RoboDecom: New modular robotic solutions for nuclear decommissioning in Norway and abroad
&
LiveDecom: Digital support for management of nuclear decommissioning in Norway and abroad

Prepared by István Szőke

Institute for Energy Technology, Halden, Norway

Contact: Istvan.Szoke@ife.no

Institute for Energy Technology (IFE)

Annual turnover:
> 100 Mill €

Annual scientific publications with referee:
120

1948: IFA

1980: IFE

No. of employees:
650

Nationalities: 37
Researchers: 218
PhDs: 105

14000
Visitors a year

Advanced Laboratories:
24

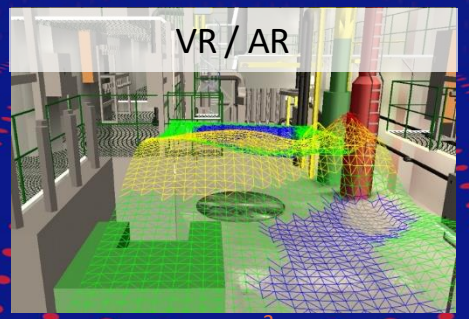
National Centers for Environment-friendly Energy Research
2

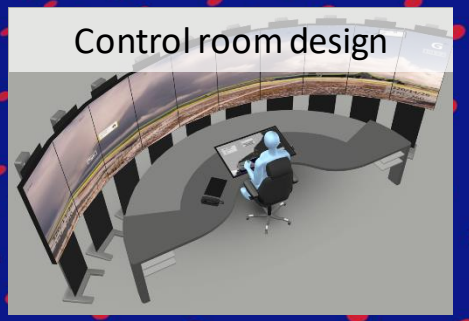
International projects:
> 120

Research for a better future

Institute for Energy Technology

Digital Systems





IFEs Digital Capabilities

Impact of digitalization on organizations and people 	Cybersecurity and risk managent 	Visualisation of complex data 	Modelling/ Simulation 	Processing and distribution of large amounts of data 
Generating data/ data collection 	Data analyse/ Data science 	Forecasting and prediction 	Decision support 	Automation/ autonomous systems 

OECD Halden Rector Project HRP

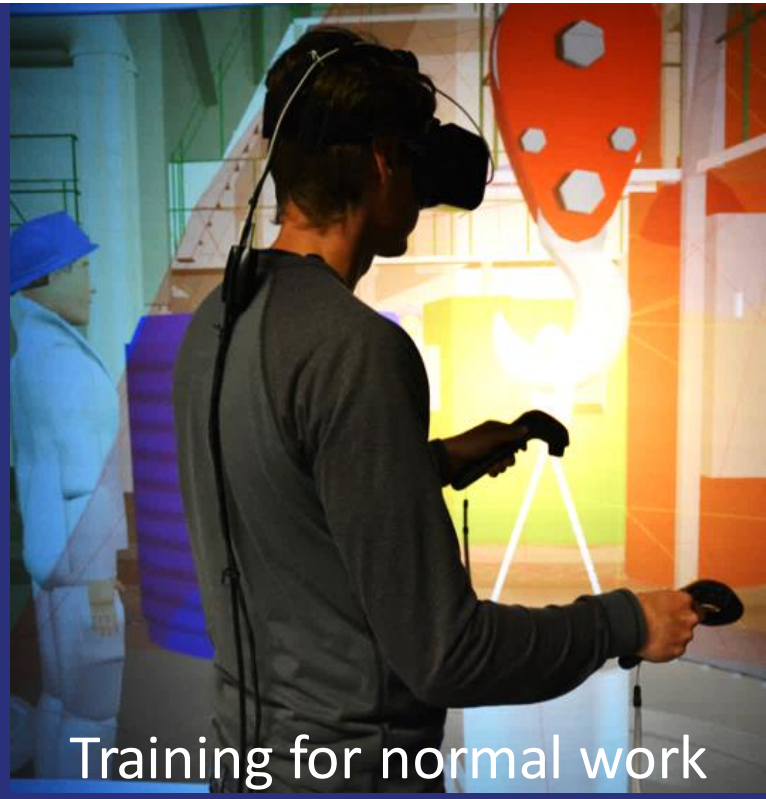
One of the World's longest collaboration program within the nuclear

Safety management for nuclear decommissioning

<u>>100 organization</u>
<u>19 countries</u>

utilities, suppliers, authorities and R&D centers:

CEA, CIEMAT, CNPRI, CRIEPI, FRAMATOM, DTU, EDF, E.ON, ENSI, EPRI, EU JRC, FANR, GE/GNF, GRS, IRSN, JAEA, KAERI, Kazatomprom, MEE, Mitsubishi, **<u>MTA EK</u>**, NNL, NRA, NRG, PSI, SCK/CEN, SNERDI, SSM, TVEL, UJV, US DOE, US NRC, VUJE, Westinghouse …



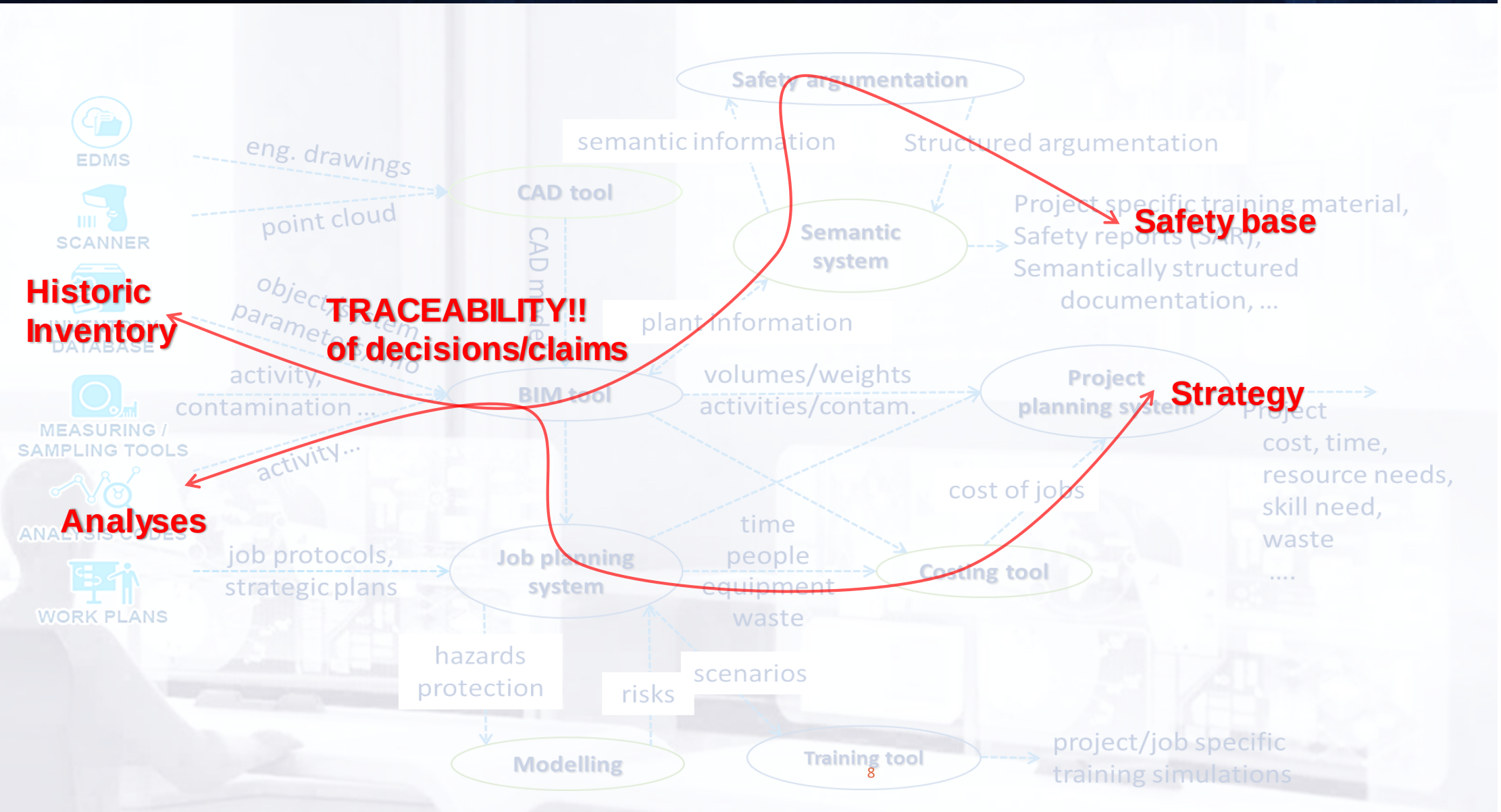
Training for normal work and emergencies in nuclear decommissioning

Business case – digitalization for nuclear decom

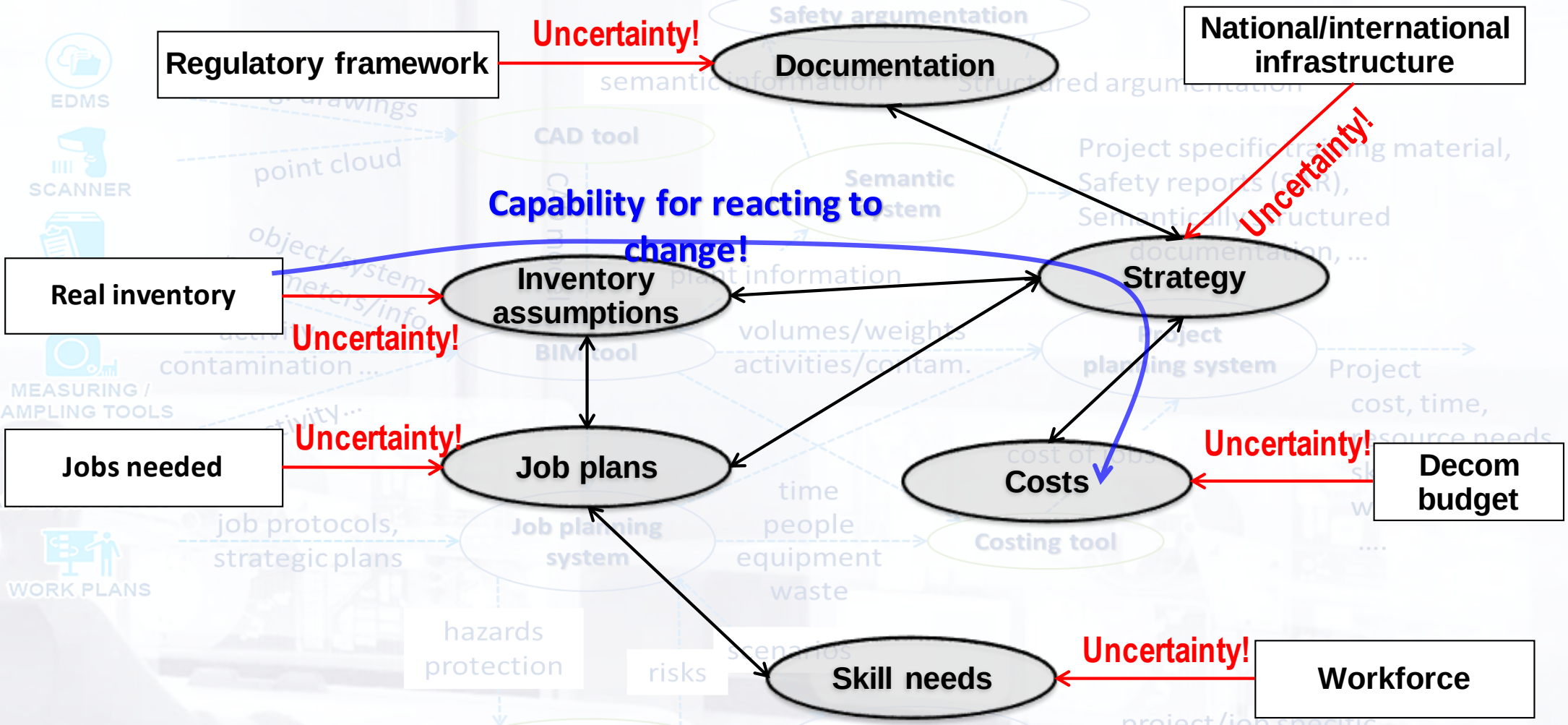
1. **Special situations**
    1. Accident sites e.g. Fukushima, Chernobyl, …
    2. Unique work e.g. degrading nucl. Sties, graphite reactors
2. **Holistic approach (integration)**
    1. Application across domains (disciplines)
    2. Use across the whole stakeholder team
    3. Start early, use through the whole process
3. **Don’t underestimate the impact on motivation**
4. **Leverage capabilities across projects/domains**
    1. Big organisations, national strategy
    2. Other domains

