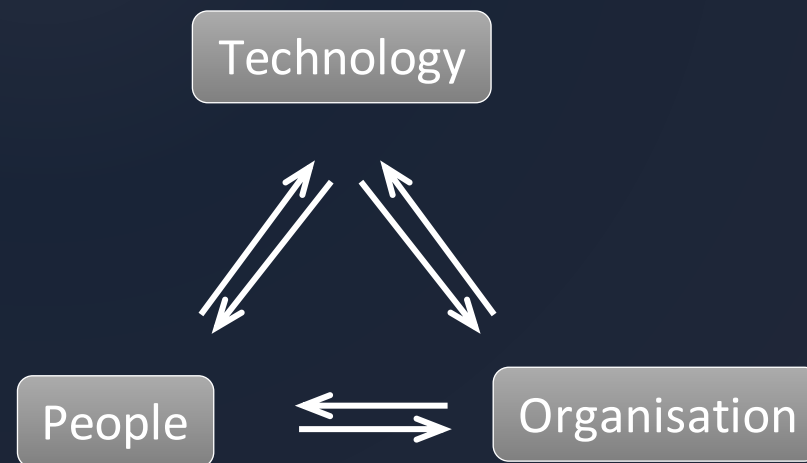
- Real time radiation transport
- Geostatistics
- Monte Carlo radiation transport
- Source deconvolution
- 3D gamma mapping
- Aerosol inhalation
- Internal rad. dosimetry

Non tech

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

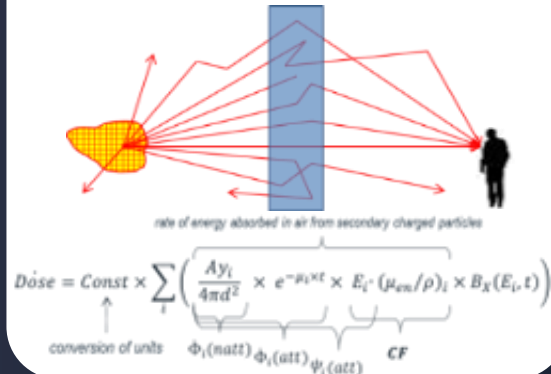


- 3D modelling
- Virtual and Augmented reality
- Advanced user interfaces
- Mobile and wearable devices
- Machine Learning (AI)

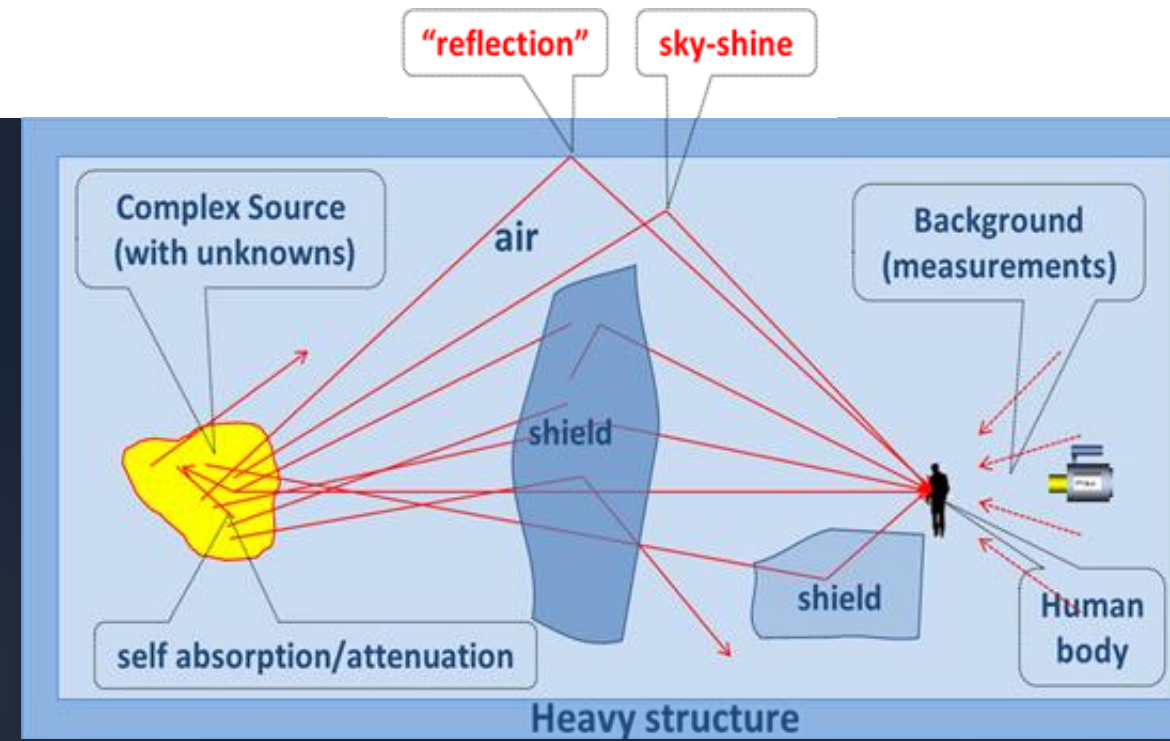
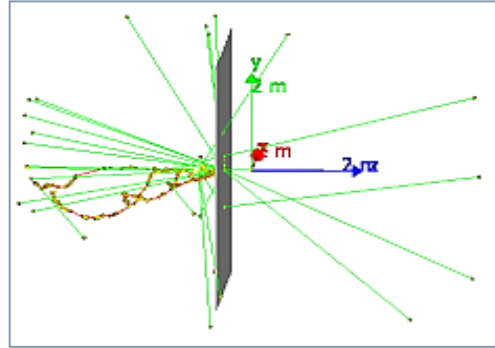


Radiological hazard modelling

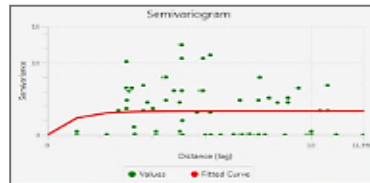
Real-time (Point Kernel) radiation transport



MC radiation transport (MCNP, GEANT4)



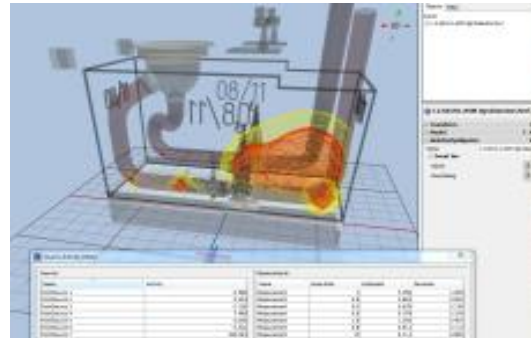
Interpolation, Geostatistics



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

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

Source deconvolution

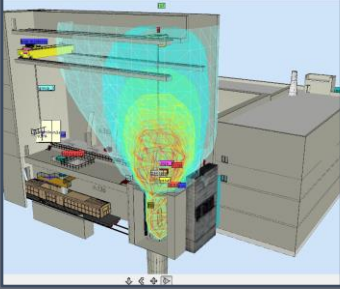


Atmospheric dispersion

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

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

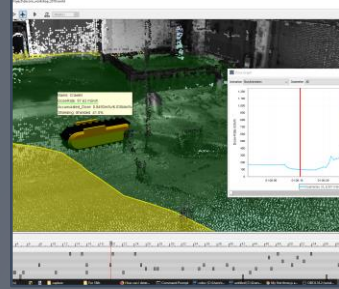
Hazard modelling applications in decom



Work planning -
ALARA



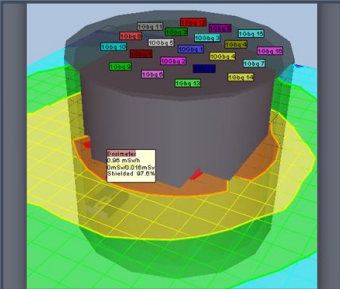
Rad characterisation



3D gamma mapping



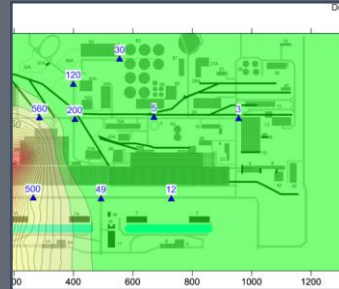
Training



Waste packaging
modelling



Waste management
modelling



Rad mapping /
sampling optim



Env modelling

Long term decom support projects by IFE abroad



Fugen NPP (JAEA)
(1995 -)



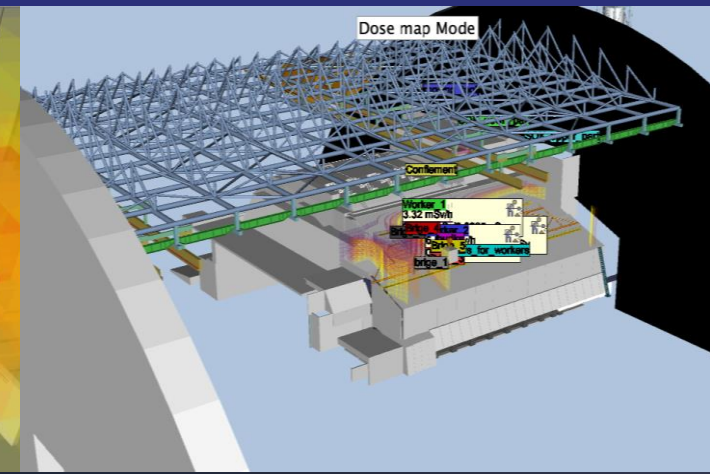
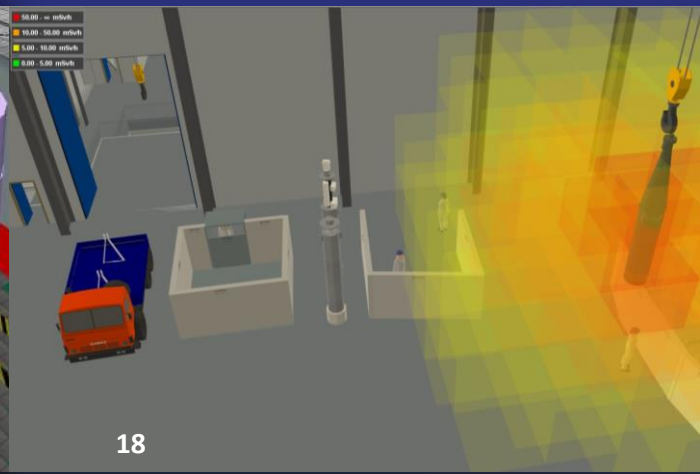
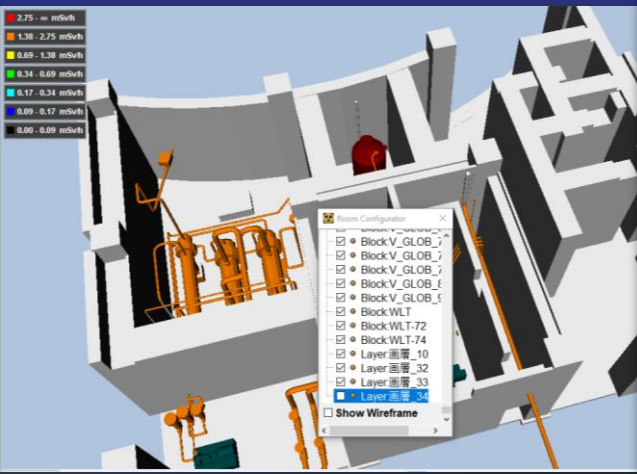
Leningrad NPP
(1999-)



