Digitalization and robotics for Nuclear Decommissioning

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2019 Sep 9-13 Miami

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

Institute for Energy Technology

Research and Development

- Material and Process Technology
- Flow Technology and Environmental Analysis
- Digital Systems

Nuclear Technology

- Two research reactors
- Research within physics, materials, nuclides for medicines, nuclear safety, denuclearization, nuclear waste and decommissioning

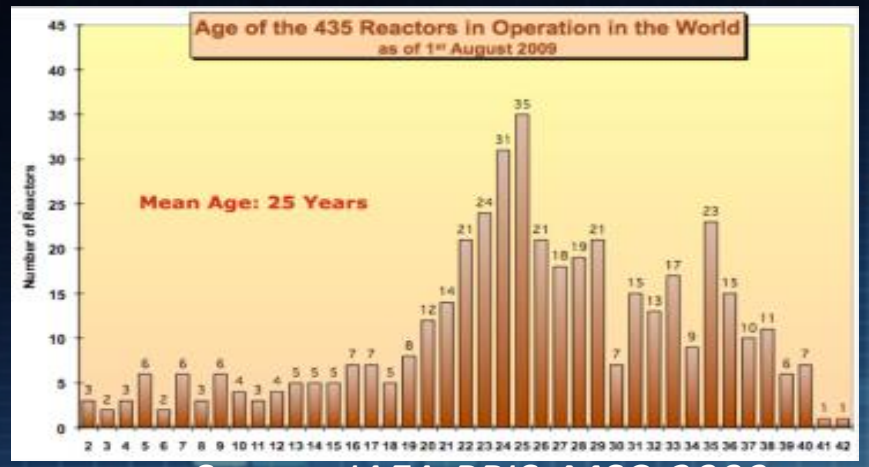
Radiopharmaceuticals

- Development of radiopharmaceuticals
- Production of Xofigo for Bayer
- Production of other radiopharmaceuticals
- Pharmacy and distribution of radiopharmaceuticals

Decom - Why is innovation needed?

Aging plants, political decisions, commercial issues =>

Nuclear decom. will be a major activity Worldwide



Source: IAEA-PRIS, MSC, 2009

Decommissioning process has to be modernized

- Sporadic decom. R&D — outdated methods
- Assorted teams — communication/data exchange issues (regulators, licensees, contractors, …)
- Mixture of hazards and risks, new types of jobs
- Robotics not ready/expensive
- Low probability of accidents BUT not negligible — preparedness

Digitalisation

Digitalization is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business. (GARTNER, 2017)

"Simplified, digitalisation is about how we can use digital technology to do more with less effort and get it done quicker, safer, and cheaper" (IFE, 2018)

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 

Machine age | **Atomic** age | **Jet** age | **Space** age | **Information/ Digital** age | **Next** age

- Information tech: exponential growths (Moore's, Metcalfe's, Gilder's and Kryder's laws)
- Digitally powered communities - "Smart" concept – smart infrastructure, resource allocation
- Process automation / efficiency
  - Enterprise wide info solutions
  - Data analyses, pattern recognition, advice - machine intelligence
  - Dynamic decision making
- Robots and remote operations
- Wearables and embedded comp., Internet of Things, ubiquitous comp.

- Accelerating need fort ability to invent and adopt – agility, creative thinking and rapid learning VS. mainly STEM subjects
- Online platforms and E-learning VS. traditional college
- Virtual Reality VS. hands-on/field exercise

Customers/users will expect major new features in future services and products

Majority of people will be wiling to wear technology to help them do their jobs

Digitalization for nuclear decom

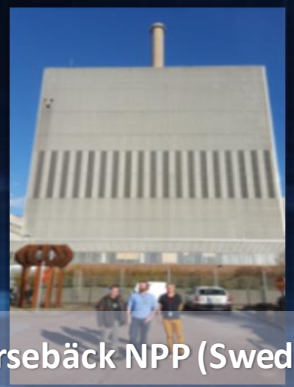
Are we (the tech.) there yet?
When is it worth it?
Who? Where? How? to apply
Is there enough proof-of-concept?

R&D at IFE

- OECD Halden Reactor Project research
- EU and other projects
- Industrial support projects (Japan, Chernobyl, NW Russia)
- In-house decom activities

Interviews with decommissioners

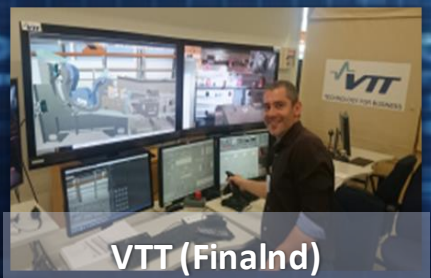

Ringhals NPP (Sweden)


Barsebäck NPP (Sweden)

AREVA Germany


EC JRC (Italy)

SSM (Sweden)



VTT (Finalnd)


CEA (& NUVIA) (France)


NNL & Sellafield (UK)


EDF (Lyon, France)


IRSN (France)

Interviews with decommissioners

General conclusions on training:

- Many specific tech and non-tech skills compared to operation
  - Characterization, decontamination, waste management,…
  - Project management (work planning, costing, …)
  - Agility, self-efficacy, creative thinking
  - Leadership, change management, communication, …
- (Safety) Skills required change during the decom project
  - Radiological vs. other industrial risks
- Training needs for different team members are very different
  - In-house, contractors, …
  - Existing skills of in-house staff
- Training is decentralized
  - Who: licensee, contractor, emerging training centers, …
  - Where: home, visiting other decom sites, …