Holistic digital support - theory

Integration – traceability of reasons



Holistic planning – agile decom



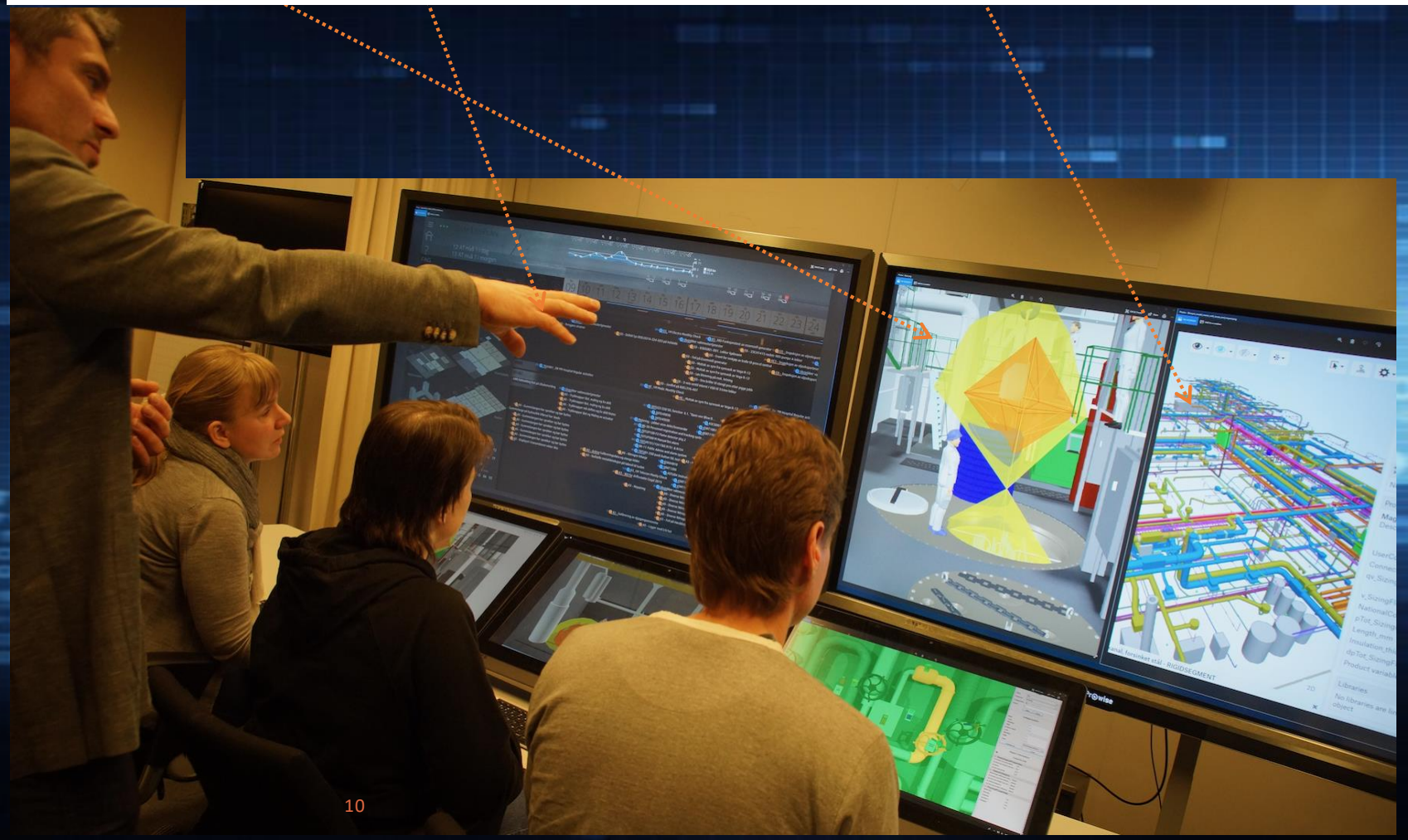
LiveDecom: Prototyping integration of digital capabilities

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,
- …



Business case – digitalization for nuclear decom

1. Special situations ✓
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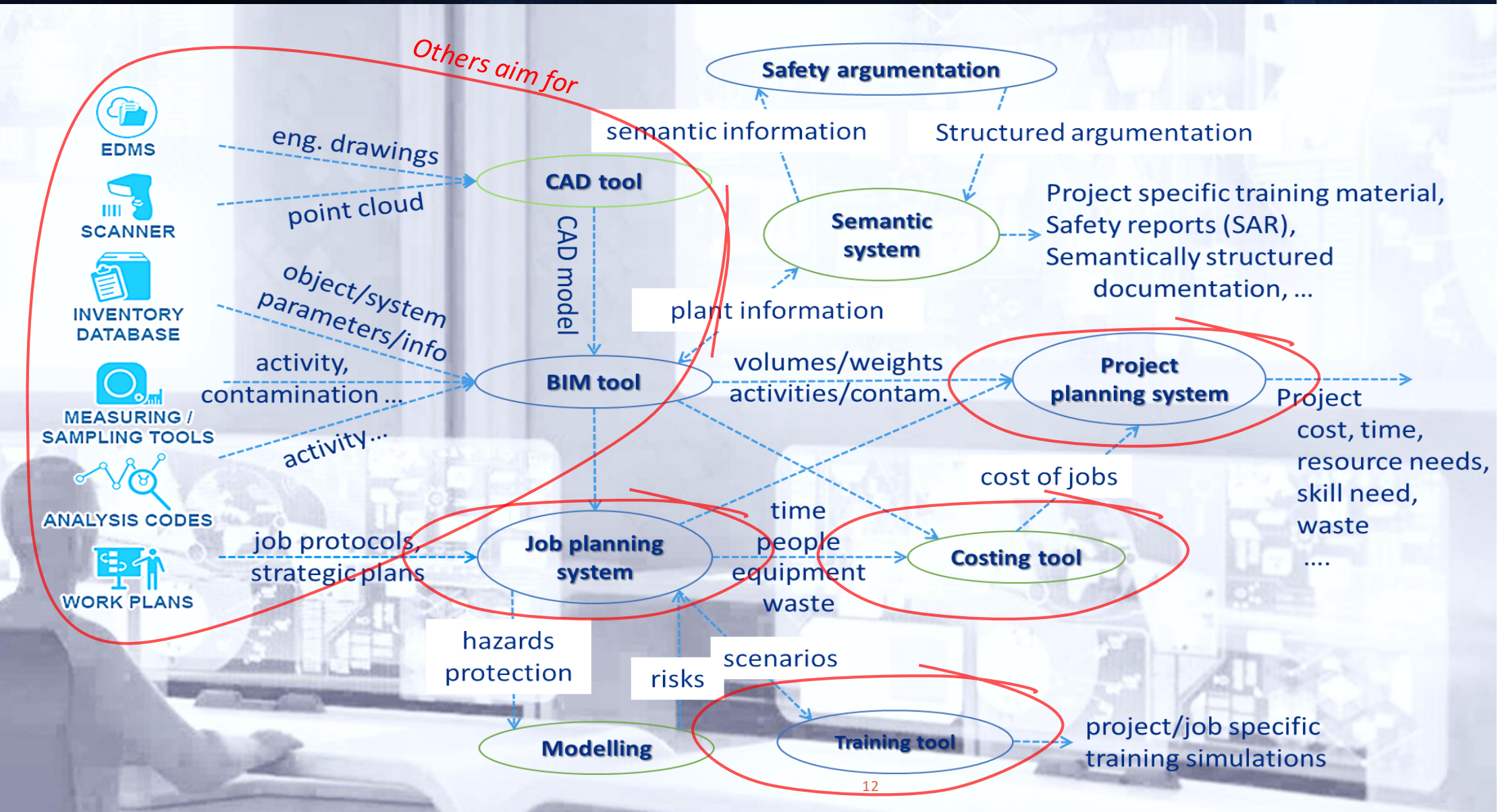
Attempts for integration



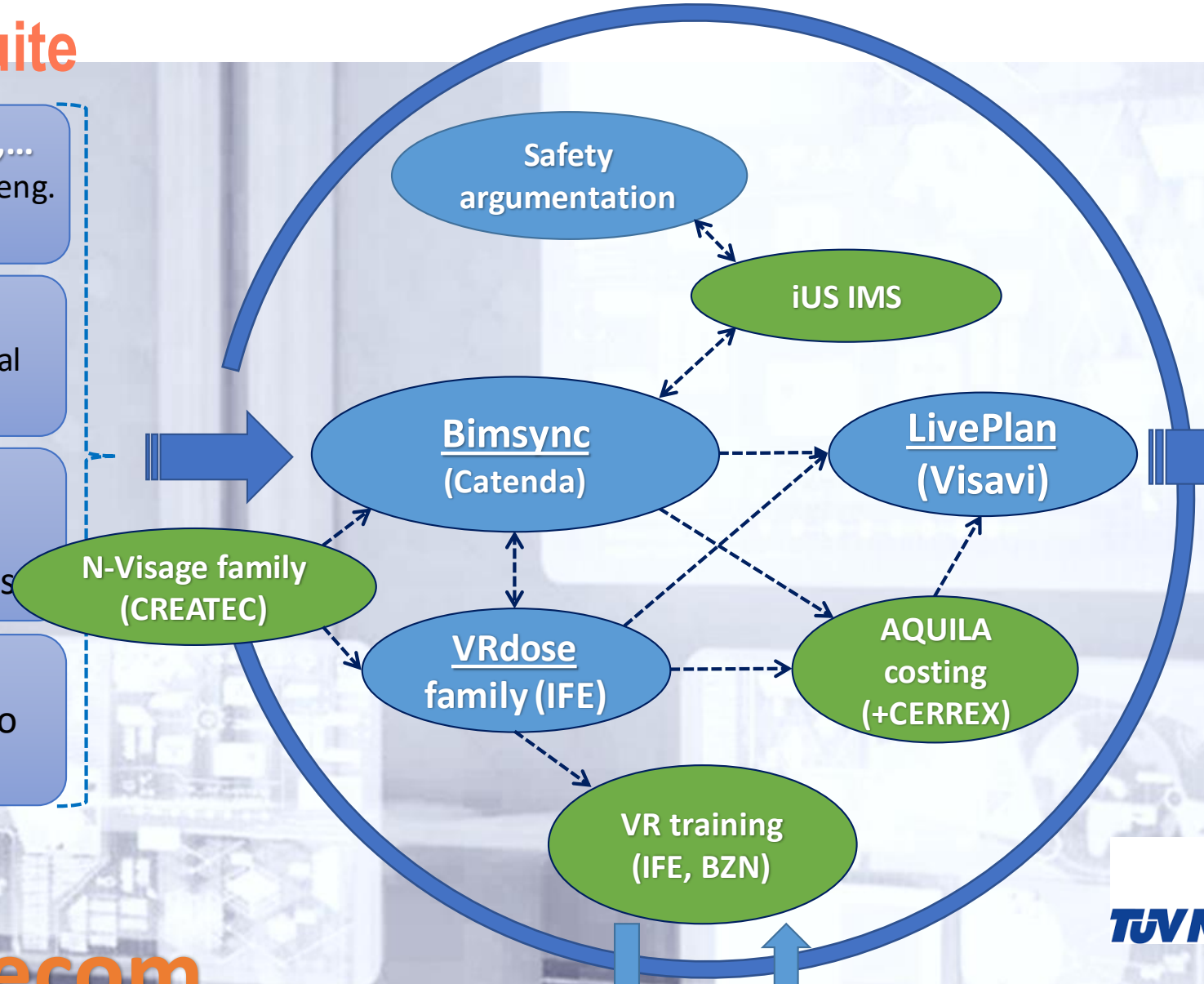
LiveDecom suite

EDMS, SCANNERS,…
point cloud (3D scan), eng. drawings, photos

INVENTORIES
physical & radiological characteristics

INSTRUMENTS
measurements, samples, calculations

WORK PLANS
strategies, scenario descriptions, …



Strategy 1

Strategy 2

Strategy 3
Waste
Exposure
Costs
Risks
Time
Uncertainty
Resources
Skills
Equipment
…