Andreeva bay, NW Russia
(2011-)



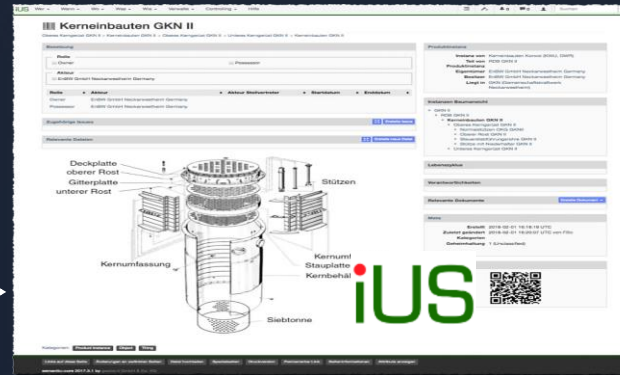
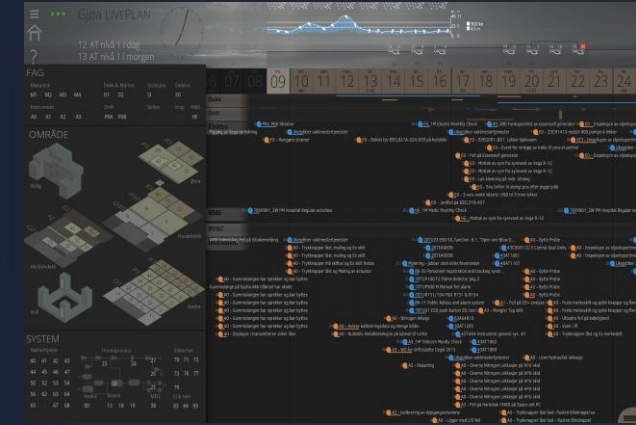
Chernobyl NPP
(2008 -)



Towards holistic support

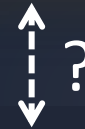
Project planning, costing ... systems

Semantic info systems



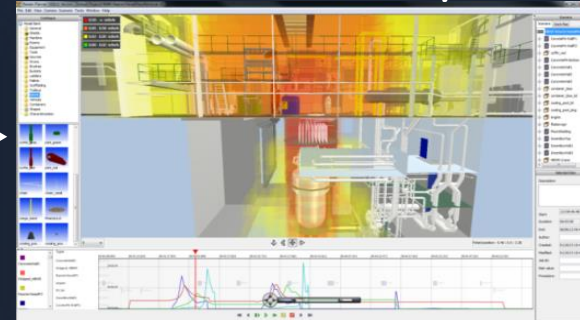
3D scanners
Hazard sensors
Other analyses
codes

Documents →

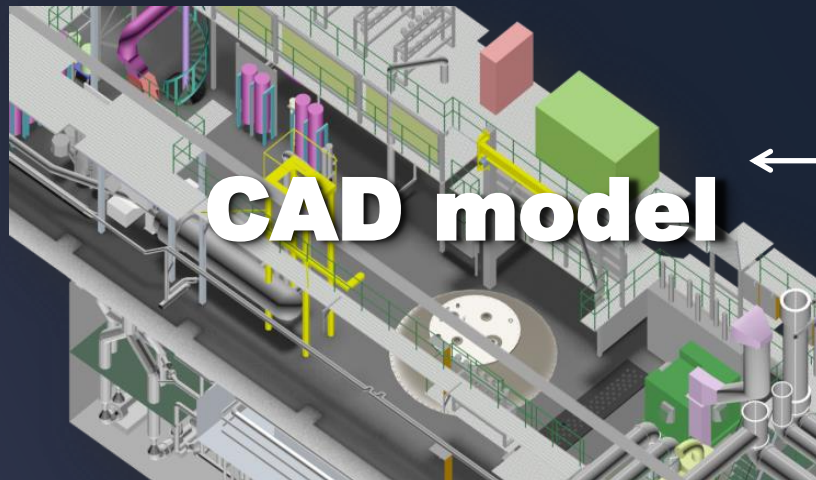


3D sim. supported work planning/training

VRdose family



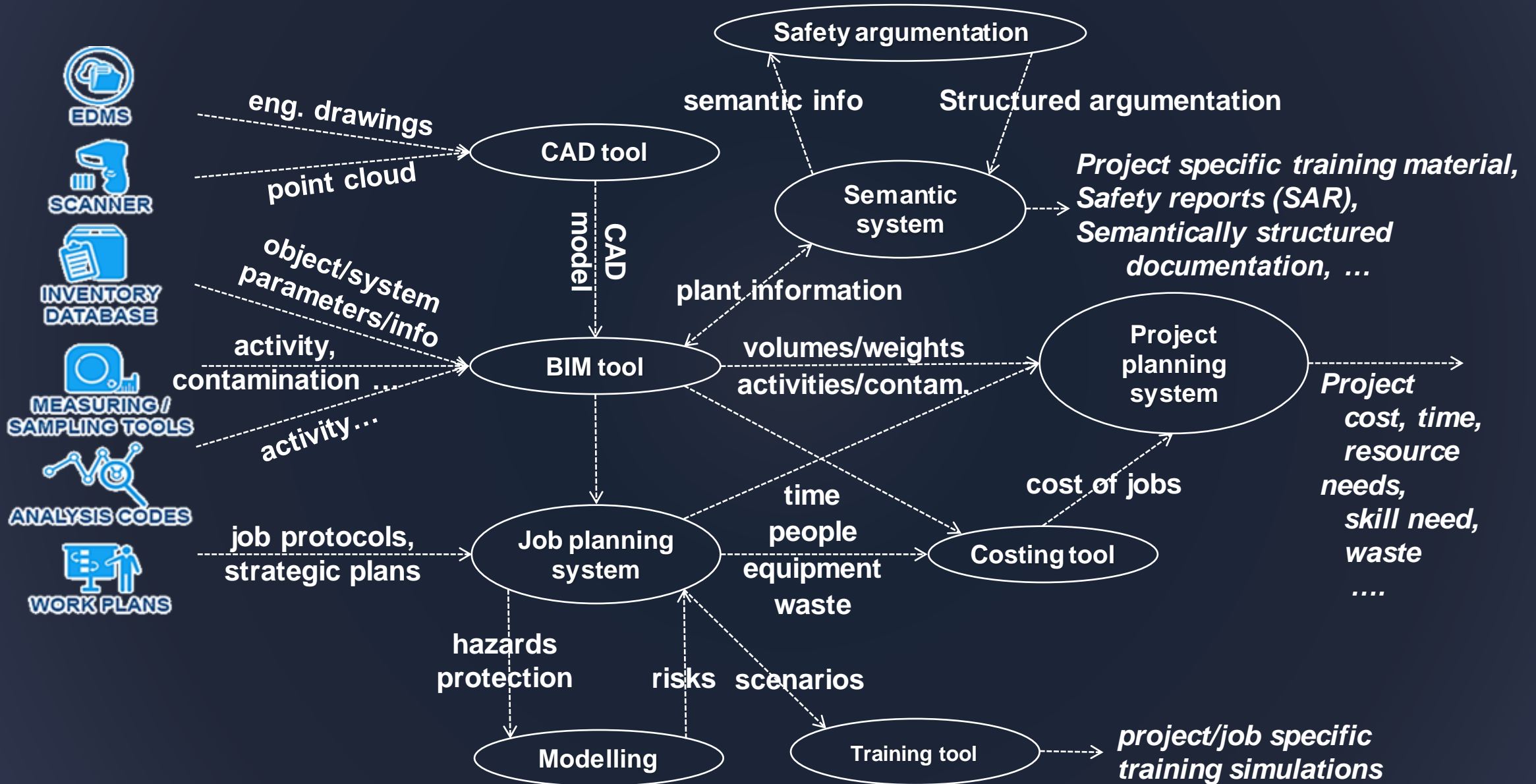
MCNP



CAD model

- User defined rad. data
- Custom importers from historical database(s)
- Linked documents

Holistic digital support for decom



LiveDecom: Prototyping integration of digital capabilities for decom

Demonstrate **integration** of digitalized capabilities for

- project planning,
 - configuration management,
 - rad. characterisation,
 - job planning,
 - training,
 - costing, and
 - reporting for decom
- through integration of tech. like
- BIM/PIM,
 - advanced project planning interface,
 - 3D job and hazard simulation,
 - 3D gamma mapping,
 - ISCD costing,
 - ...



Holistic approach to decom



When transitioning to decommissioning
many capabilities need to be built up, adjusted or strengthened!
All these functions need to work together!

The LiveDecom suite

BIM



Information management



Characterisation



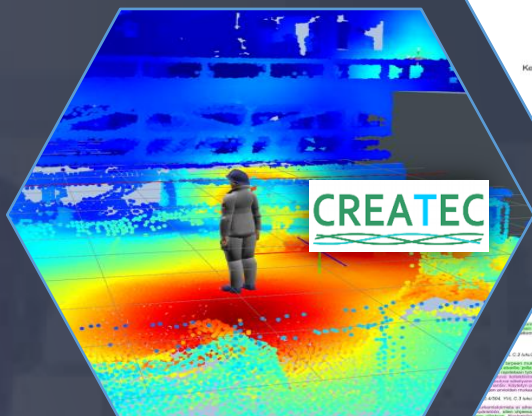
Project management



Costing



Radiological mapping



Job planning



Training



Safety demonstration

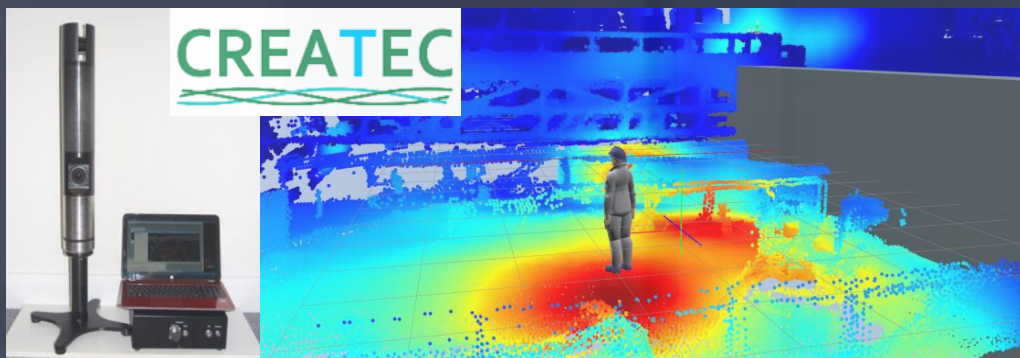


BUT how can we get the data?