Interviews with decommissioners

General conclusions on knowledge management

- Knowledge loss is critical issue (changing staff)
- Knowledge (experience) is still limited / non-public in an international level
- Acquisition of the right information is a challenge – old, incorrect records, unrecorded info, incompatible formats, too much info (data filtration)….
- Information management across life-cycle, team members, units… is very inefficient
- Human and organizational challenges are higher – motivation, personal conflicts, unclear roles, …

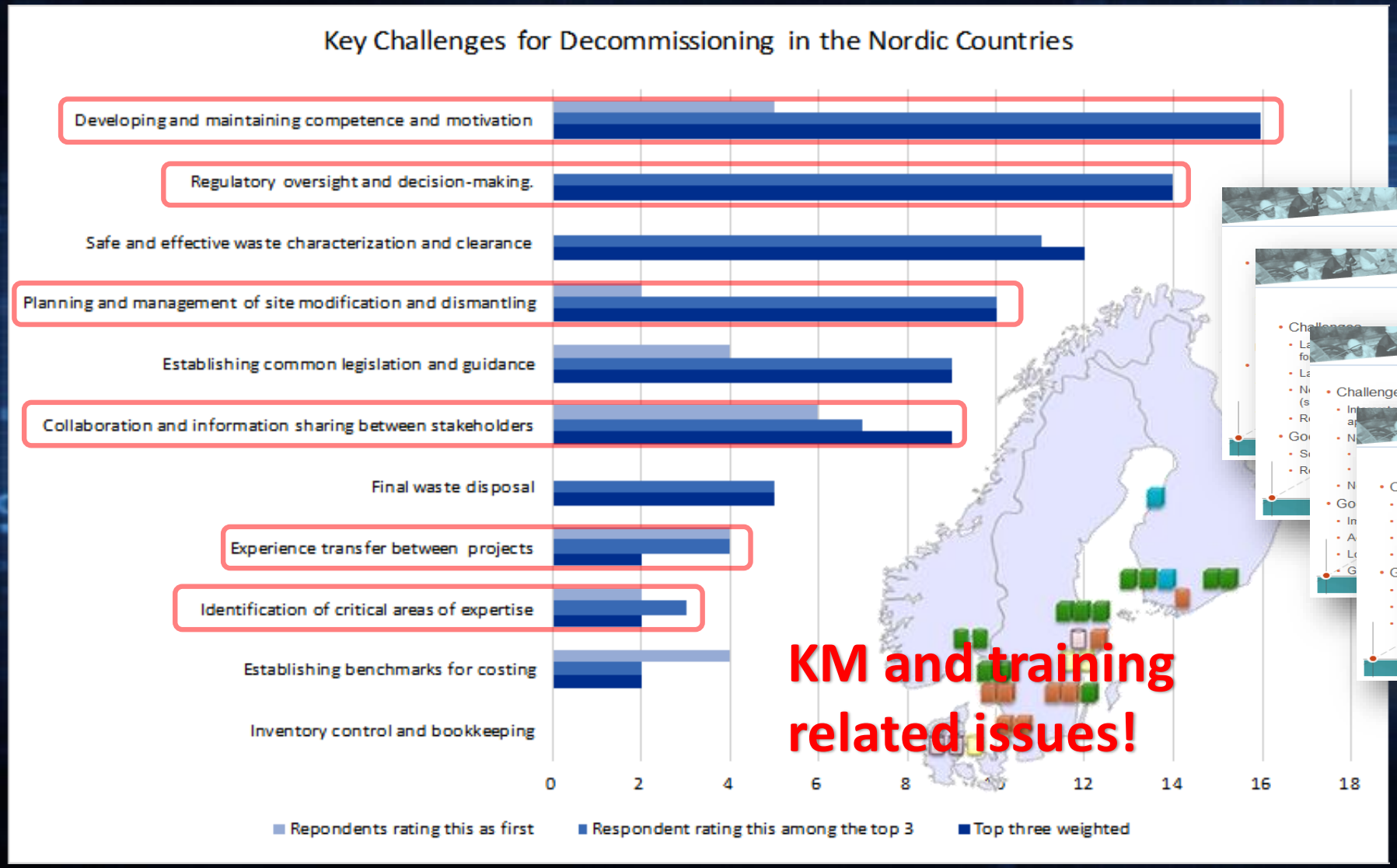
Issues for application emerging digital solutions