Other software interfacing with LiveDecom
EDMS, MRO, EPR, Safety evaluation, … systems

LiveDecom suite

TÜV NORD

JRC EUROPEAN COMMISSION

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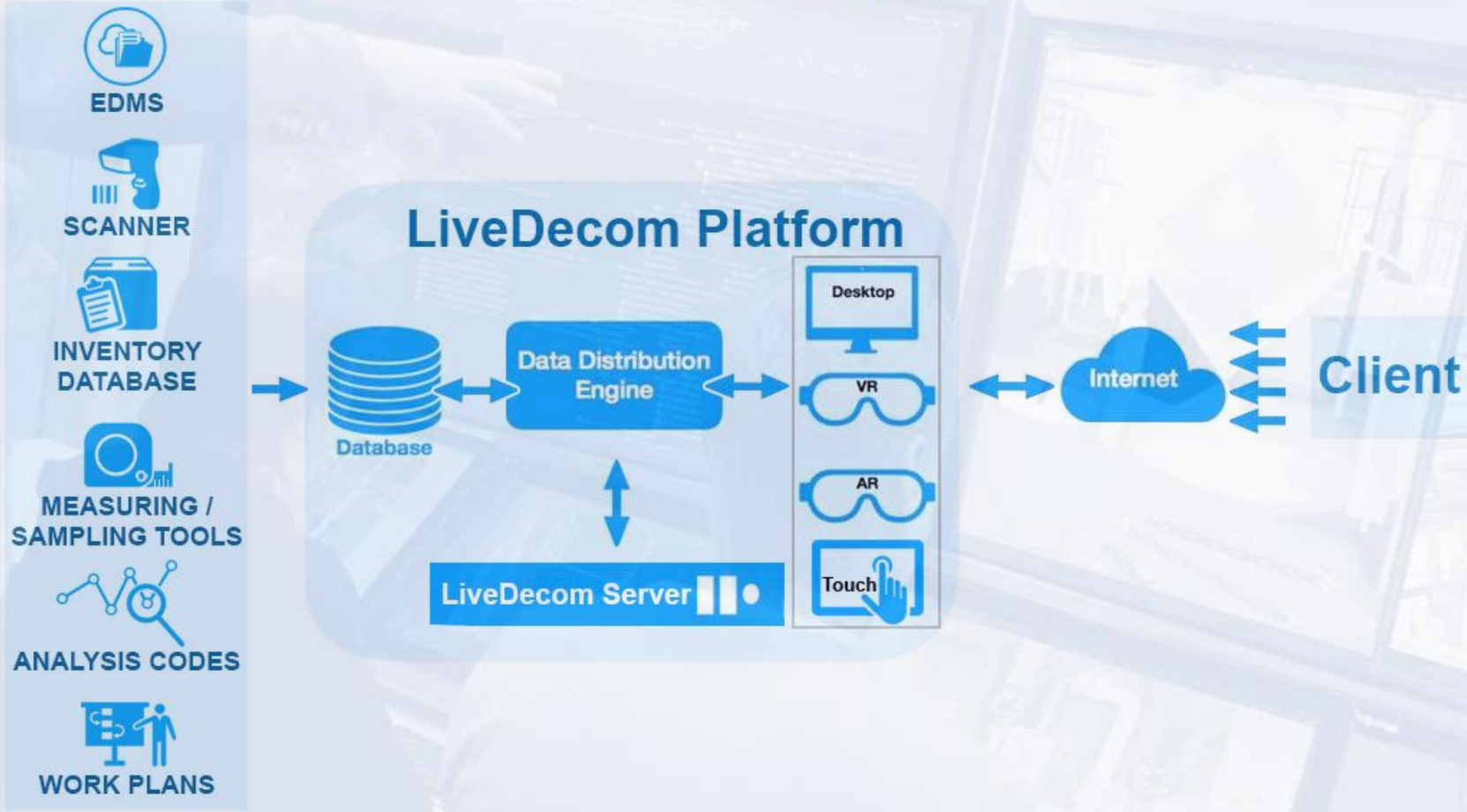
LiveDecom Platform



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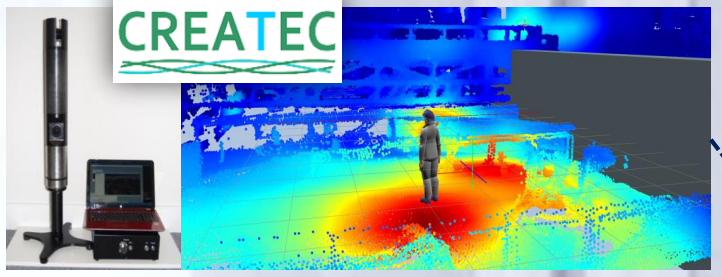
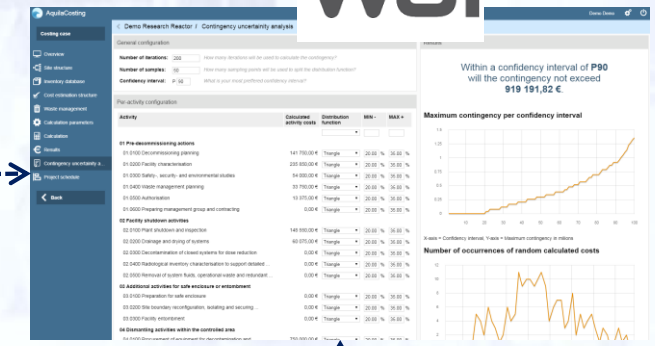
LiveDecom suite

CREATEC



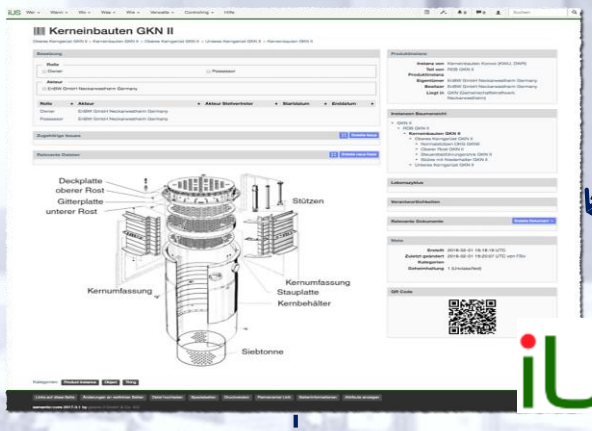
Catenda

wai



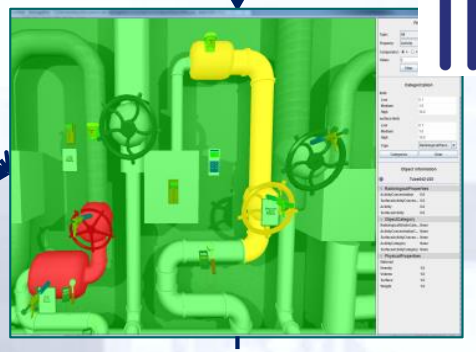
JRC
EUROPEAN COMMISSION

TÜV NORD

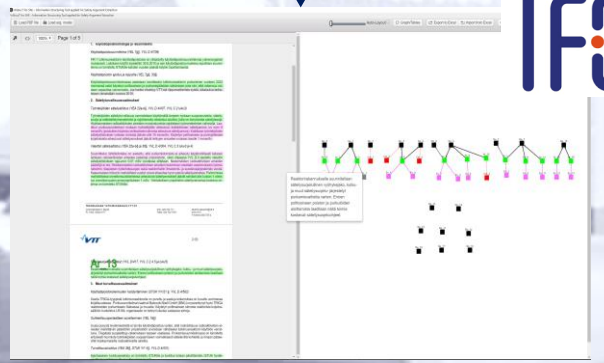


iUS

IFE



VISAVI TECHNOLOGY



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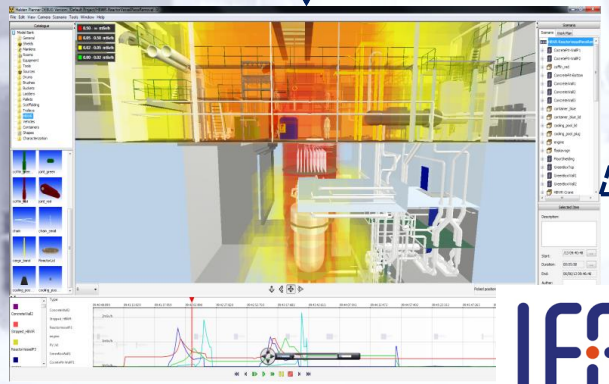