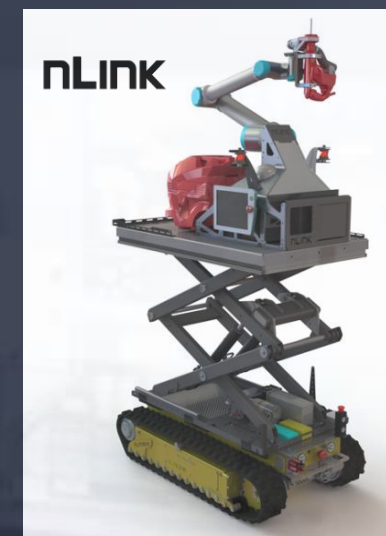
- New cheap tech for 3D data



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

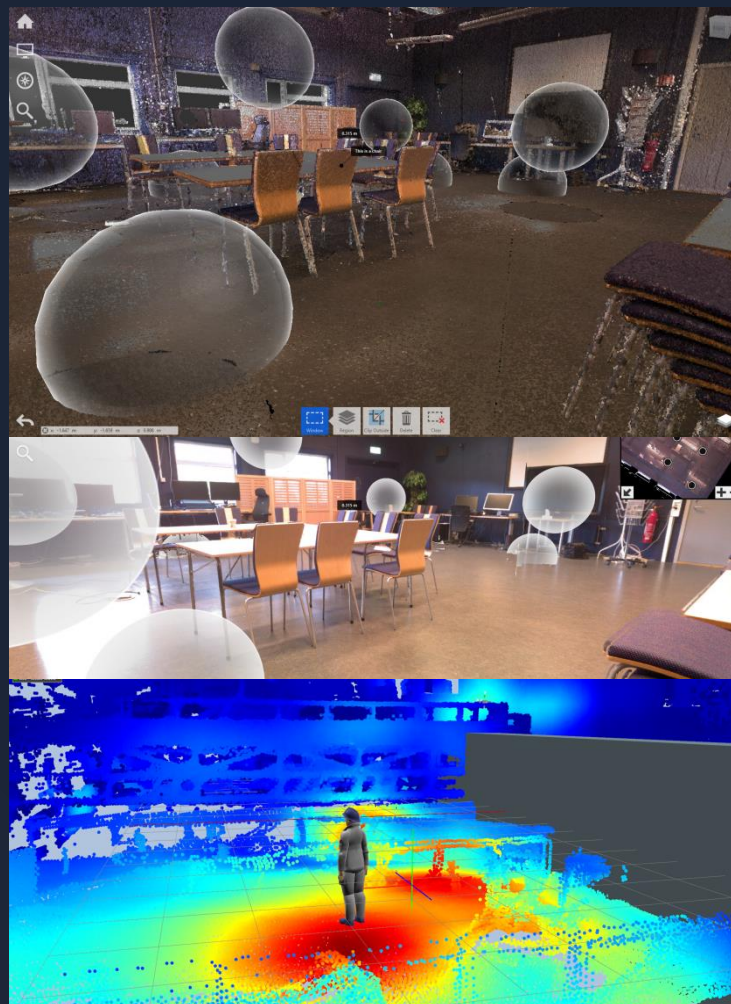
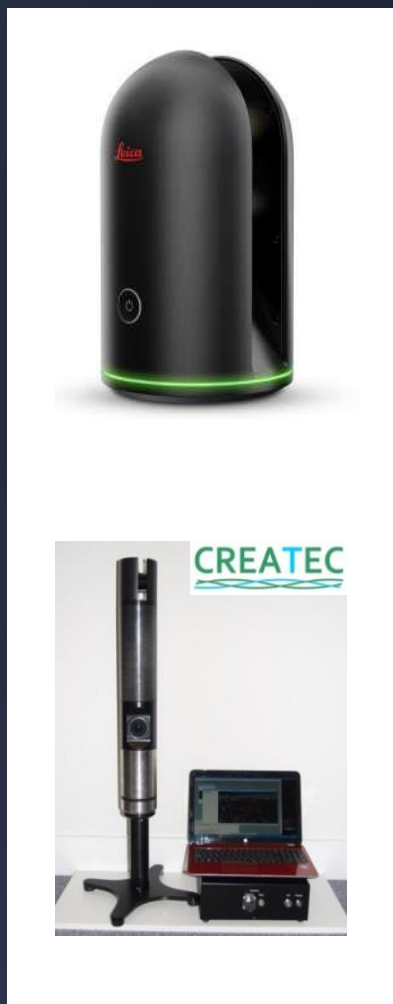


- New tech for deploying sensors/samplers – remote systems, robotics, automation, autonomy,



Strategic research programmes (SIS)

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



3D simulating based
support platform

Business case / trend for robotics

1. Special jobs that cannot be performed by humans due to high hazards or ergonomics

- Accident sites e.g. Fukushima, Chernobyl, ...
- Legacy sites with high hazards to humans
- Specific jobs at 'normal' sites

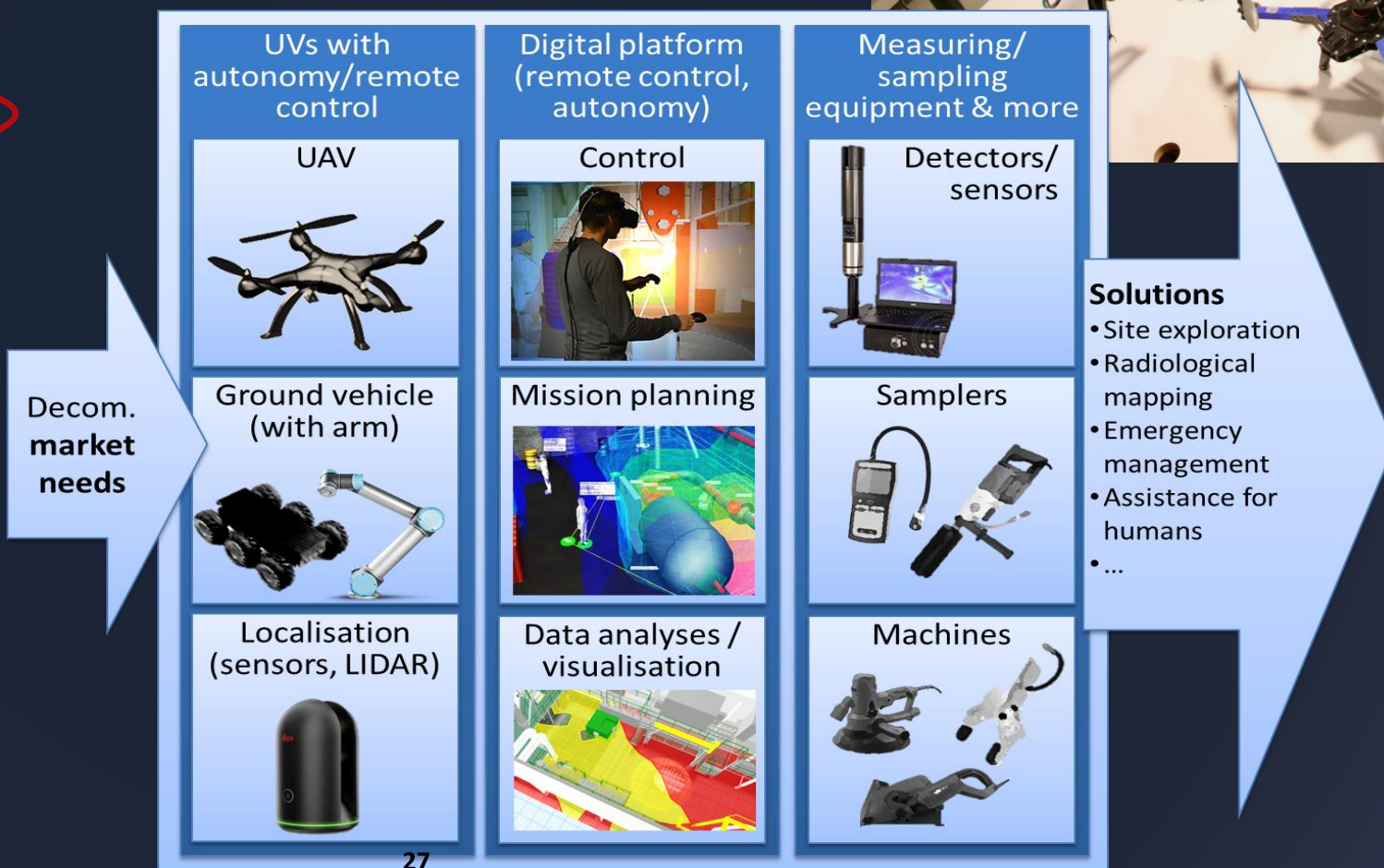
2. Replace or assist humans in jobs that can be performed by humans

- Risky jobs requiring extensive safety measures
- Dull, repetitive jobs
- Smaller jobs requiring assistance by geographically remote experts