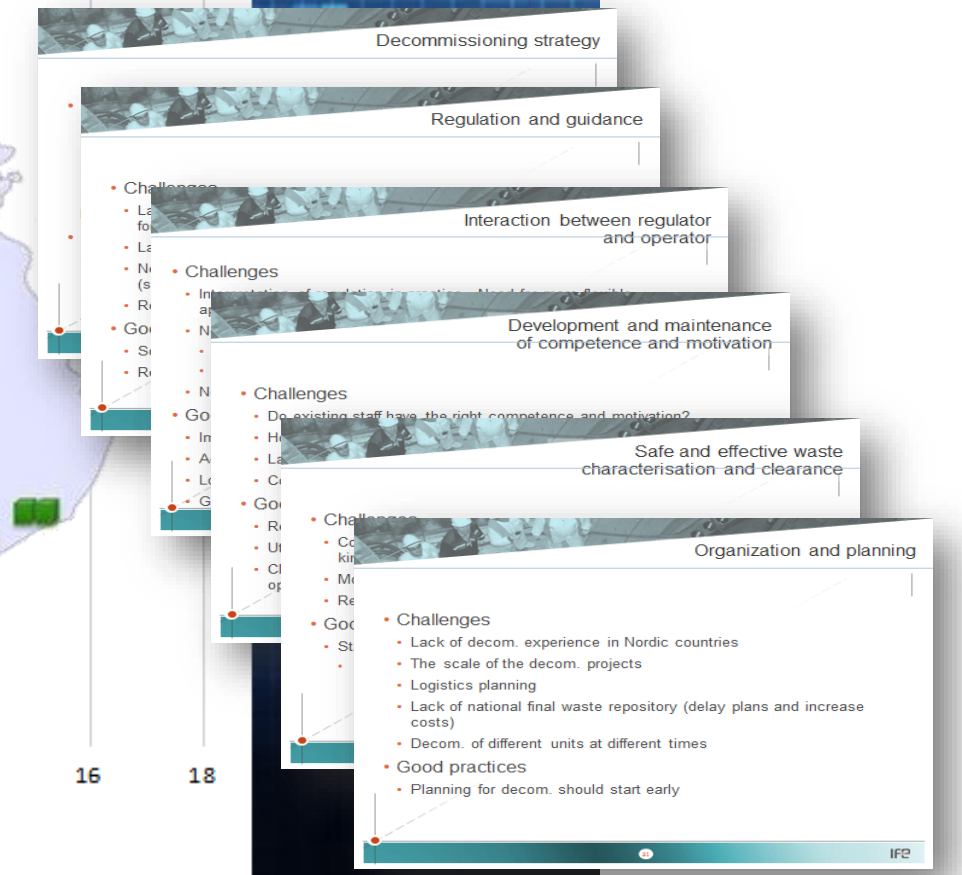
- Management wants cost – benefit and risk analyses
- Management may not be open-minded
- Tech is used for individual goals rather than across units, tasks, project(s), …
- Tech needs to be integrated into organizational practice
- Need for dedicated team at the end-user for testing and implementation
- Vendors are still trying to create super-tools that, allegedly, will solve everything
- Originations try to implement own solutions – compatibility issues, concerns for long term support, plans for commercialisation, …
- Tech is not ready for everything – must know when and how to use it (negative training), motions sickness, …
- Training tech is mainly based on gaming tech - needs integration with physics modelling, human performance measuring, …

NorDec: Challenges and opportunities for improving Nordic nuclear decommissioning

nks
Nordic nuclear safety research

IFE, SSM, NRPA, STUK, SIS, VTT, Fortum, Vattenfall, ÅF





KM and training related issues!

Need for decom competence

In-house operational staff

Contractor staff

Staffing and competences

	Radiation safety training	Plant experience / knowledge	Decom skills	Decom mindset
In-house / operational staff	✓	✓	✗	✗
Contractor staff	✗ / ✓	✗	✓	✓

Typical role allocation

- Managers / planners
  - Coordinate between contractor, owner & regulator
  - Handle licensing towards regulator
- Control-room (monitor essential systems)
- Radiation protection
- Waste management

- Blue-collar work
  - Dismantling
  - Demolition
- Waste management
- Radiation protection
- Special competences

Large differences (and no consensus) in use of in-house and contractor staff

VR training – systematic literature review (SLR)

Goals:

1. Gather scientific evidence for effectiveness of VR in professional training
2. Identify gaps and needs for research

Domains:

- Industrial training
- Firefighting
- Safety and emergency management
- Healthcare
- Space missions
- Defense

General findings:

1. Sometimes VR training is the only effective way to acquire skills
2. In many situations, VR training is more effective (quicker acquisition of knowledge and skills, longer retention, lower human and material investment)
3. In some situations, traditional training outperforms VR training
4. VR training is more effective when systematically integrated with the training curriculum

VR VS. classical training

‘Retention rates for lecture style learning were at 5% and reading rates were at 10%, while the method of **VRLearn had a retention rate of 75%**.’

Virtual Reality Learning report by Masie.com

‘The biggest barrier to wide adoption of immersive technologies is the lack of **good user experience design**’

© 2019 Gartner

- User acceptance
- Effectiveness
- Recall decay
- Cost
- Time
- Portability
- Flexibility

- Situation awareness
- Agility (understand and react)
- Procedural training
- Psychomotor skills

VR VS. classical training

Based on 360 photos/videos	Based on 3D scanners point could + 360	Based on CAD models
Quick and cheap Low hardware req. High realism **BUT** limitations for • Trainee freedom • Physics modelling …	High resolution requires more time and/or cost **BUT** Free navigation Limited physics modelling …	Requires relatively high manual labour for good resolution **BUT** High interactivity Can include meta-data -> physics modelling

Can combine these!

Depending on the training objectives

KM and training in the oil & gas

Are there any synergies?

KM and training in the oil & gas

- Higher focus on major accident prevention – explosions
- Negligible attention on radiological hazards
- Many industrial hazards are the similar (fire, falling objects, lifting large objects, rust, asbestos, confined spaces, gas leak, shipping,…)
- Similar trends and needs for 3D digitalized info management – for safety assurance, asset recovery, …
- 3D digitalized training is based on classical gaming tech
  - rare examples for physic simulation for fire
  - training objective oriented measurable training is generally non existent
- Training is not regulated by safety authority

Where? How?