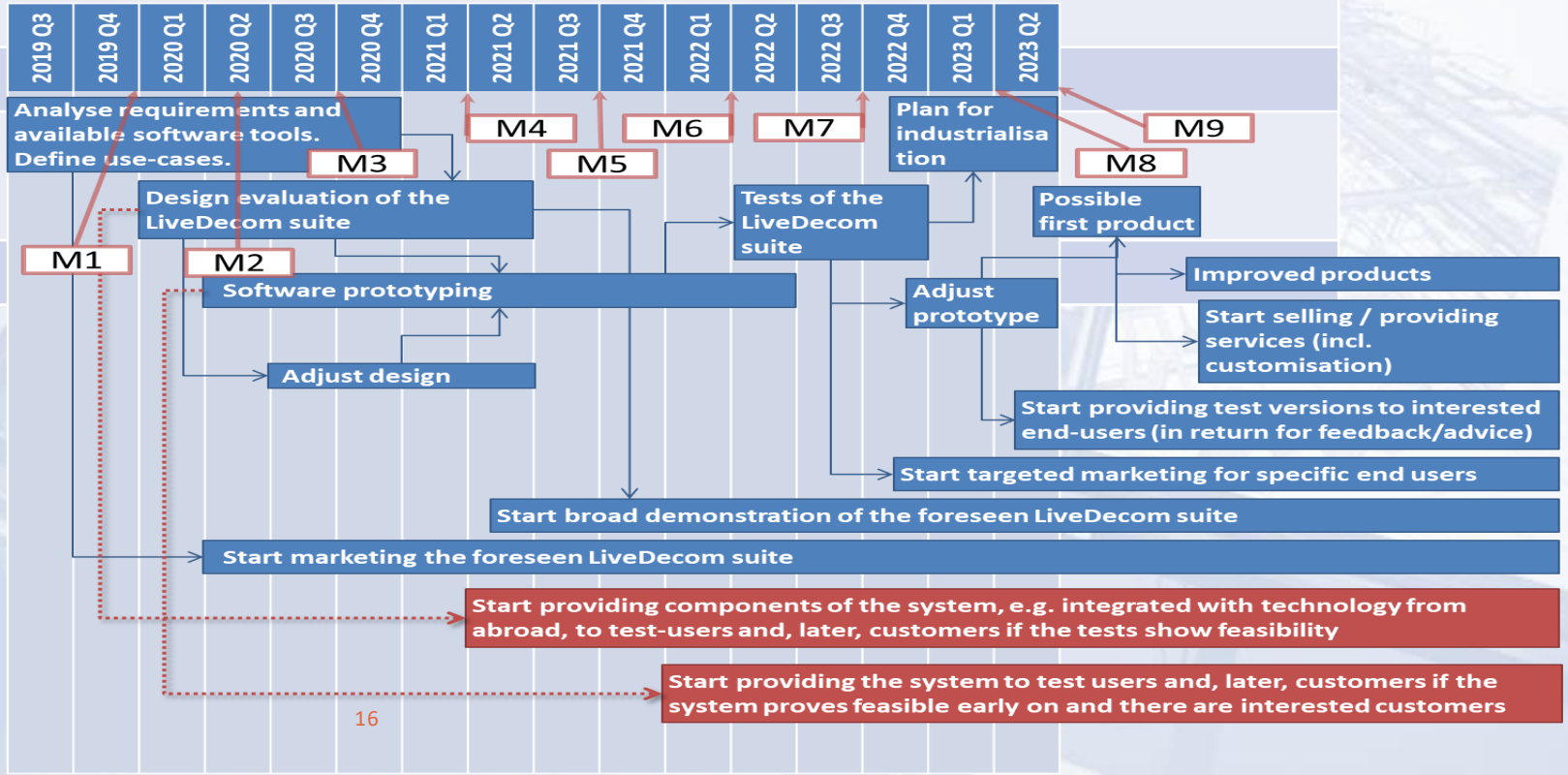
IFE

IFE

bay®

LiveDecom project plan

Milestone	Month from start	Title
M1	6	Key user needs and requirements in nuclear decommissioning (and other domains)
M2	11	Key safety (including regulatory) requirements impacting upon applicability
M3	15	Integration protocols
M4	21	Realistic (practical) use-cases
M5	27	Designs for the LiveDecom prototype for the identified use-cases
M6	33	Laboratory testes
M7	39	Real-life tests
M8	45	Feedback and interest from potential end-users
M9	48	Final evaluation



LiveDecom budget

Norwegian funding (kNOK)	Mean/1year	2019	2020	2021	2022	2023	Sum
Visavi	1 641	938	1 875	1 875	1 875	938	**7 500**
Catenda	1 138	650	1 300	1 300	1 300	650	**5 200**
IFE	1 706	975	1 950	1 950	1 950	975	**7 800**
TOTAL	**4 484**	**2 563**	**5 125**	**5 125**	**5 125**	**2 563**	**20 500**

International in-kind (kNOK)	Mean/1year	2019	2020	2021	2022	2023	Sum
CREATEC	1 000	500	1 000	1 000	1 000	500	**4 000**
iUS	63	32	63	63	63	32	**252**
JRC	100	50	100	100	100	50	**400**
WAI Ltd	300	150	300	300	300	150	**1 200**
Bay Zoltán Nonprofit Ltd.	100	50	100	100	100	50	**400**
TÜV NORED EnSys GmbH	75	38	75	75	75	38	**300**
Total	**1 368**	**782**	**1 563**	**1 563**	**1 563**	**782**	**6 252**

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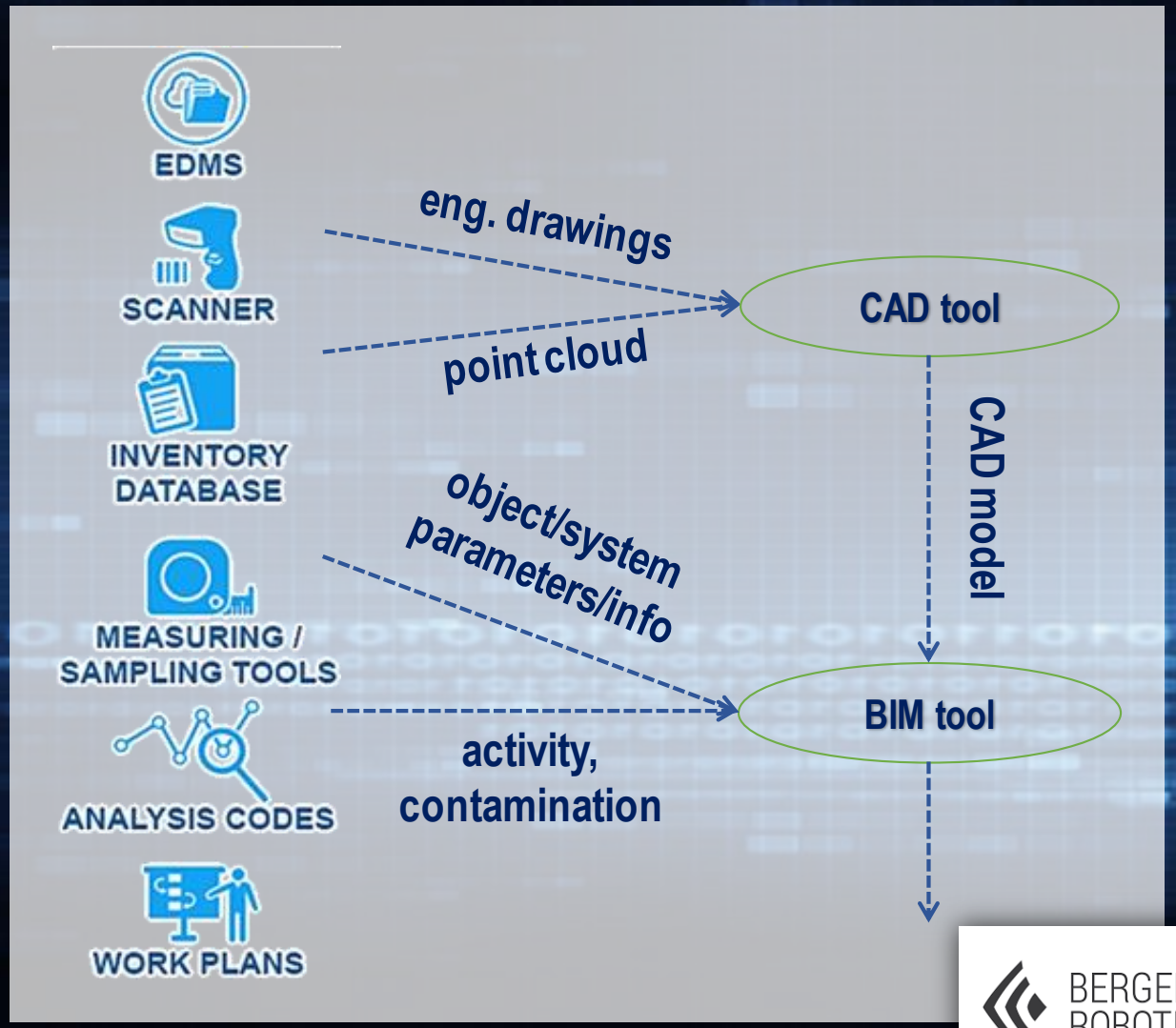
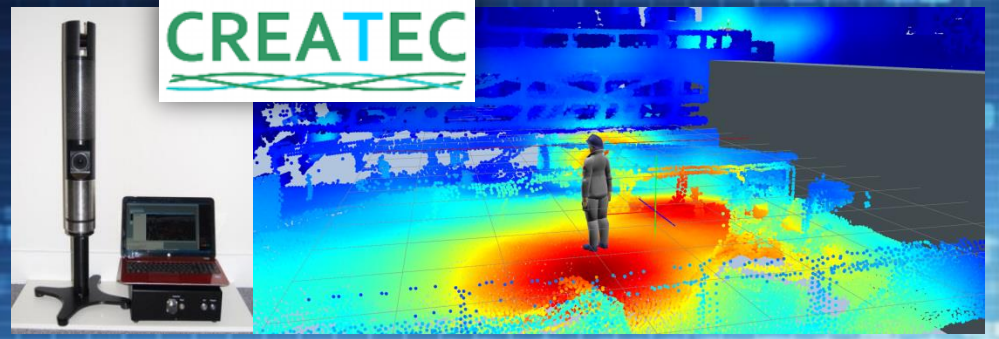
Business case for digitalization

Data/information acquisition!



- 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,

BERGEN ROBOTICS

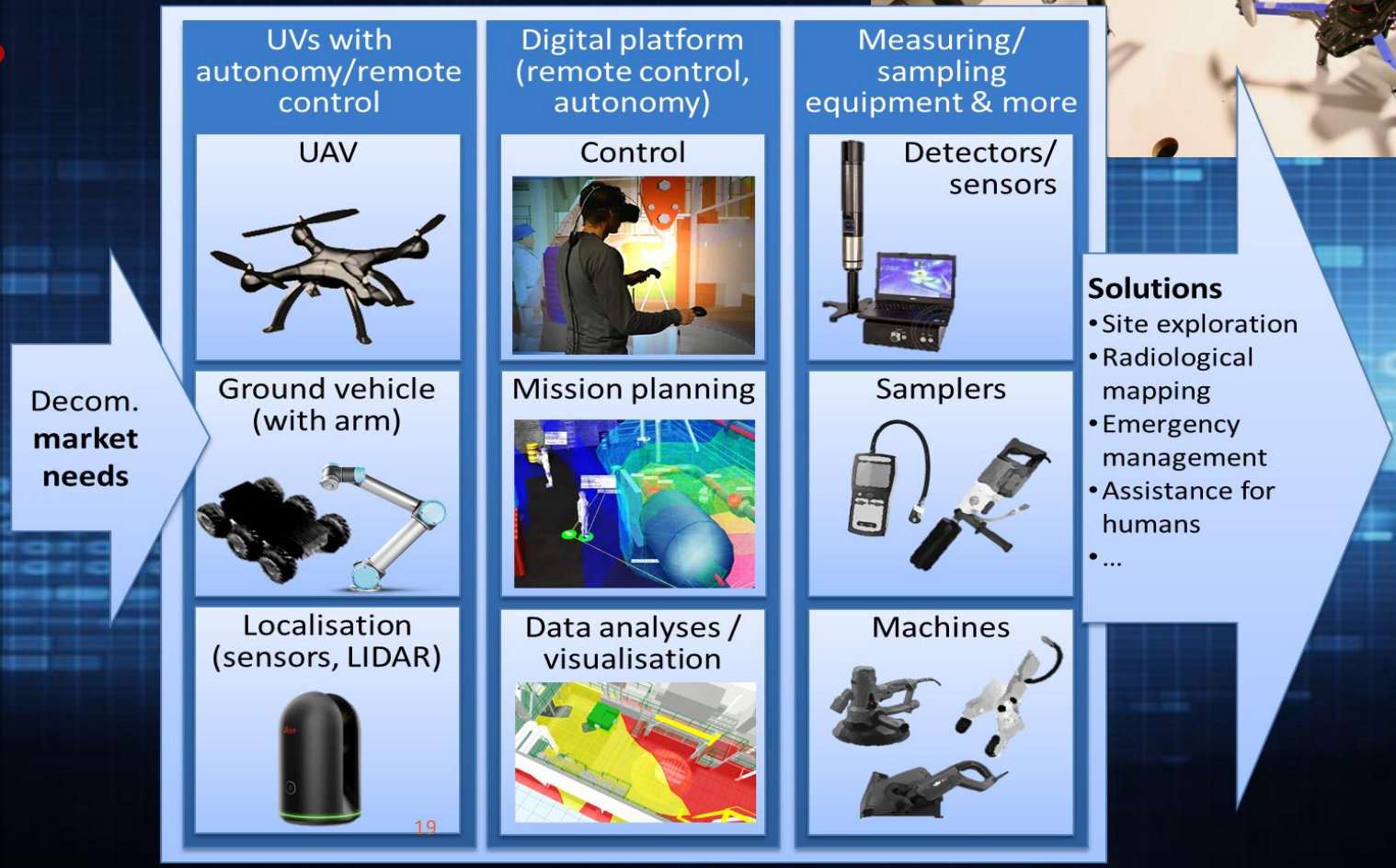
MARITIME ROBOTICS

nLink

RoboDecom – Digitalisation for Robotics in decom.