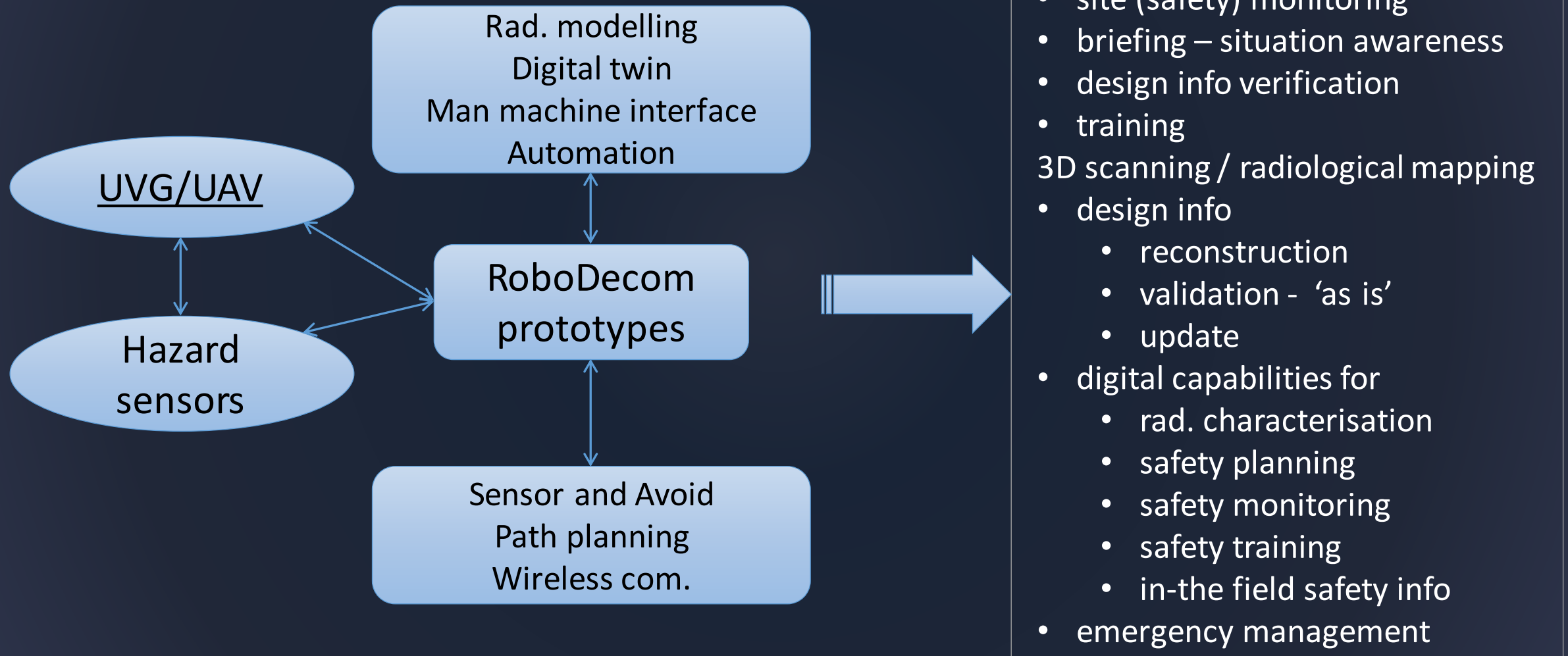


RoboDecom – Robotics for decommissioning

- 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 concept



Manual → Remote / semi autonomous → autonomous

RoboDecom prototypes

LiveDecom
suite



Prototype 1

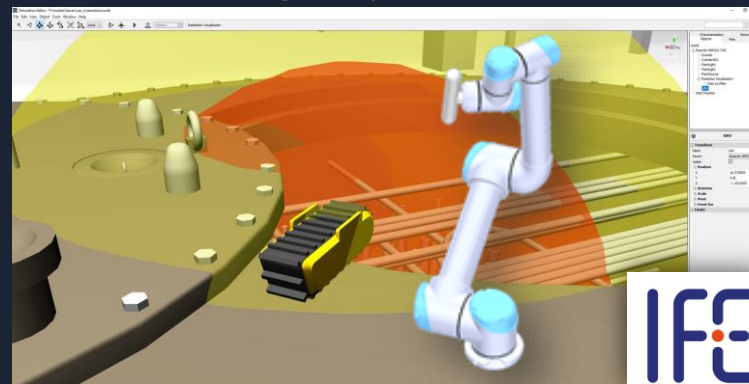
Hazard
sensor



UGV system



3D sim based
digital platform



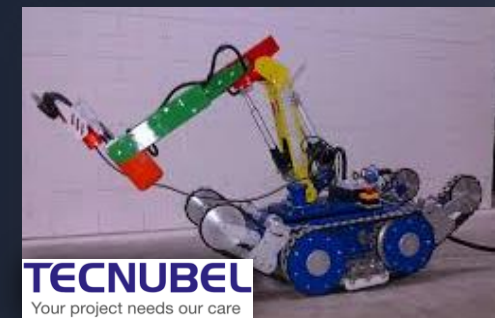
Sensor and Avoid
Path planning
Wireless com.



UAV system



Prototype 2

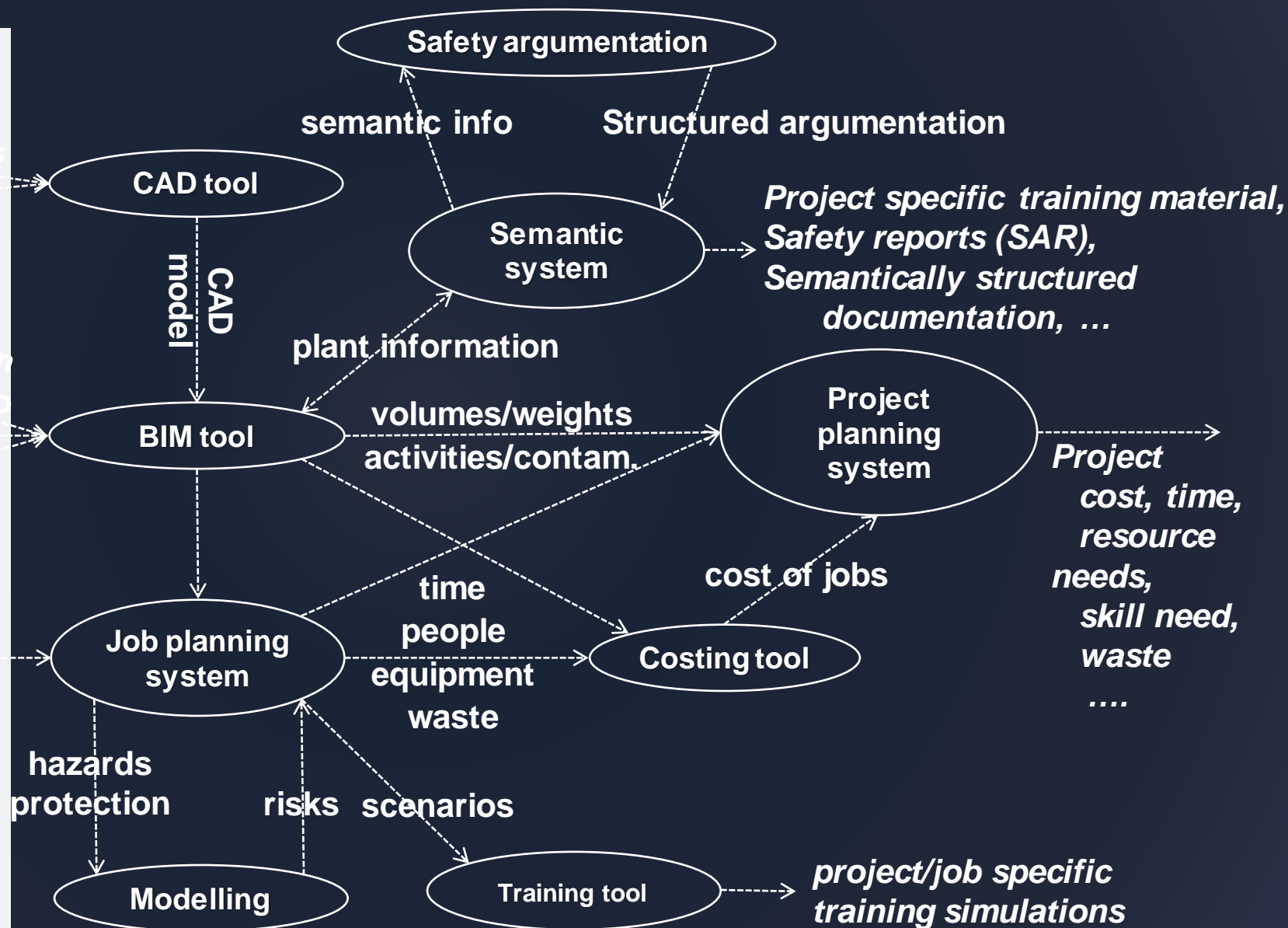


Holistic digital support for decom

Robots equipped with sensors

Targeted and regular safety supervision

- Input for understanding/modelling the environment
 - 3D point cloud
 - photos, videos, ...
- Radiobiological measurements and samples
- Data on other hazards
 - Chemicals, rust, ...
 - Detect possible dangerous conditions



Robotics + digital support systems

- Robotics = Integral piece for enabling holistic digital capabilities
- Digital technology can also facilitate adoption of robotics:
 - Digital twin based safety and efficiency evaluation
 - Training for robotics in mixed reality
 - VR and digital twin based control – incl. telepresence
 - Real-time hazard simulation based mission planning and control
 - AR and hand-held based (health) monitoring of robots

Digitalisation + robotics

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

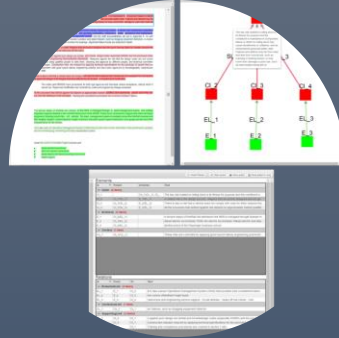




Spatial
Computing and
Augmented
Reality for
Hazard Mapping
and Visualisation



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



Digitally-
Enhanced Safety
Assurance



Enabling Robotic
and Remote
Operations



Overview
Displays for
Decommissioning
of Nuclear
Reactors



EU projects: SHARE

Establishing SHARE Decommissioning Roadmap

Stakeholder's
Needs

Current
Available
Solutions

Questionnaire

Questions
grouped in themes
Collect opinion of
stakeholders
Rank **needs** to
importance and
urgency

Open Online
Consultations



Gap Analysis

Weighted Decision Matrix

- ✓ List of drivers to evaluate and rank current available solutions (cost, safety, time durations, sustainability, availability of waste routes, access to expertise and competence, maintenance and development of knowledge, regulations, guidelines, TRLs, SRLs)
- ✓ establish weighting factor (paired comparison analysis)
- ✓ WDM with seven-point rating scale

Strategic Research Agenda (SRA)

List of activities prioritised and grouped in thematic areas to close the gap (knowledge production, knowledge transfer, standardization and guidance, strategic studies, technological transfer, cross-cutting activities)

SRA

Strengths

Reduced Costs
Automated
TRL



Weaknesses

Insufficient funds
Waste production
No demonstration

Opportunities

Added value
Knowledge management access
Sharing costs

Threats

Public acceptance
Regulation changes
Waste disposal routes

Roadmap

Analyse SRA for implementation qualifiers (willingness to commit and share resources, regional distribution, inclusiveness of actors and instruments (working groups, information exchange platforms, technical project, co-funding, technological transfer)