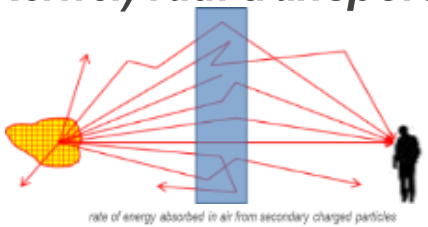
Special (difficult) situations

Clear need for advanced methods for ensuring safety

- Accident sites e.g. Fukushima, Chernobyl, …
- Unique work e.g. degrading nuclear sites, graphite reactors, …

Difficult sites – 3D+hazard modelling

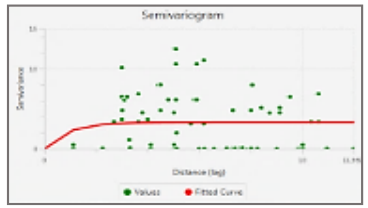
Real-time (Point Kernel) rad. transport



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

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

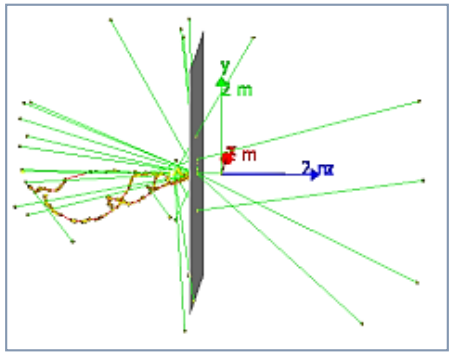
Geostatistics Kriging Interpolation



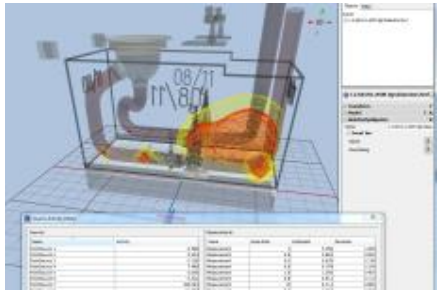
$$Z^*(\mathbf{u}) = m(\mathbf{u}) + \sum_{\alpha=1}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u})[Z(\mathbf{u}_\alpha) - m(\mathbf{u})]$$

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

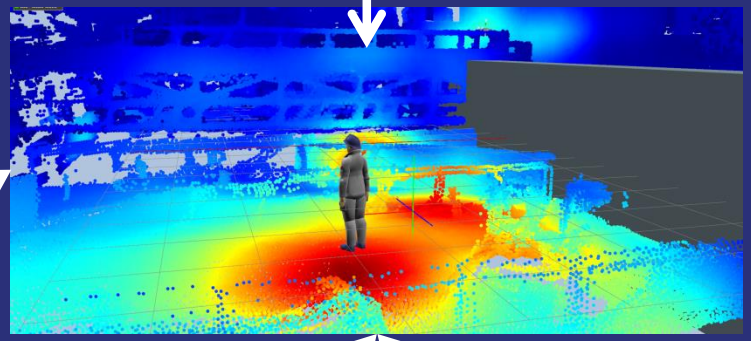
MC rad. transport (MCNP, GEANT4)