IFE · nLink · Bergen Robotics · Maritime Robotics · SINTEF · CREATEC · TECNUBEL (Your project needs our care) · MAGICS®

- 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



Business case – digitalization for nuclear decom

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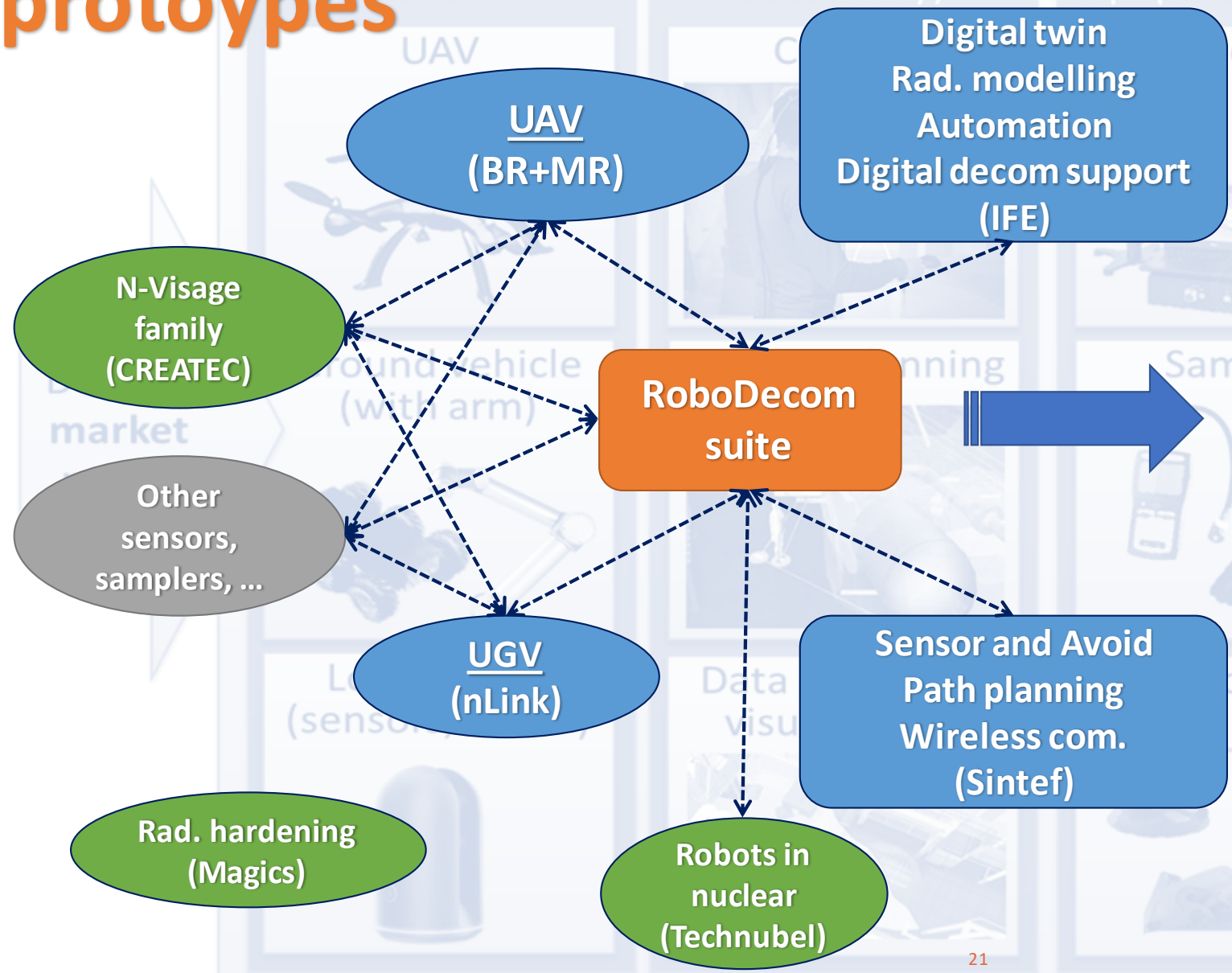
    2. Other domains

RoboDecom protoypes



Remote, semi- or autonomous capabilities for:

360 photography supporting:

- site monitoring
- briefing – situation awareness
- design/config. info checking
- training

3D scanning & radiological mapping for supporting

- design/config. info
  - reconstruction
  - validation - ‘as is’
  - update
- digital capabilities supporting
  - safety planning
  - safety monitoring
  - safety training
  - in-the field safety info

Sampling? – rad. characterisation

Emergency management

RoboDecom prototypes

MARITIME ROBOTICS

SINTEF

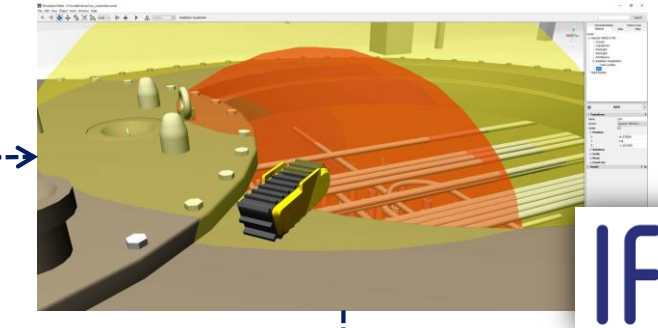
Sensor and Avoid
Path planning
Wireless com.