LA&KC ©JRC

CONSORTIUM

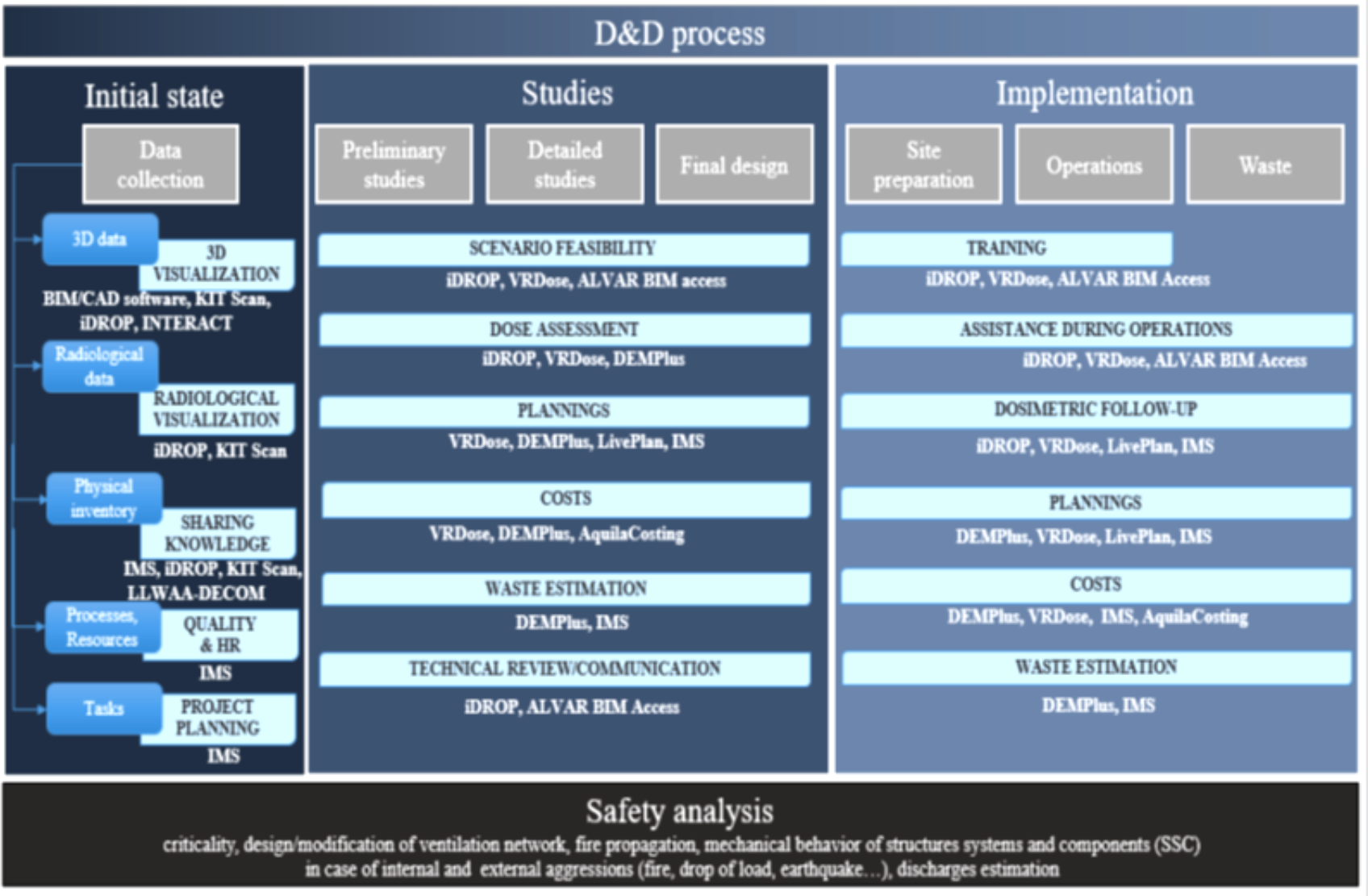


EXPERT REVIEW



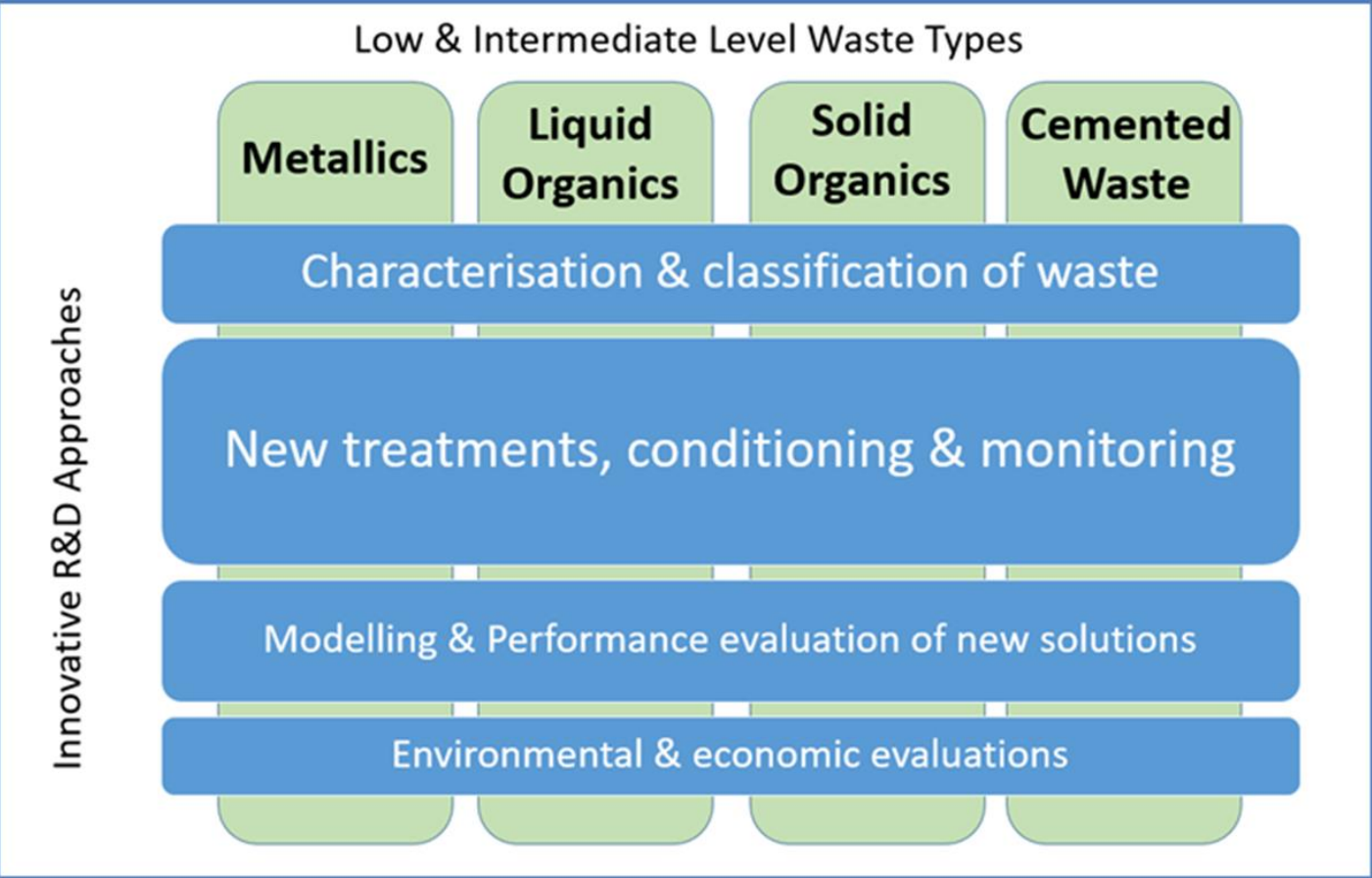
**SHARE: StakeHolder-based
Analysis of REsearch for
Decommissioning**

EU projects: PLEIADES



PLEIADES:
*Platform based on
Emerging and
Interoperable
Applications for
enhanced
Decommissioning
processES*

EU projects: PREDIS

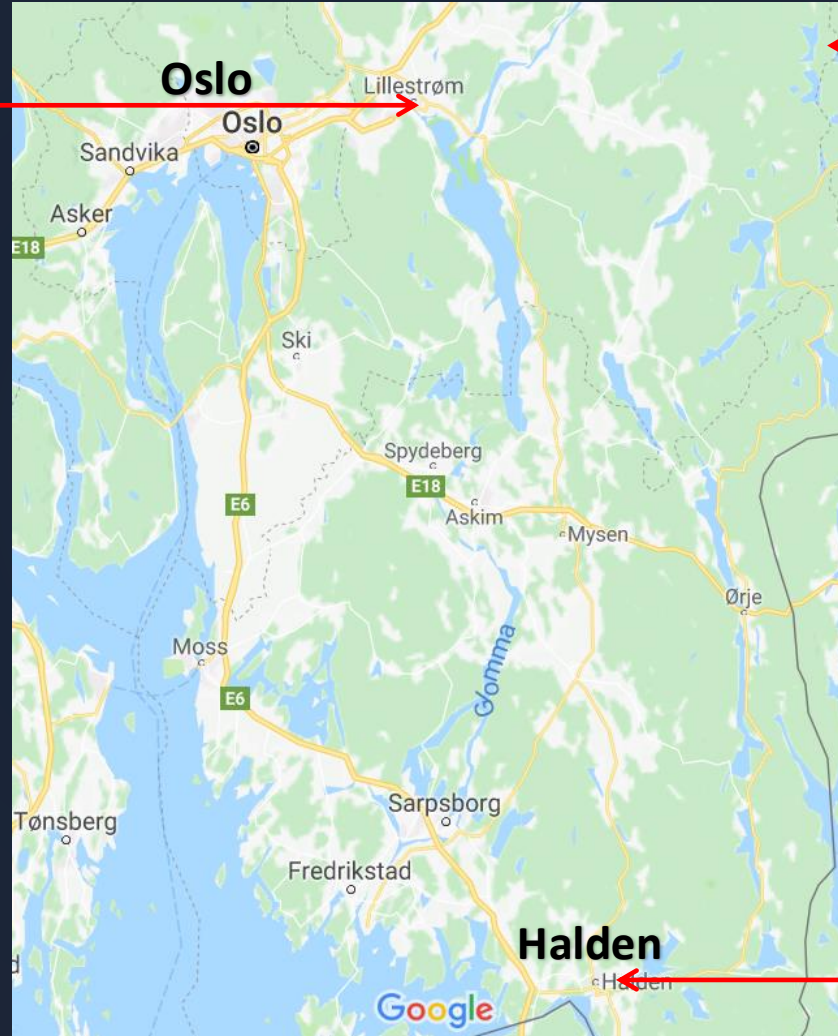
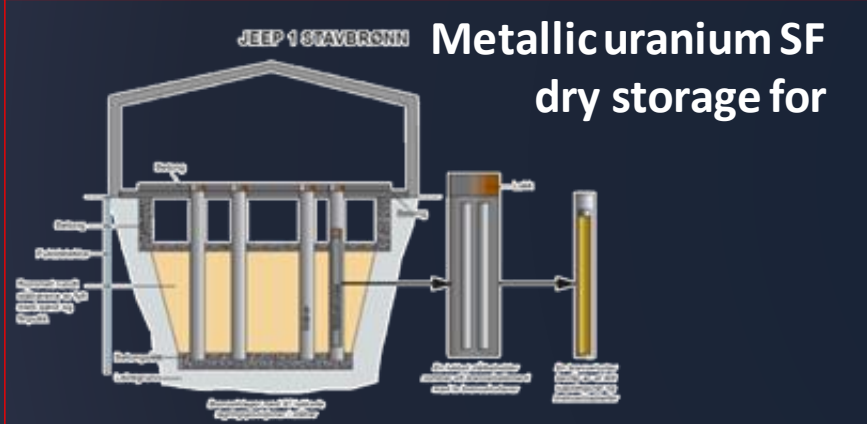