Source deconvolution



Sensors, databases, documents, …

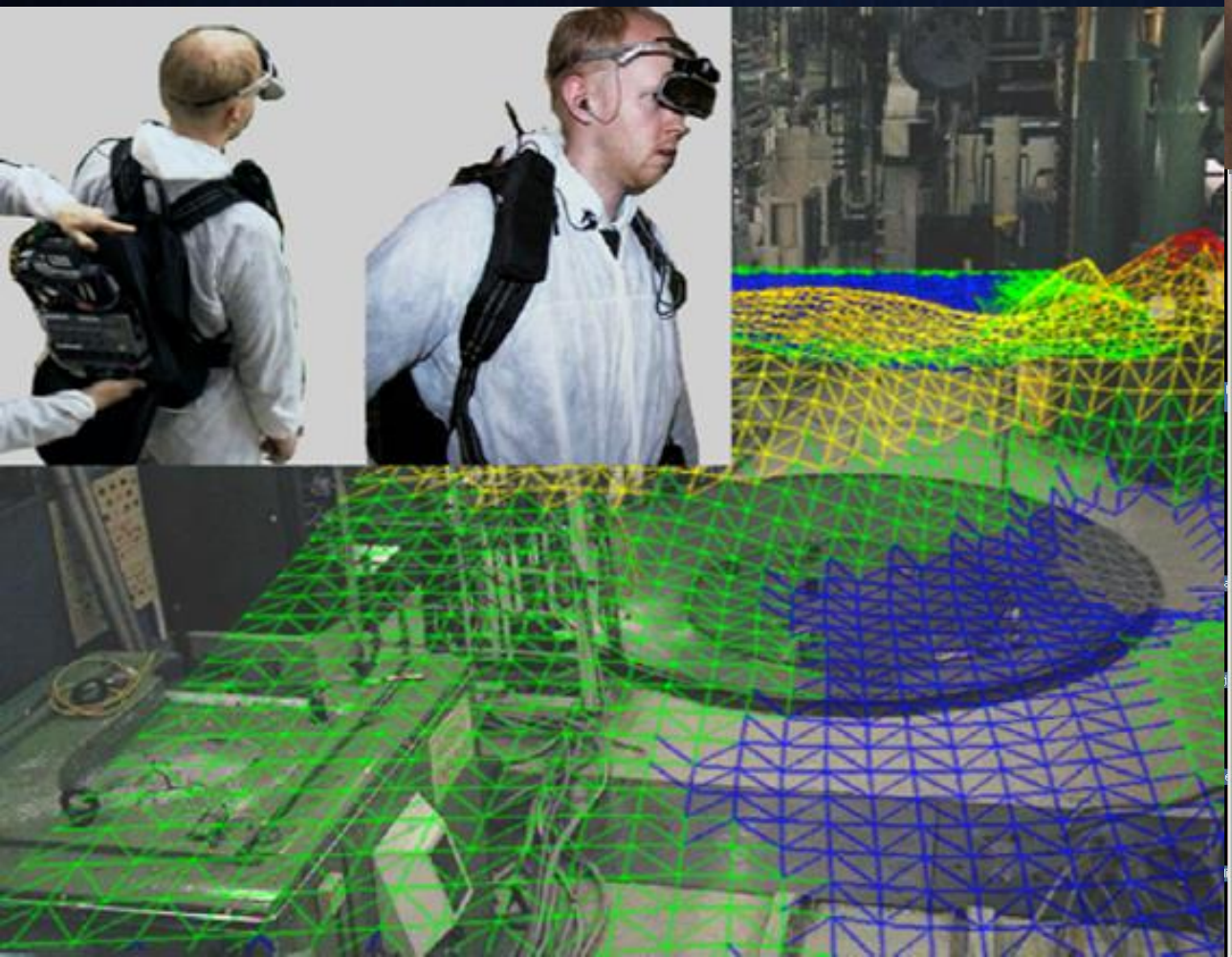


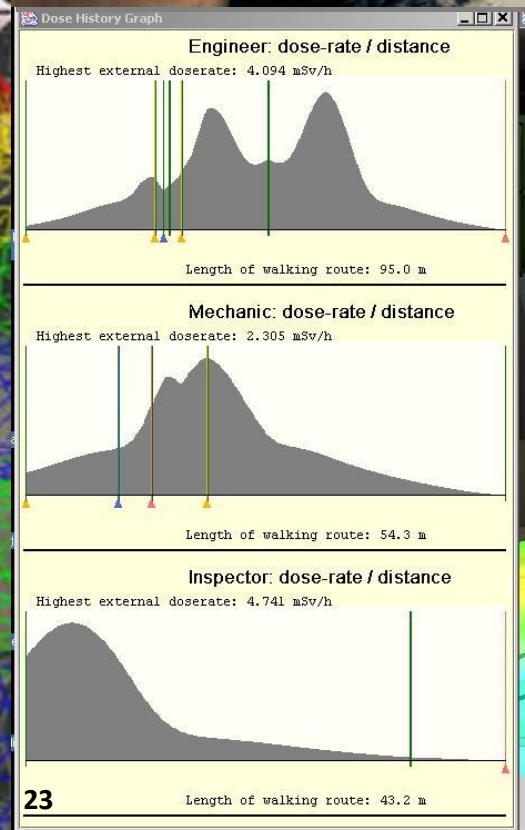
Advanced safety planning with BIM tech based support

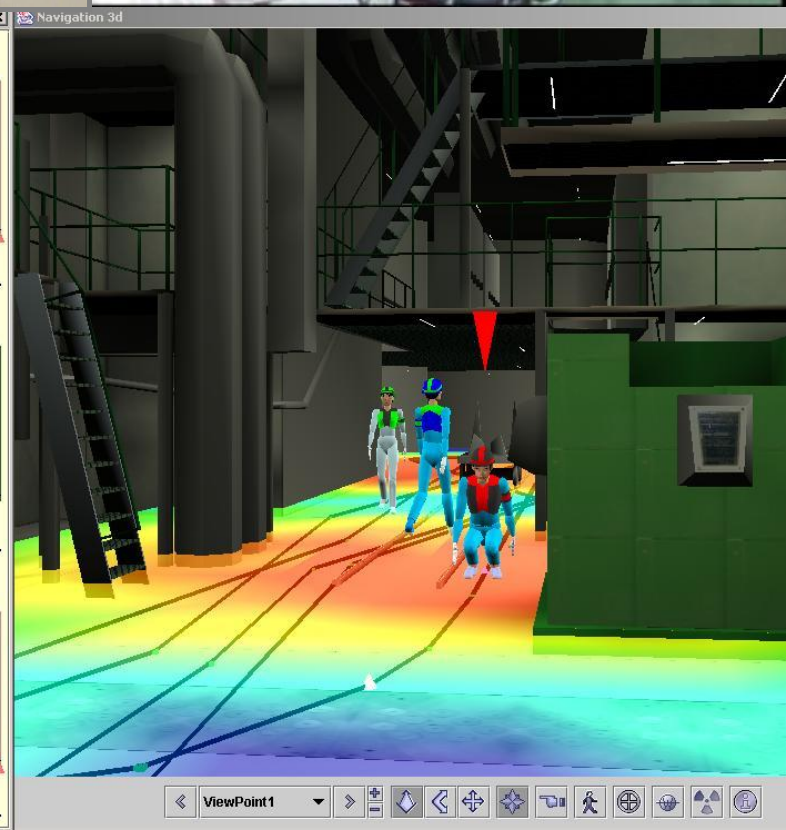
Advanced safety training with BIM tech based support

VR applications for the nuclear

(since 1996 till today)







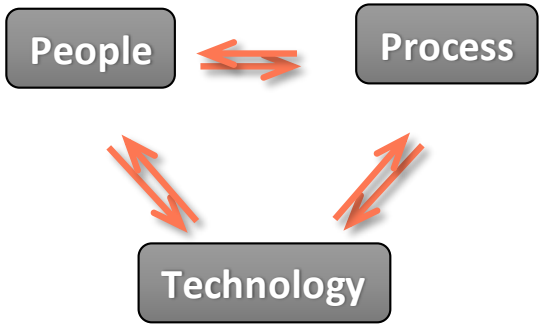
Where? How? (cont'd)