BERGEN ROBOTICS

CREATEC

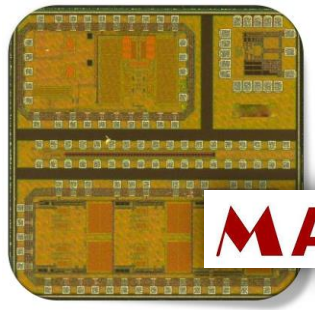
RoboDecom
SW suite

IFE



IFE

Digital assessments, Field tests

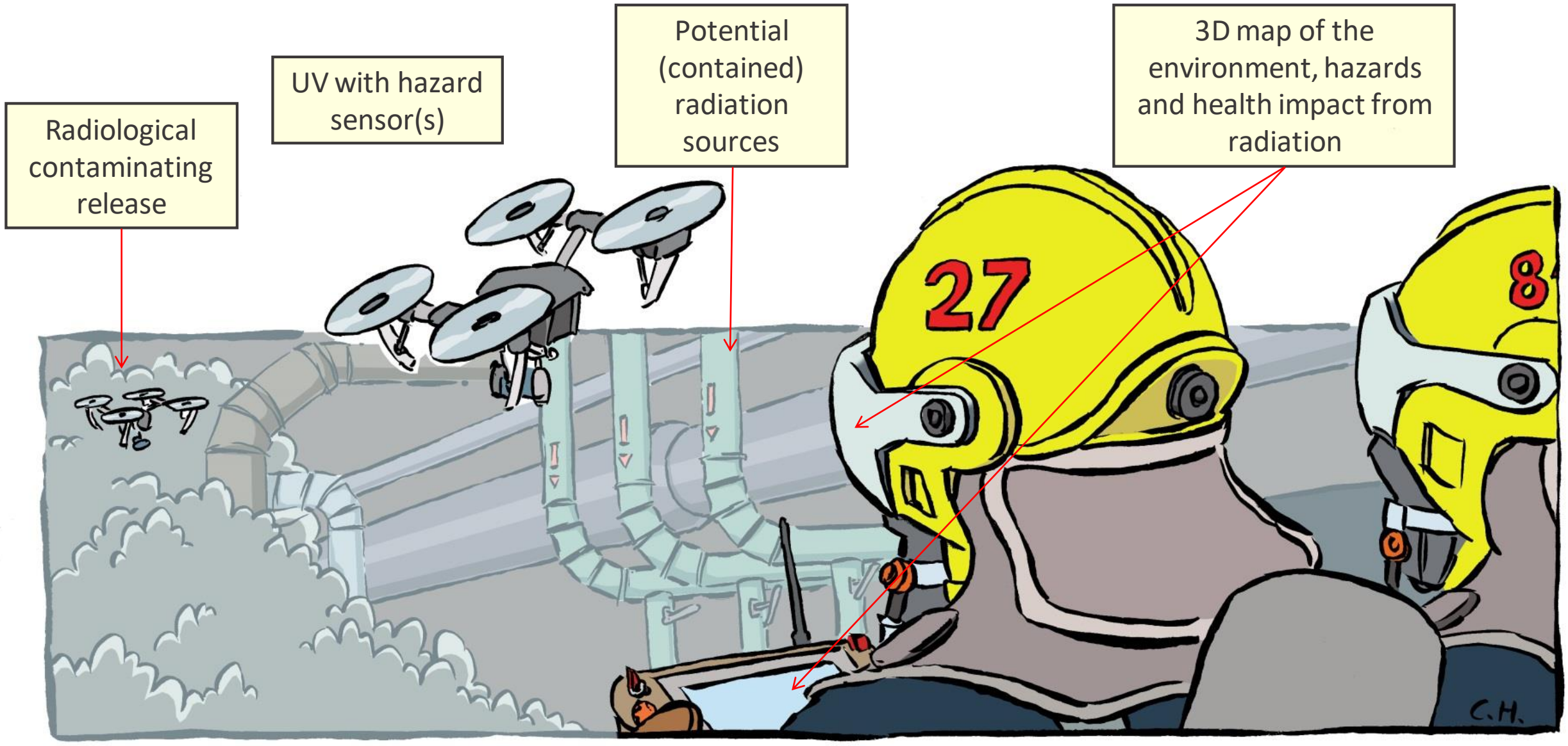


MAGICS®

nLink

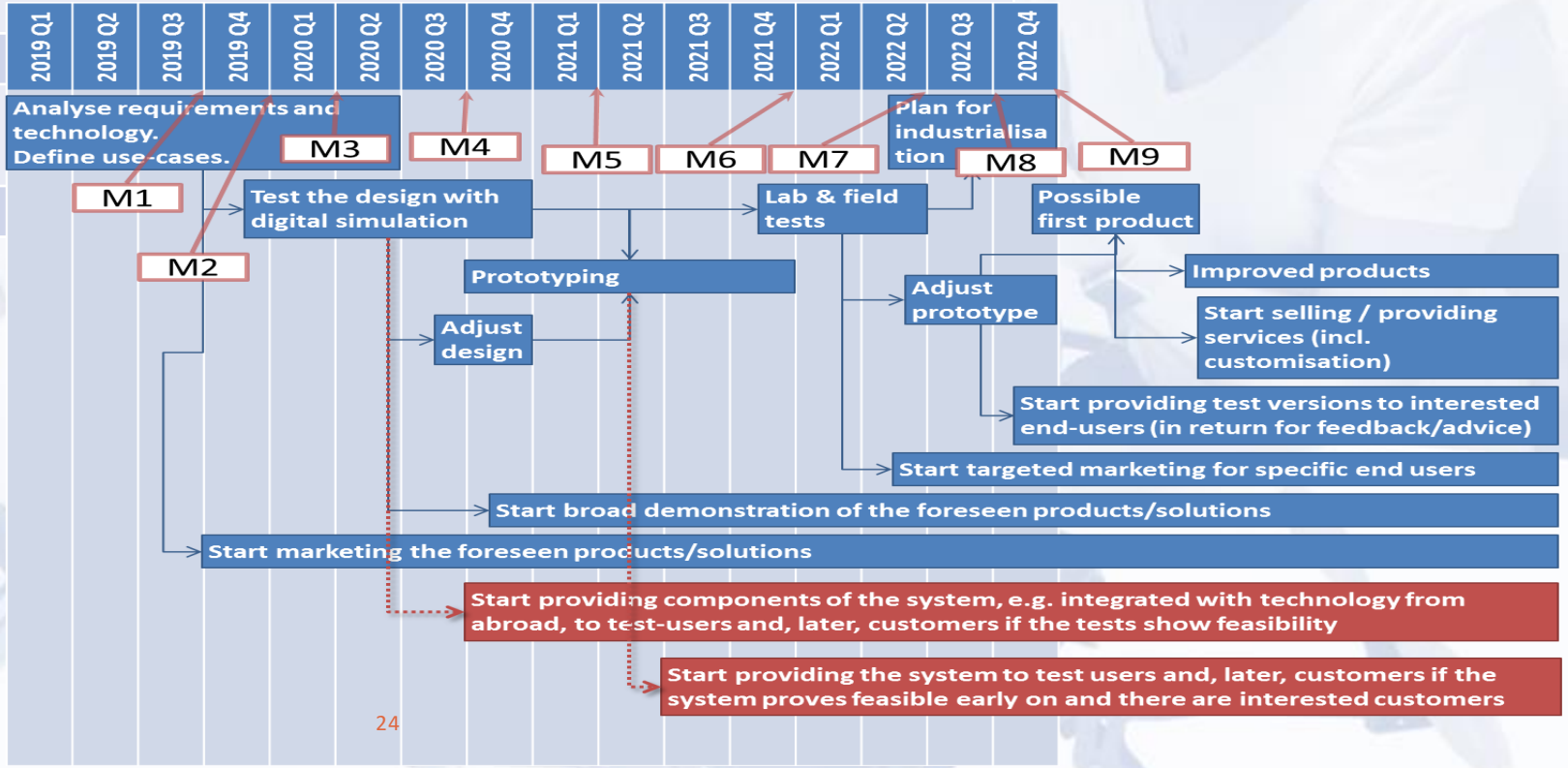
LiveDecom suite

RoboDecom - emergency management



RoboDecom project plan

Miles tone	Month from start	Title
M1	9	Key user needs and requirements.
M2	12	Key safety (including regulatory) requirements.
M3	15	Key technology, and their performance, candidates for RoboDecom components.
M4	21	Realistic (practical) use-cases - for which suitable components are available
M5	27	Digital evaluation of designs for the two prototypes for the identified use-cases
M6	36	Laboratory tests
M7	42	Field test
M8	45	Feedback and interest from potential end-users
M9	48	Final project evaluation



RoboDecom budget

Norwegain funding	Mean/1year	2019	2020	2021	2022	2023	Sum
nLink	4 125	4 000	4 100	4 150	4 250	0	**16 500**
Bergen Robotics	1 400	1 400	1 400	1 400	1 400	0	**5 600**
Maritime Robotics	500	500	500	500	500	0	**2 000**
IFE	2 575	2 661	2 592	2 558	2 490	0	**10 300**
Sintef	1 192	1 231	1 200	1 184	1 152	0	**4 768**
TOTAL	**9 792**	**9 792**	**9 792**	**9 792**	**9 792**	**0**	**39 168**

International funding	Mean/1year	2019	2020	2021	2022	2023	Sum
CREATEC	1 000	1 000	1 000	1 000	1 000		**4 000**
TECNUBEL	1 000	300	600	1 100	2 000		**4 000**
MAGICS	250	250	250	250	250		**1 000**
Total	**2 250**	**1 550**	**1 850**	**2 350**	**3 250**	**0**	**9 000**

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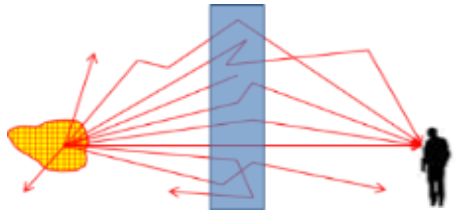
Radiation transport and dosimetry

Real-time (Point Kernel) radiation transprot

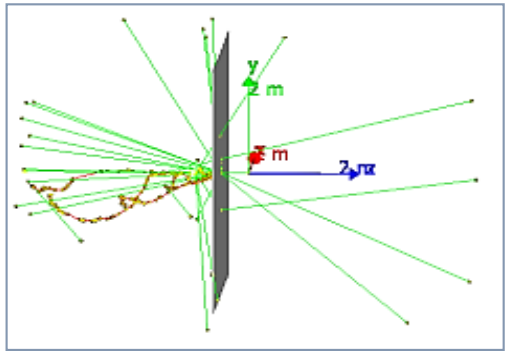


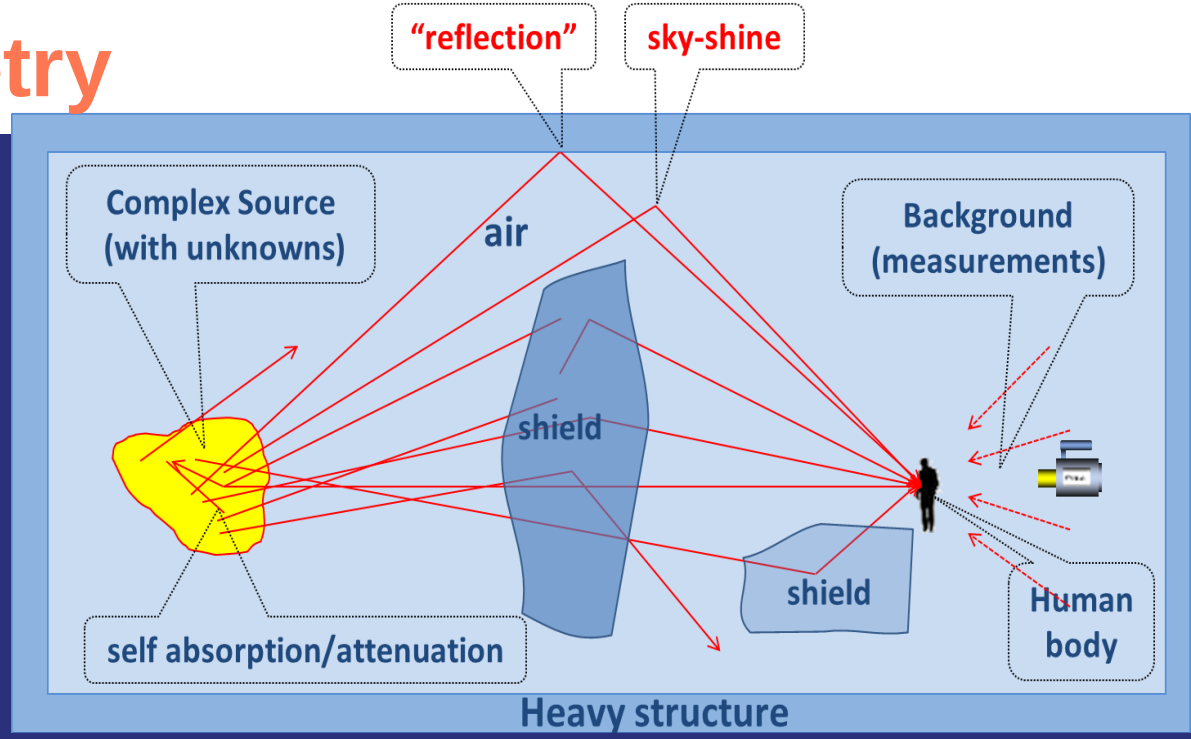
$$Dose = Const \times \sum_i \left(\frac{Ay_i}{4\pi d^2} \times e^{-\mu_i x t} \times E_i \cdot (\mu_{en}/\rho)_i \times B_X(E_i, t) \right)$$

rate of energy absorbed in air from secondary charged particles

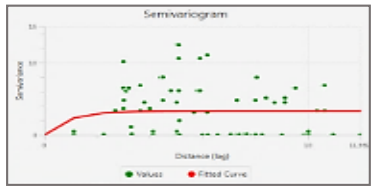
conversion of units $\Phi_i(natt)$ $\Phi_i(att)$ $\psi_i(att)$ CF

MC radiation trasport (MCNP, GEANT4)





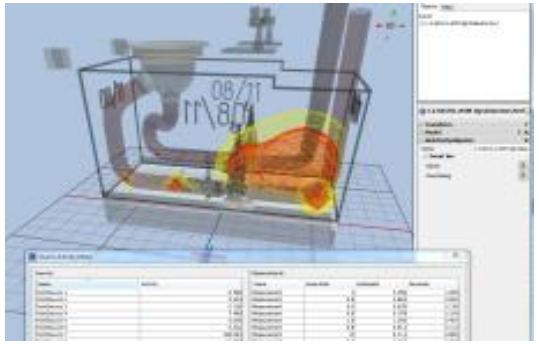
Interpolation, Geostatistics



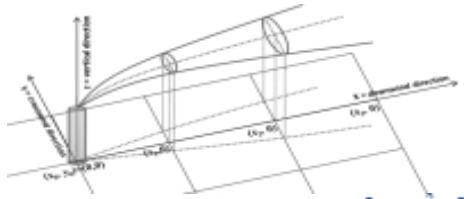
$$Z^*(\mathbf{u}) = m(\mathbf{u}) + \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u})[Z(\mathbf{u}_\alpha) - m(\mathbf{u})]$$

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

Source deconvolution



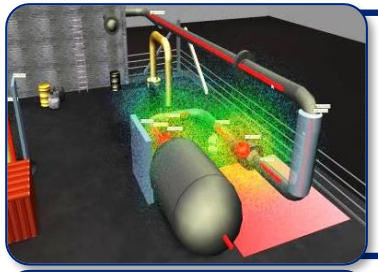
Atmospheric dispersion



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

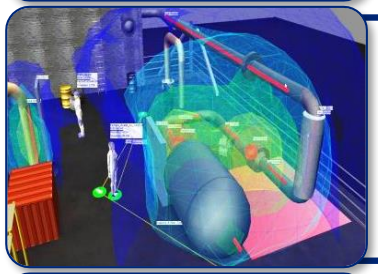
$$C(x,y,z) = \frac{Q(x)}{\sqrt{2\pi} \cdot \sigma_y(x) \cdot A \cdot u_{10}} exp\left[\frac{-y^2}{2\sigma_y(x)^2}\right]$$

Core tech base:
The IFE VRdose™ family



Visualize

- The environment (digital model),
- Radiation emission/exposure, and
- Work scenarios (3D technology)



Optimize

- Modify (interactive, real-time)
- Compare alternative scenarios

Demonstrate & document

- Playback with interactive navigation and visualisation
- Output printer-friendly reports