1	VTT	Finland	25	TSE	Hungary
2	NNL	UK	26	ANN	Italy
3	JRC	Belgium	27	ENEA	Italy
4	IMTA	France	28	INFN	Italy
5	CEA	France	29	NUC	Italy
6	SCK•CEN	Belgium	30	POLIMI	Italy
7	BAM	Germany	31	SOGIN	Italy
8	MAGICS	Belgium	32	UNIPI	Italy
9	TUS	Bulgaria	33	FTMC	Lithuania
10	CTU	CZ	34	NRG	Netherlands
11	CVRez	CZ	35	IFE	Norway
12	SÚRO	CZ	36	RATEN	Romania
13	UJV	CZ	37	A21	Spain
14	UniHel	Finland	38	CIEMAT	Spain
15	CNRS	France	39	CSIC	Spain
16	ECL	France	40	ENRESA	Spain
17	IRSN	France	41	UAM	Spain
18	ORANO	France	42	PSI	Switzerland
19	DMT	Germany	43	GSL	UK
20	FZJ	Germany	44	MCM	UK
21	KIT	Germany	45	UoM	UK
22	NCSRD	Greece	46	USFD	UK
23	ISOT	Hungary	47	KIPT	Ukraine
24	SORC	Hungary	48	SIIEG	Ukraine

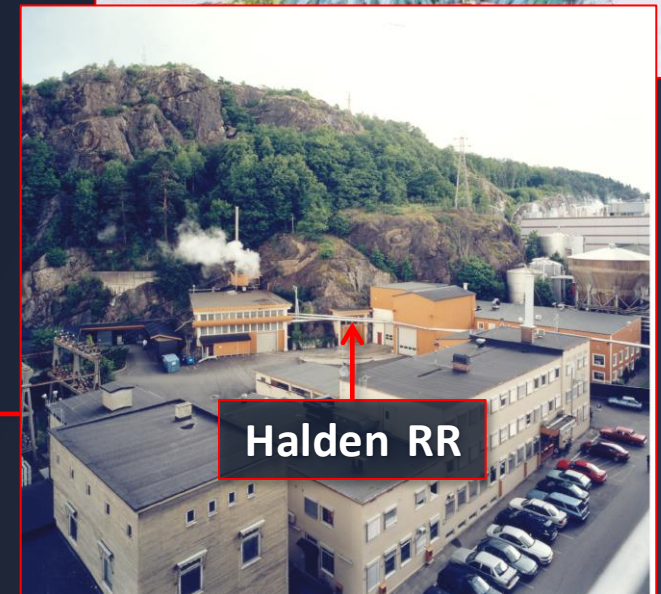
PREDIS – Pre-disposal Management of Radioactive Waste (23.7 M€)

PREDIS (VLLW to MLW) - EURAD (HLW & SNF)

Decommissioning at IFE



National radwaste repository

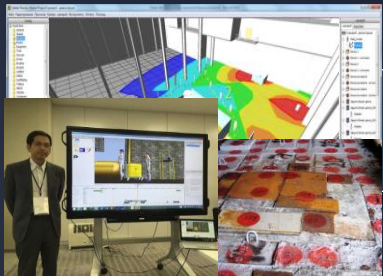




NND – IFE collaboration in decom



Completed decom work at IFE (HR, URA, Stavbrønn,...)



Decom support projects in Russia, Ukraine, Japan, ...

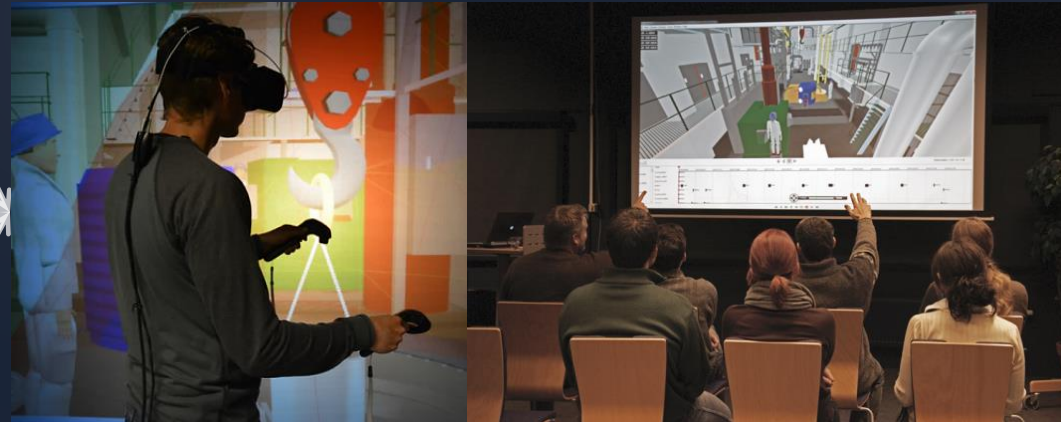


Industrial innovation & research projects



HRP research + case studies with partners

- Strategic planning support
- Support for interactions with advisors and the regulator
- Competence building (incl. education)
- Training and briefing support
- Public information
- Knowledge preservation



Information center



NND – IFE collaboration → Way forward?



3D gamma
scanning capability
dev



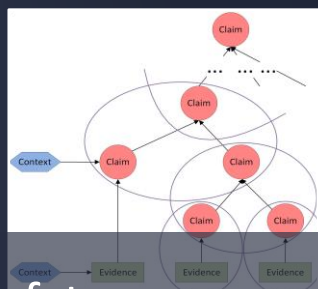
Info management
for rad
characterisation



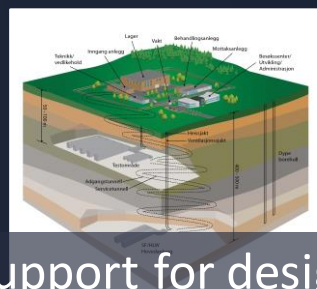
Decom info
management
(adaptation of
LiveDecom)



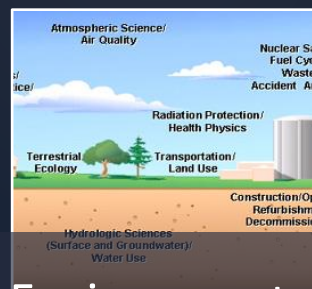
Comprehensive
training
programme



Safety assurance/
demonstration



Support for design
of new national
repository



Environmental
management



LLW & MLW
management (via
PREDIS EU project)

**Joint
decom
Centre of
Excellence**

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 2020 (Dec?)

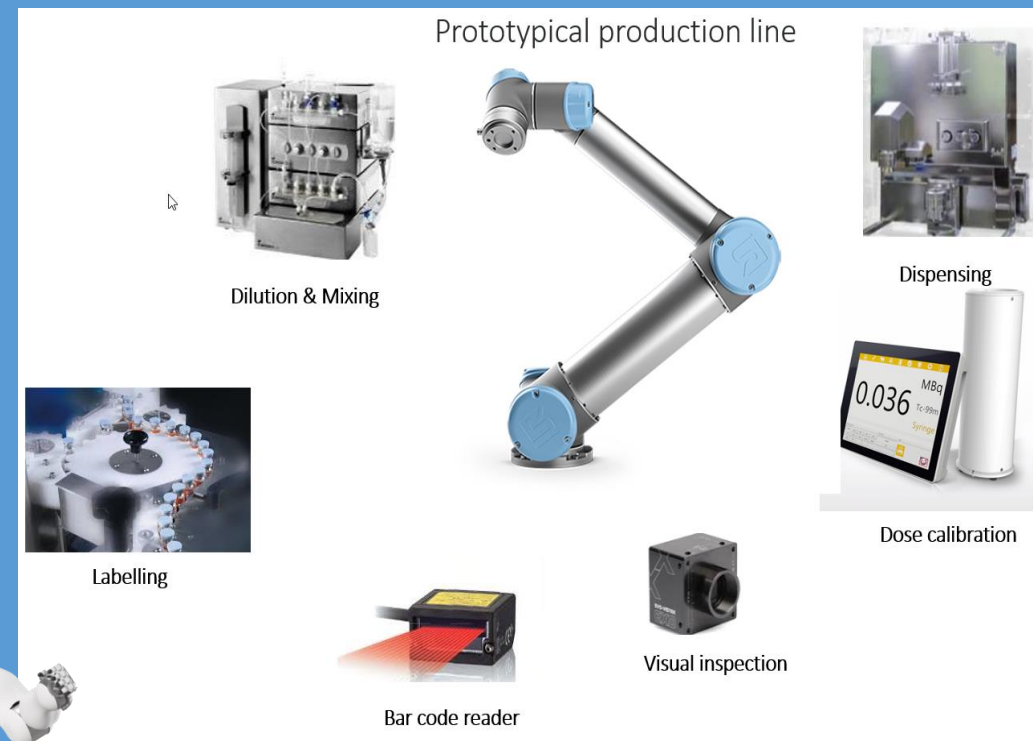
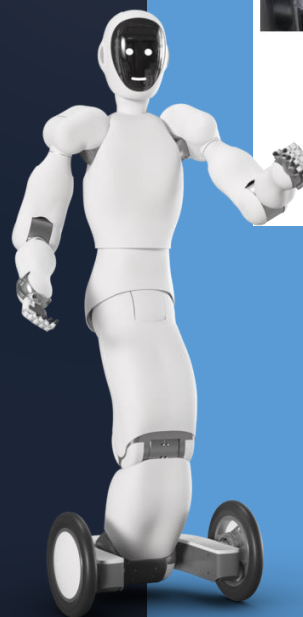


www.ife.no/digidecom2017
www.ife.no/digidecom2018
www.ife.no/digidecom2019
www.ife.no/digidecom-elinder-2020
www.ife.no/digidecom2020

The MedProt project

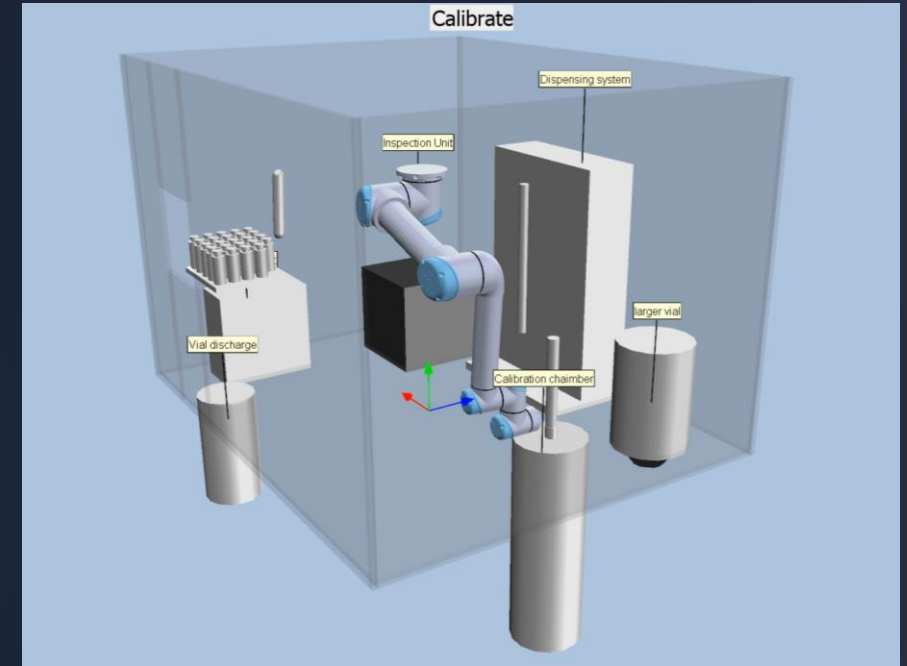
Sub-project:

Automated manufacturing
and dispensing of
radiopharmaceuticals
17 MNOK



MedProt project

- Mostly based on commercially available components
- Digital simulation (twin) based design
 - Digital twins of components
 - Digital simulation based process and safety analyses
 - In-built radiological simulation
- Machine learning and other image processing tech based visual inspection
- Modular system - robotic arm based material transport



Clean

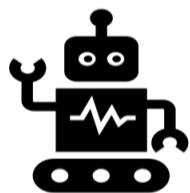
Contaminated

Difference



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

Physical World

Digital World

Environment conditions

Site information

Health data

Health & Risk Modelling

Hazard Mapping

Digital Platform

Simulation

Live Data

Teams in the field

Command Centre

Robotics

Tracking Systems

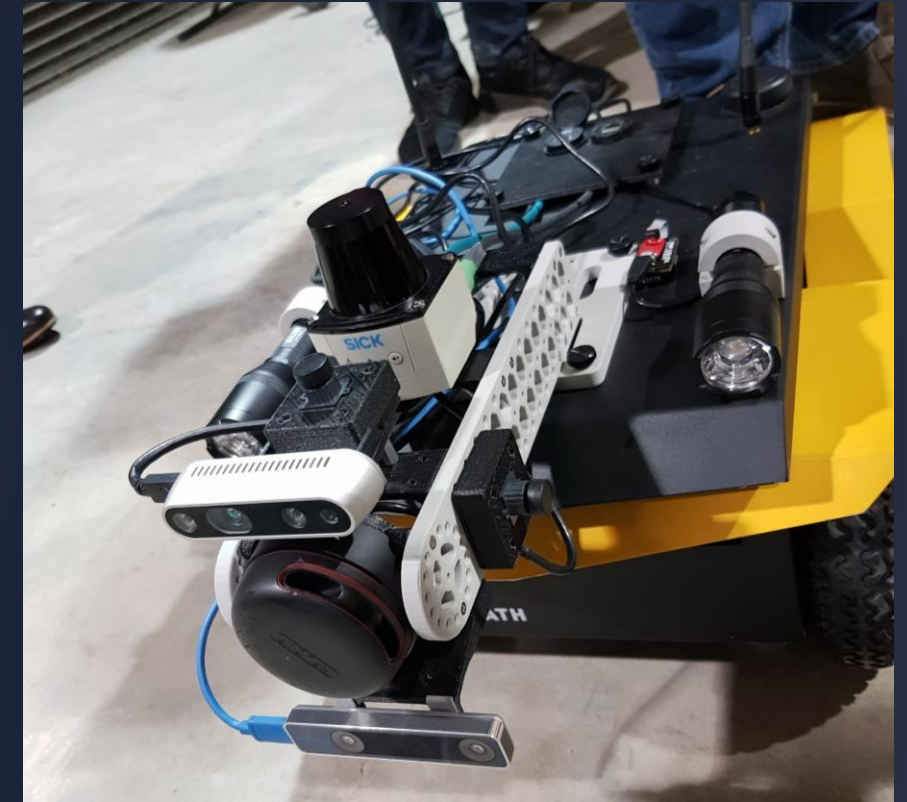
Physiological sensors

H2020
proposal
7M EUR

Proof of Concept (POC) project

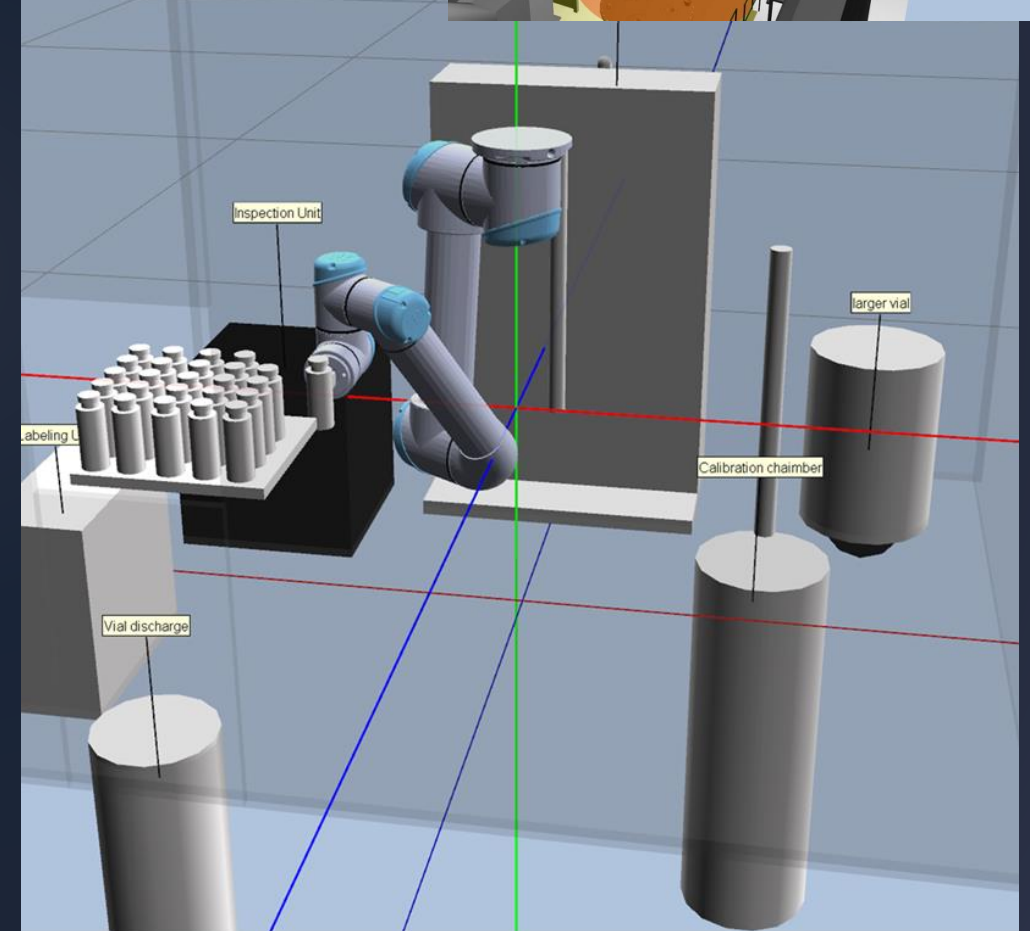
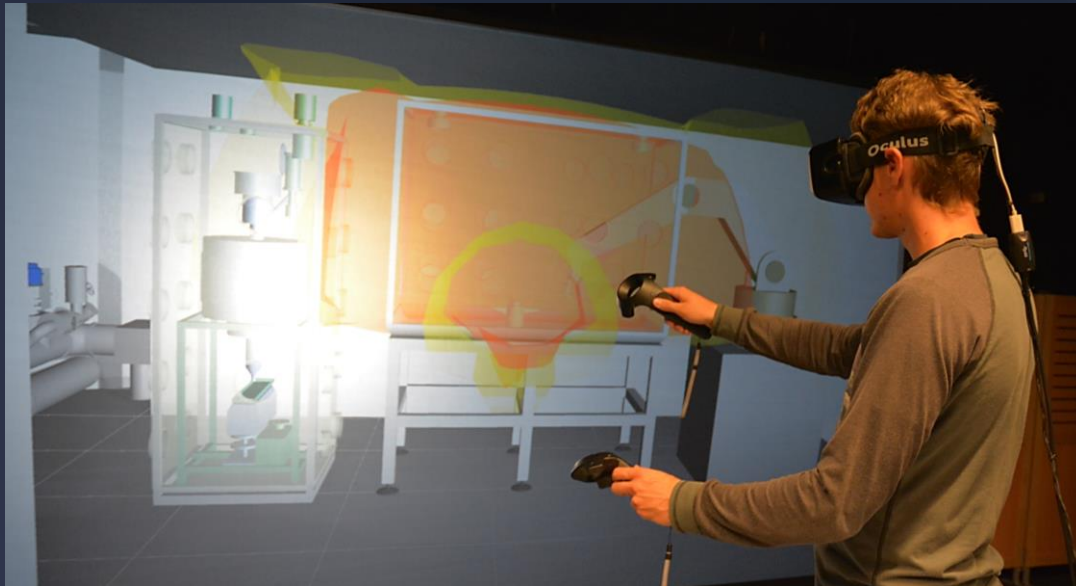
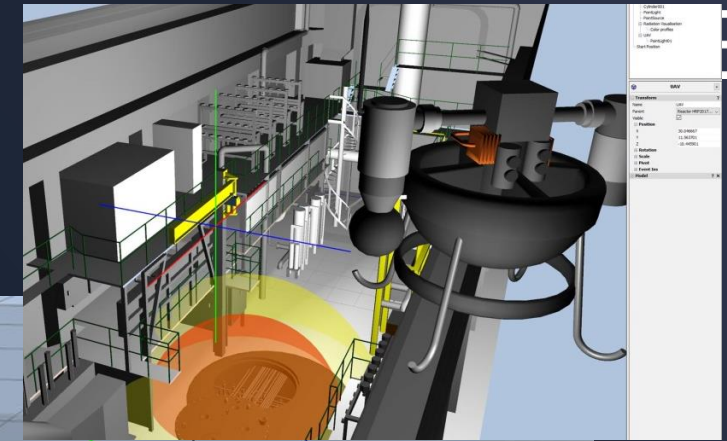
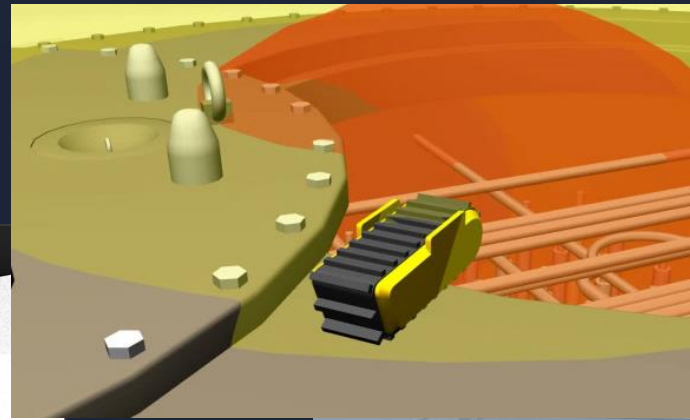
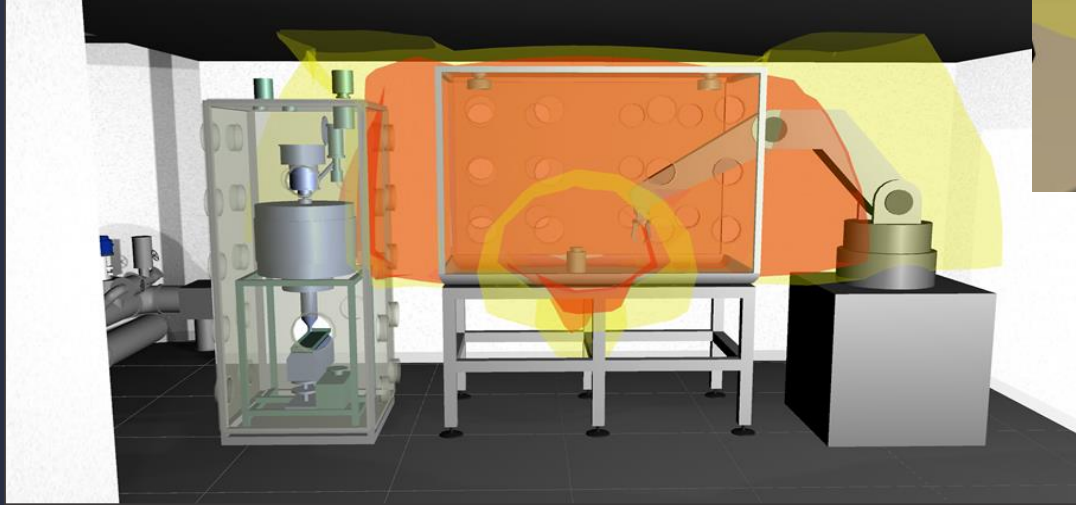
Strengthen IFE's competence in robotics and extend lab equipment => better capability participating in collaborative projects related to robotics