'Normal' decom work – make sure that you

1. **Start early – invest in digital support up-front**
2. **Apply a holistic approach (integration)**
    1. Application across domains (disciplines)
    2. Use across the whole stakeholder team
    3. Use through the whole process
3. **Don't underestimate the impact on motivation**
4. **Leverage capabilities across projects**

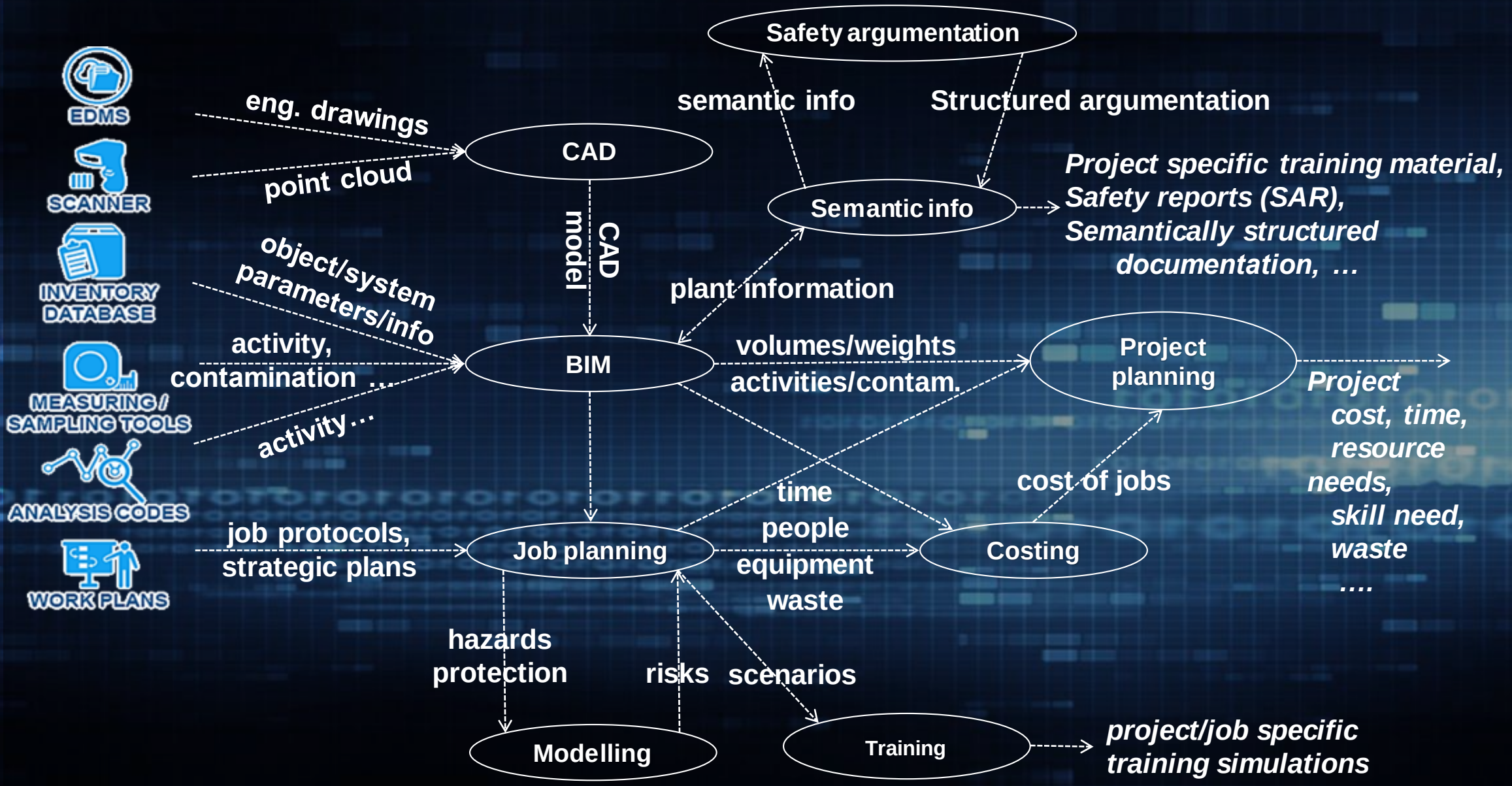
Emergency preparedness (incl. training) – no real traditional alternative