Training/field support

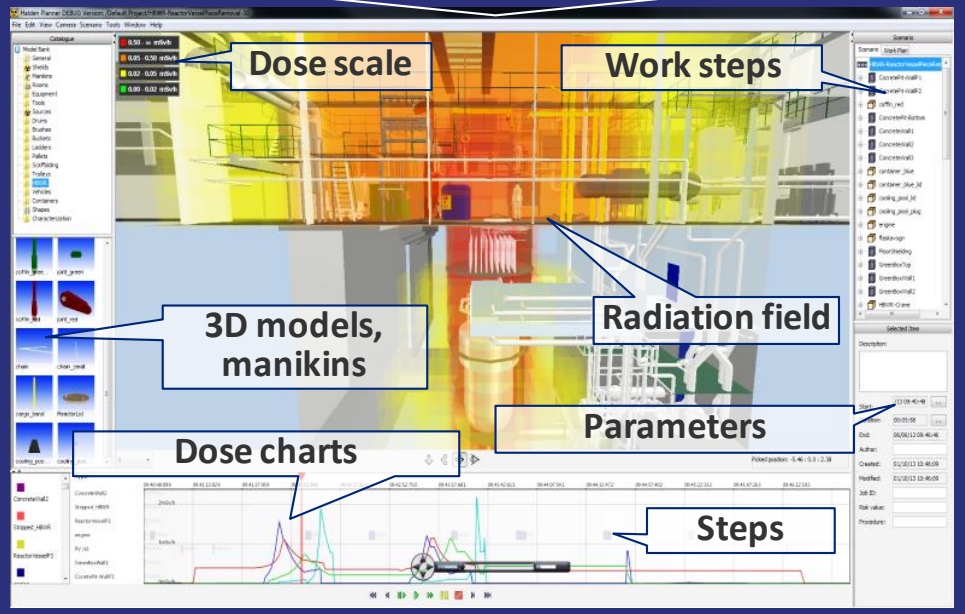
- Mobile and interactive material
- Augmented / mixed reality

User(s)

Info. systems

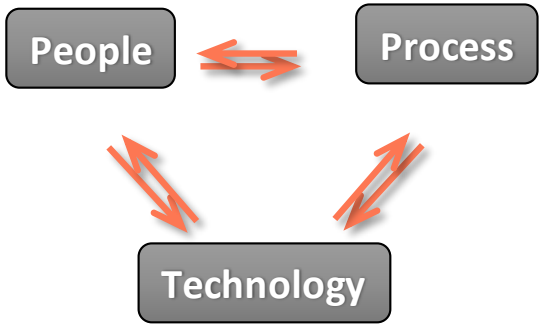
Sensors

Plant information:
3D models, radiological data, other parameters, work plan



Optimal work procedure, Worker dose/risks, Comparison of alternatives, Documentation, Demonstrations, Training material

Technology

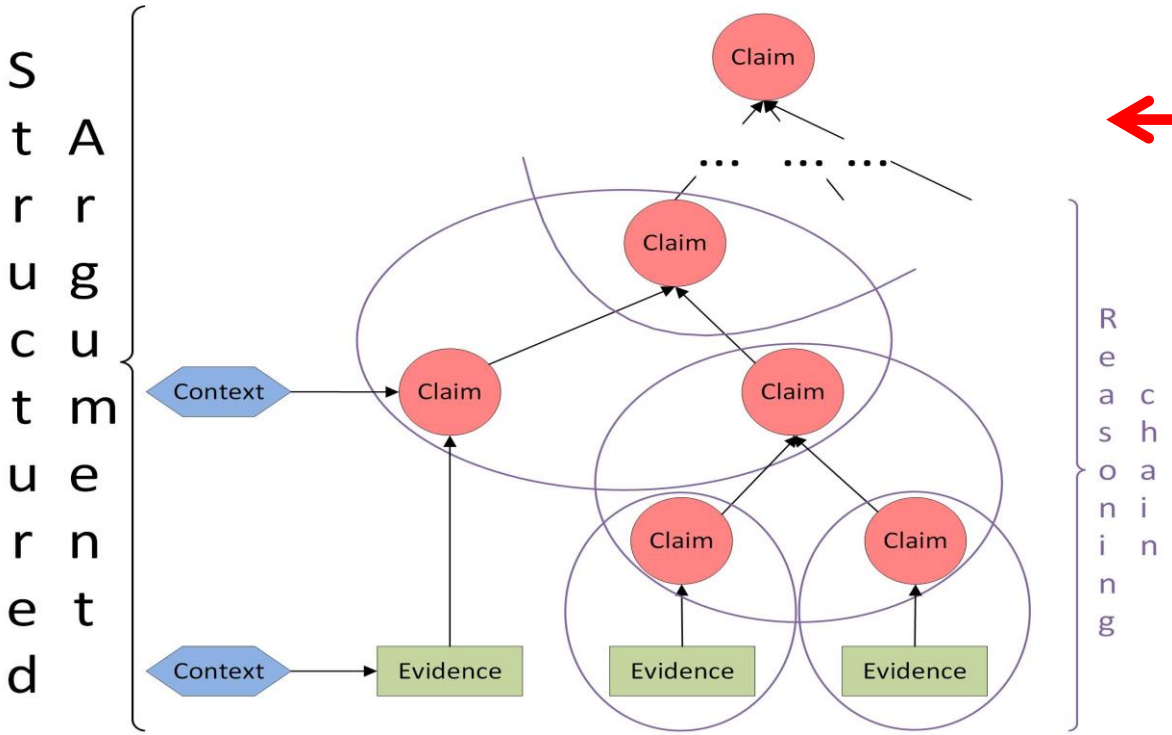


H&O factors

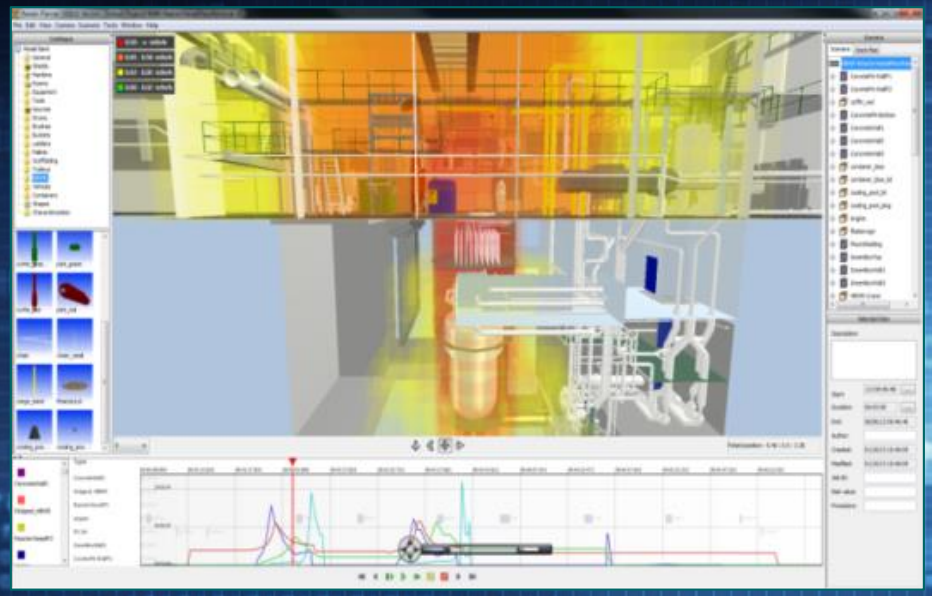
- Regulation
- Tech acceptance
- Motivation
- Skills
- Human perception
- Management support - resources
- Roles and responsibilities - in-house / outsourcing
- Existing organisational processes – change management
- …