- Complement existing hardware base – Jackal kit
- Improve competence in robotics – use the platform for hands on learning
- Support existing projects (prototype in small scale) and generate new ideas

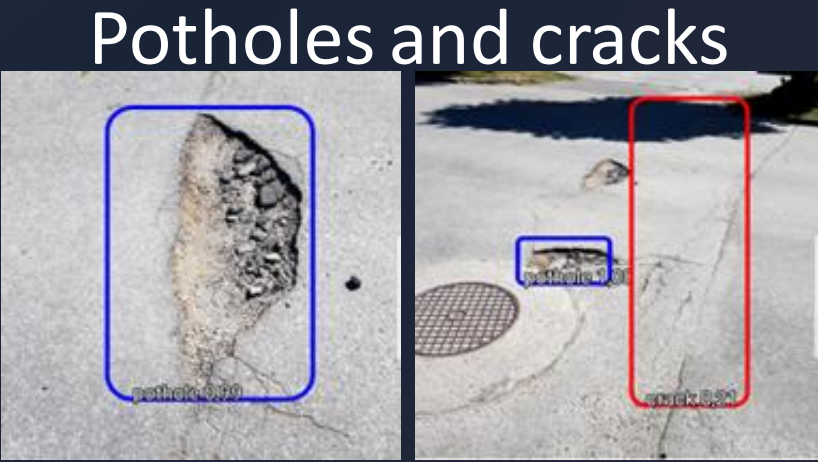
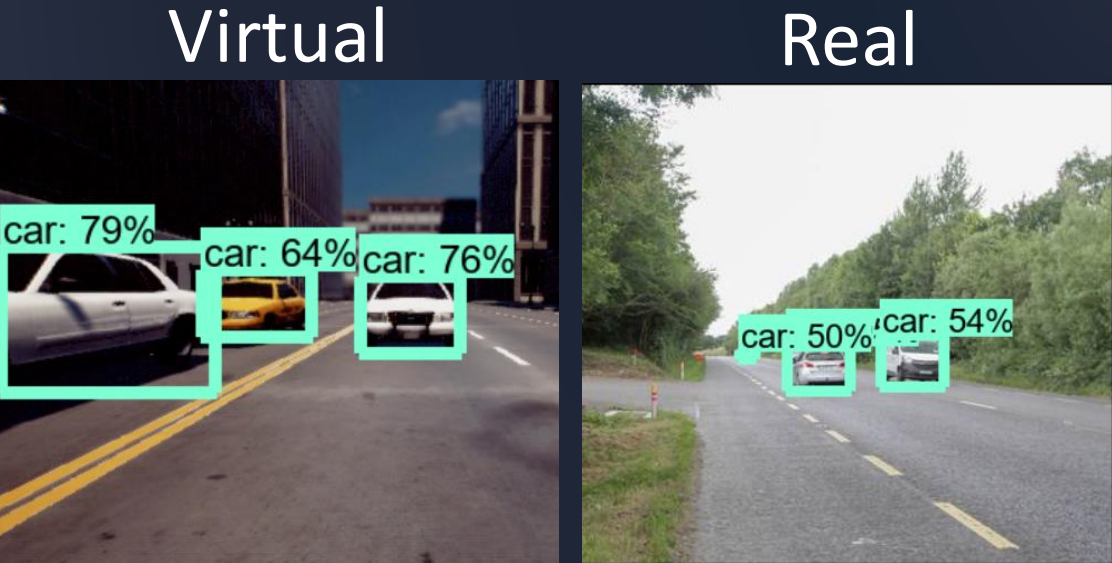
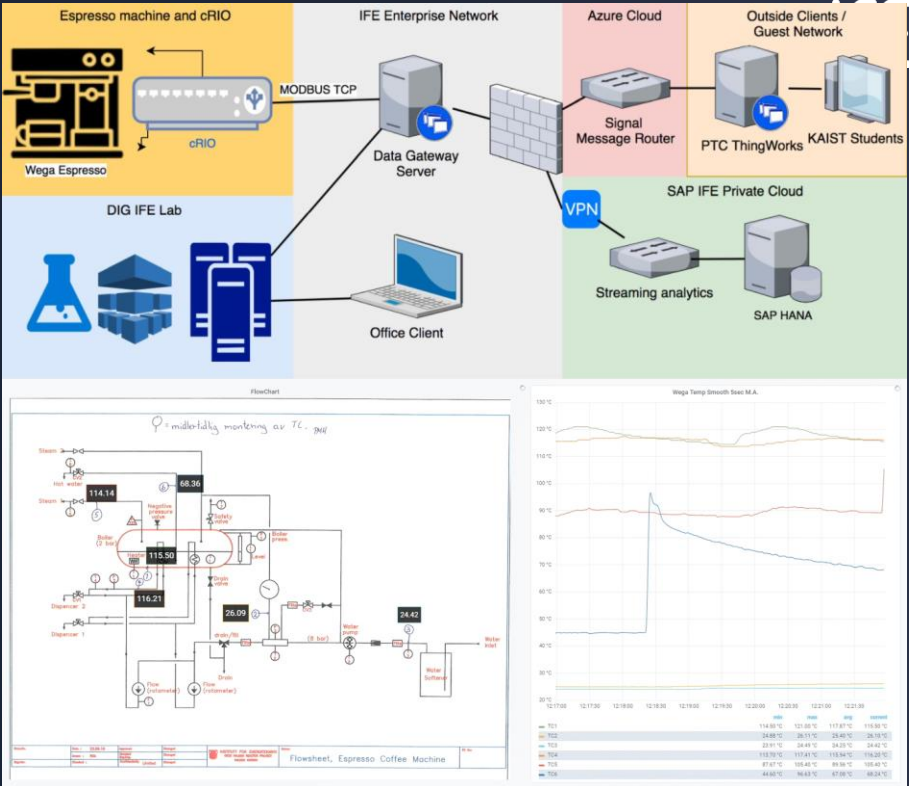


Courtesy of Florida International University

Digital twins for robotics



Machine learning and AI



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



DroneMob

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 professionnals and newcomers with background in the nuclear and interets in digital innovation.

Elinder2020@digidecom.eu **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

Making Future.

Norsk nukleær
dekomisjonering



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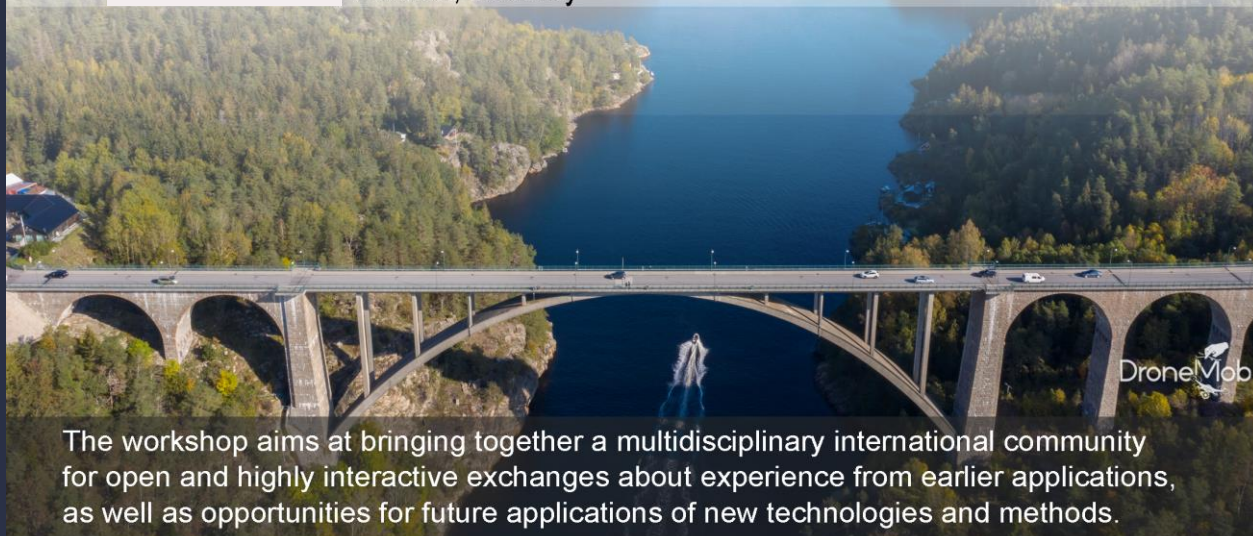
DigiDecom 2020



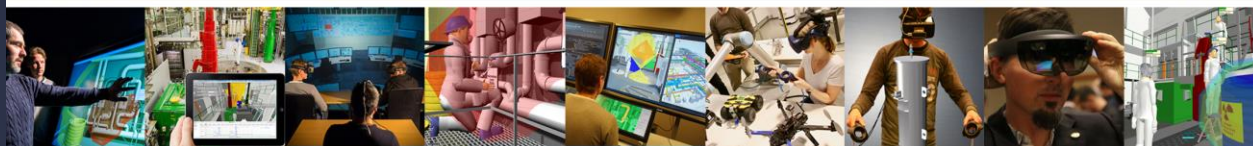
DigiDecom 2020: International Workshop on Roadmap for Decommissioning Innovation

Digital transformation and other game changing trends

Date TBD 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



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



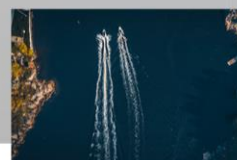
Connect the dots together

- 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
Contact: digidecom@ife.no

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