Holistic (digital) support

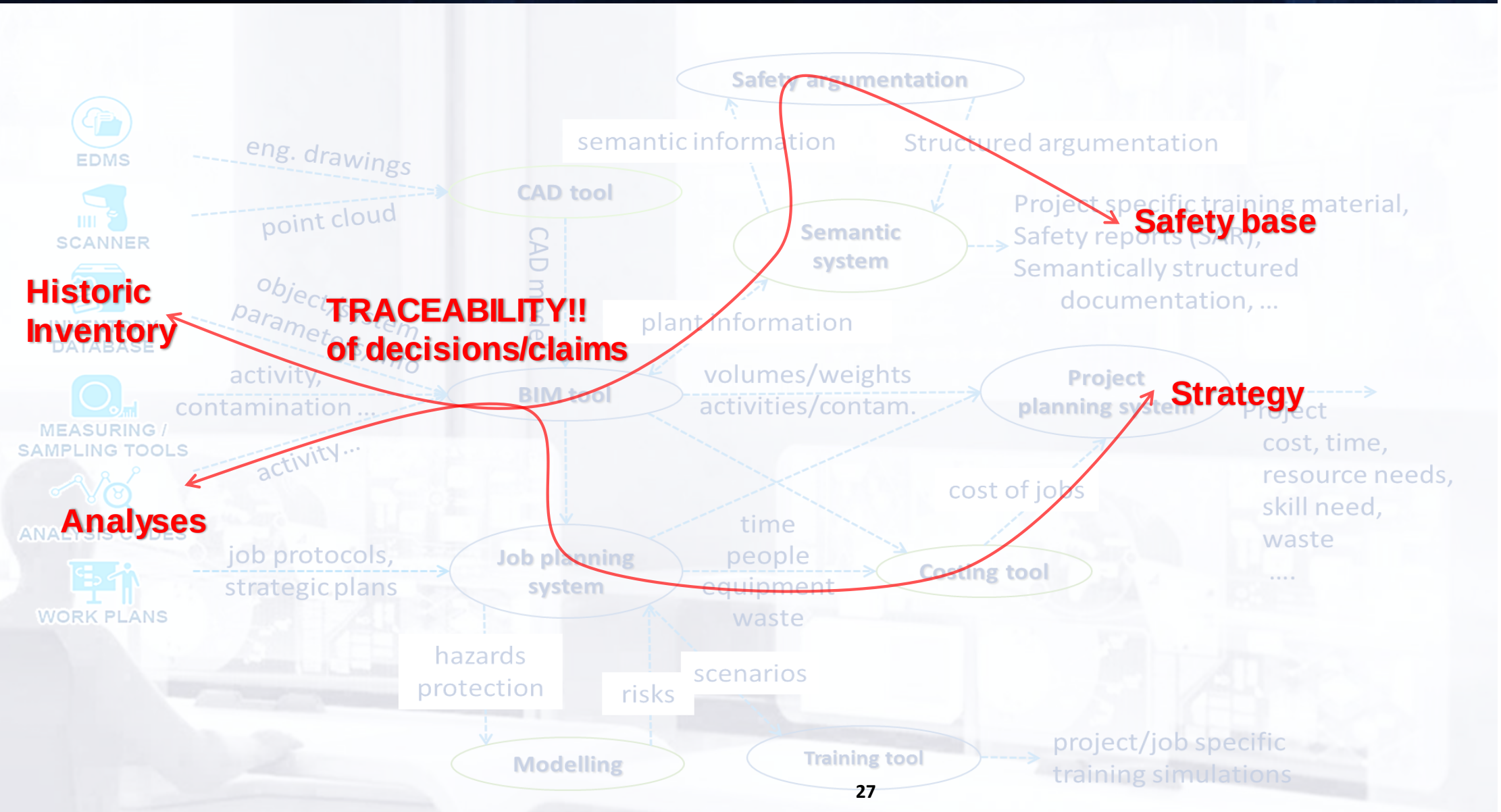


- Plant information management (PIM)
- Rad. characterization
- Informed decision making
- Job planning (optimization: risk/hazards - costs)
- Regulatory interaction
- Team collaboration & coordination
- Training & Briefing
- Knowledge Management (KM)
- Emergency preparedness
- Robotic & autonomous systems

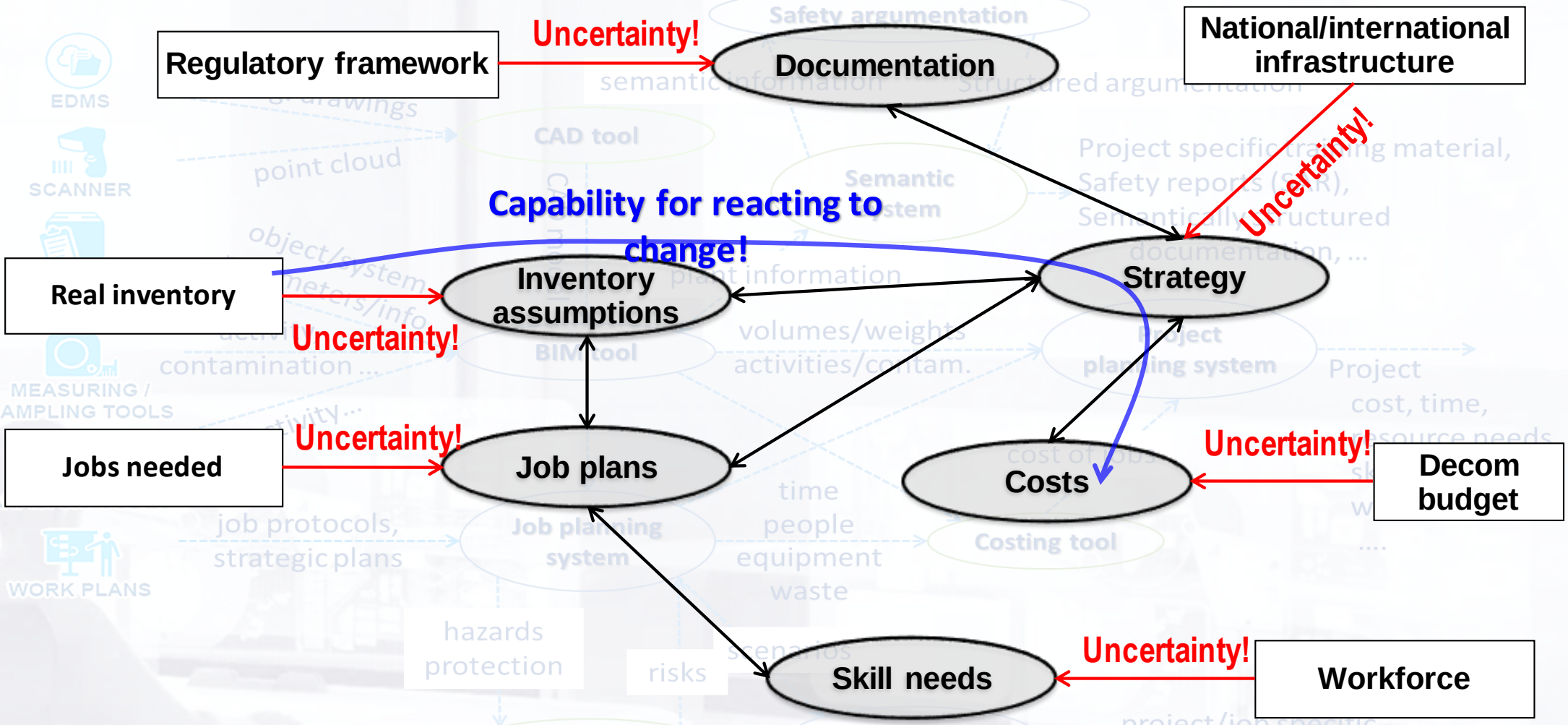
Holistic digital support – training solution for free