Safety assurance

Argumentation based textual



3D Digital

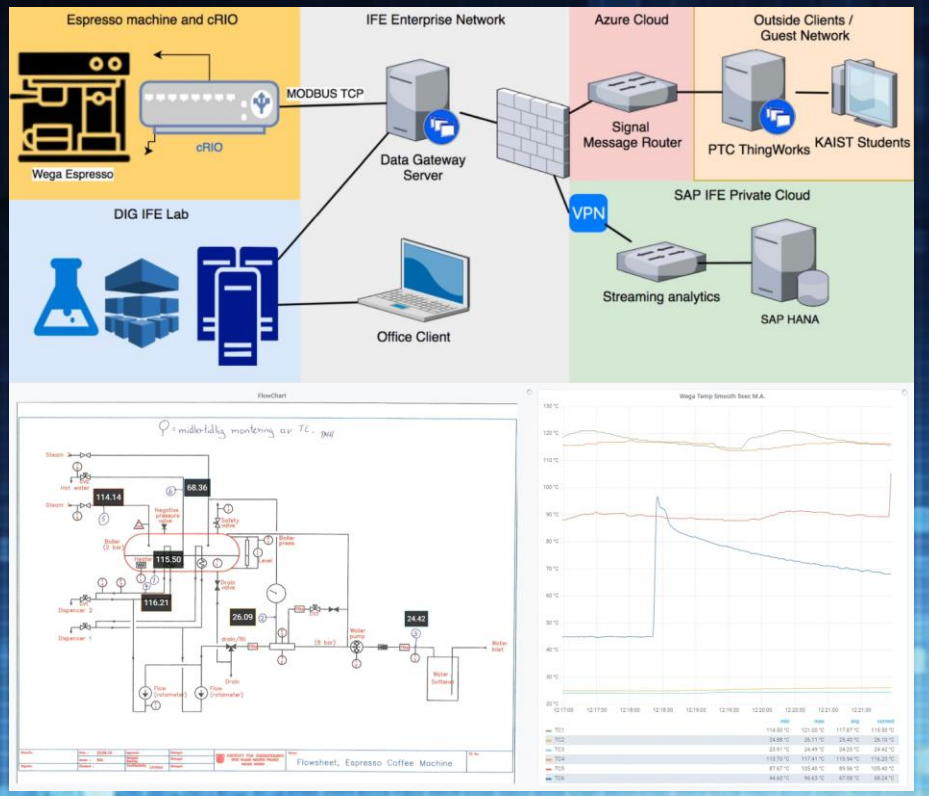


Safety analyses – HAZOP…
3D simulation supported

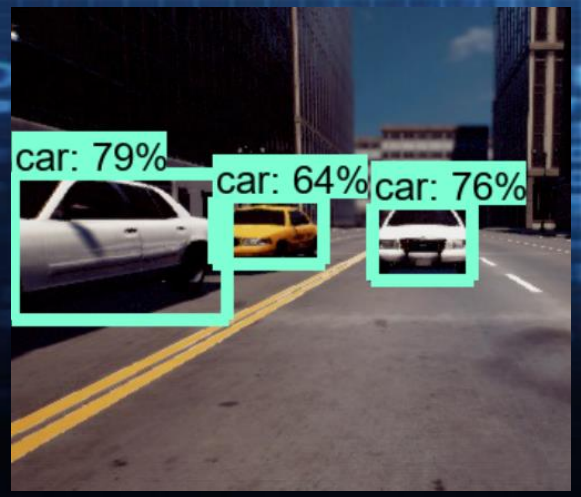
Machine learning and AI

Rust

Clean



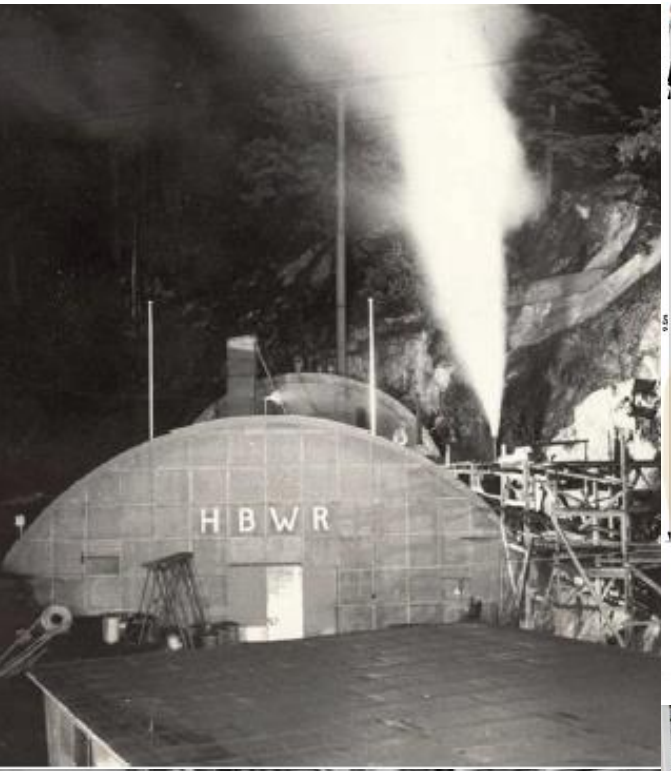
Virtual



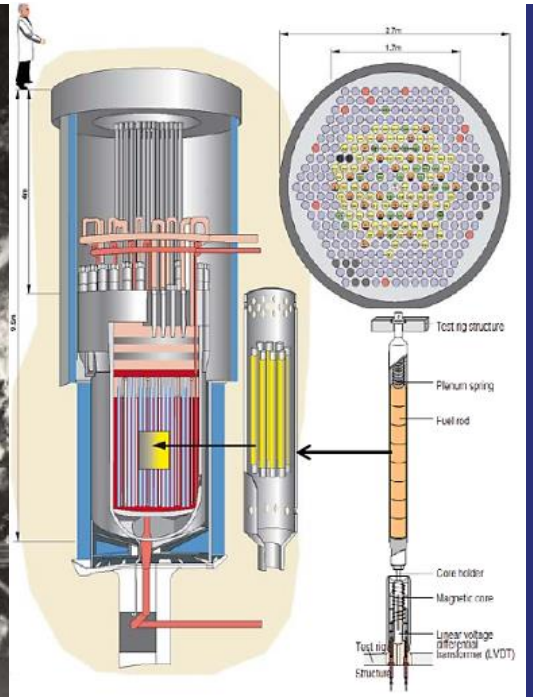
Real

Potholes and cracks

Wider competence area for research

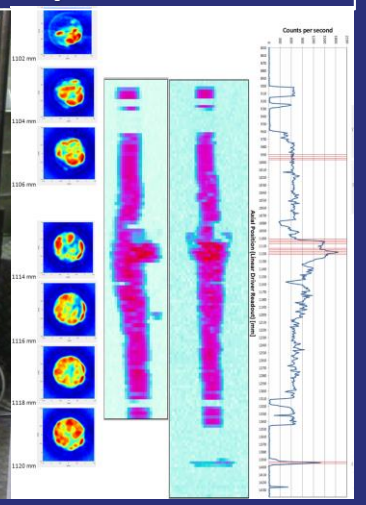


Official opening Oct 10, 1959



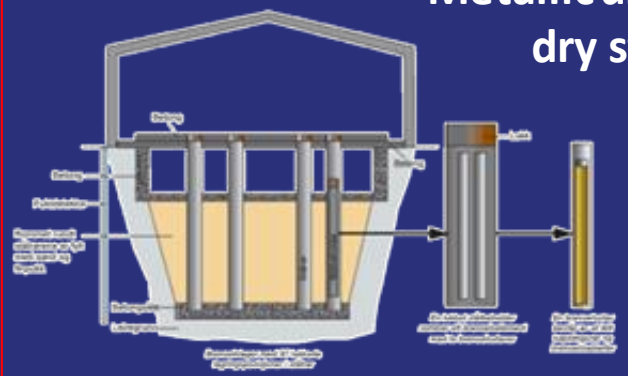
Machine learning / AI/ digital twins…

Gamma spectroscopy/tomography, nuclear analyses codes, material/fuel performance…



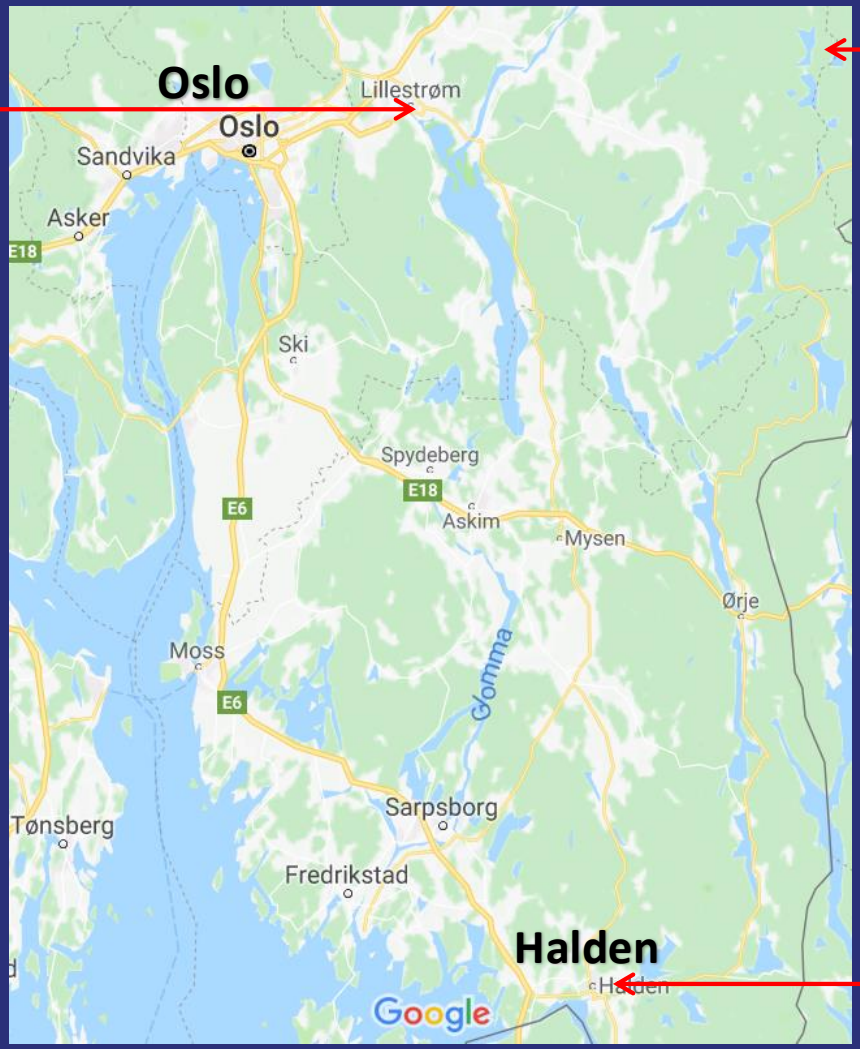
Research into decom

Decommissioning sites at IFE



Metallic uranium SF dry storage for

Uranium pilot plant



Workshops and training courses in 2019

Focus on knowledge management and training/education

- Immersive and interactive presence
- Serious gaming
- Mixed reality – AR based in-situ info
- Trainee performance measures
- Story telling
- Simulation based knowledge exchange

Invitation

Digitalisation for nuclear decommissioning (2019)

Workshop on

Advanced methods for knowledge management, training and education for nuclear decommissioning

Tentative date/venue :

2019 June 18-20

Halden, Norway

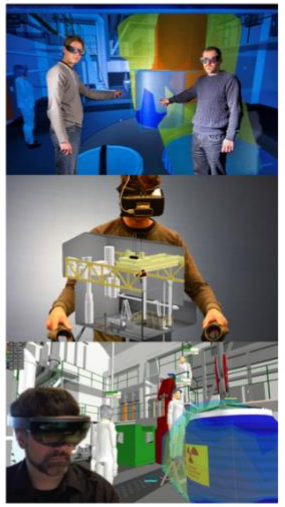
Photo: Joachim Bratteli / IFE

Based on feedback from the participants of our first event under the umbrella of **digitalisation for nuclear decommissioning** (www.ife.no/hrpdecom2017), we are organising this third event for 2019 www.ife.no/digidecom2019. (see also: www.ife.no/digidecom2018).

A growing shortage of skilled nuclear decommissioning specialists is foreseen in the upcoming decades, due to the rapidly increasing demand and low supply (resulting from social and political trends). The workshop will bring together a multidisciplinary group representing the professional community working on implementation and oversight of decommissioning for discussing opportunities and lessons learned from innovative digital methods for knowledge management, training and education in nuclear decommissioning.

The workshop aims at taking advantage of technologies like **storytelling, serious games, 3D simulation, digital twin, and virtual/augmented reality** allowing the participants to:

- **Demonstrate** technology, tools and methods
  - Software and tech support will be provided by IFE
  - Best demos will be rewarded!
- **Share** interesting technical solutions
  - Input will be provided for IFE beforehand
  - Technical demos will be prepared in groups
  - Selected demos will be rewarded!
- **Experience**
  - Become immersed in 3D interactive virtual decommissioning sites: explore site, control equipment e.g. robotic/remote equipment, …
  - Be engaged in entertaining stories from our experience through serious gaming
  - Participate in virtual/augmented tour of our facilities



Rewards may include a gift pack, 2 year license for the VRdose® tool (www.ife.no/vrdose_overview), *exemption from registration fee…*

Organising committee: digidecom@ife.no

International advisors: G Kwong (OECD NEA), PJ O'Sullivan (IAEA), V Michal (IAEA), A Ganesan (IAEA), O Glöckler (IAEA), V Ljubenov (IAEA), R Reid (EPRI), J. de Grosbois (indep. consultant)

Chairman: I Szőke, Institute for Energy Technology, Norway

Digitalisation for Decommissioning S?

This course focuses on digitalisation of the nuclear decommissioning process from early planning (during operation) up to the final site release, with special focus on integrated digital concepts enabling holistic management of project and safety.

Technologies include: 3D modelling and simulation, semantic information technology, physics modelling, digital twins, pr[illegible]ess simulation and visualisation, immersive pres[illegible]d advanced user interfaces.

Applicatio[illegible]s [illegible]de: information management (BIM/P[illegible] [illegible]odel[illegible]g, strategy and work planning, safety [illegible]essm[illegible] and [illegible]demonstration, emergency prepared[illegible] trainin[illegible] [illegible]efing of workers, robotics, as well as tea[illegible]coord[illegible] and monitoring.

Trainees will [illegible]example tas[illegible] in interactive group sessions using [illegible]l technolo[illegible]

The course will al[illegible]ke a[illegible]ge of storytelling, serious games, and mixed rea[illegible] provi[illegible] highly engaging deep learning expe[illegible]ce ba[illegible] real-life project experience.

Norway

Next courses:
2019 November

Language: English

Expected audience: All professio[illegible]d in pl[illegible]nning or overseeing decommissioning, [illegible]as pro[illegible]ls starting a career in decommissio[illegible]g

Education level: EQF Level 6 or 7

Learning outcomes from the course:

- ✓ Overview of the international landscape [illegible]r resea[illegible]lication of digital technologies for nuclear decommissioning
- ✓ International overview of available technolo[illegible]as w[illegible]s needs and trends for future development and application
- ✓ Understanding of the regulatory aspects of digi[illegible]ion for[illegible]ioning
- ✓ Overview of digital technologies applied in the Oil&Ga[illegible]ry
- ✓ Lessons learned from application of digitalization fo[illegible]om[illegible]and waste management in Norway
- ✓ International experience from application of digitalizatio[illegible]decommissio[illegible]of hazardous legacy nuclear sites (including Chernobyl NPP)
- ✓ Skills in application of digital technology for different aspects of de[illegible]ng
- ✓ Learnings from experiencing examples and solving problems t[illegible]gh immersive (gaming) experiences based on international real-life projects

Institute for Energy Technology

Price:
2000 EUR

www.ife.no/digidecom2019