Integration – traceability of reasons

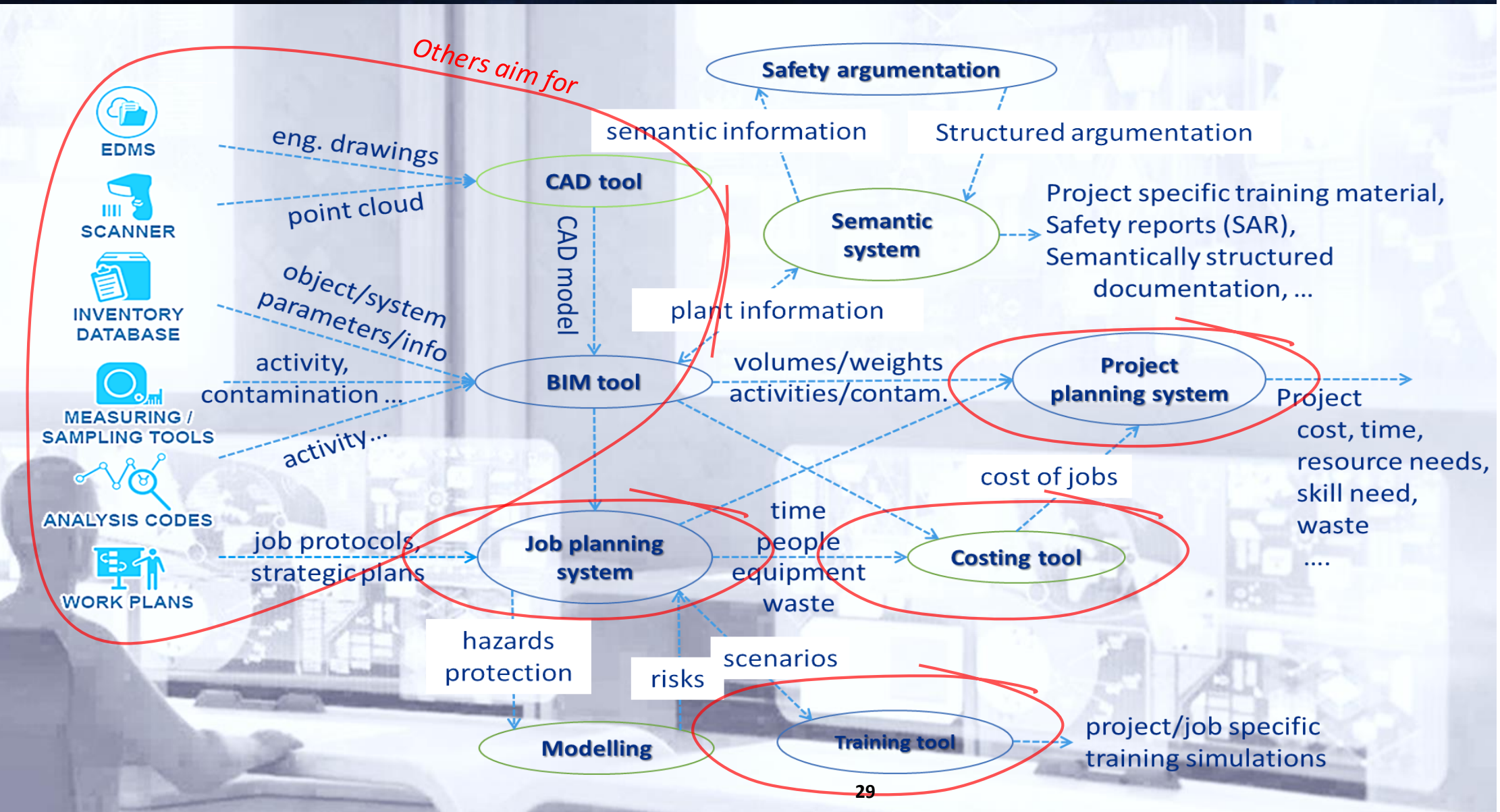


Holistic planning – agile decom

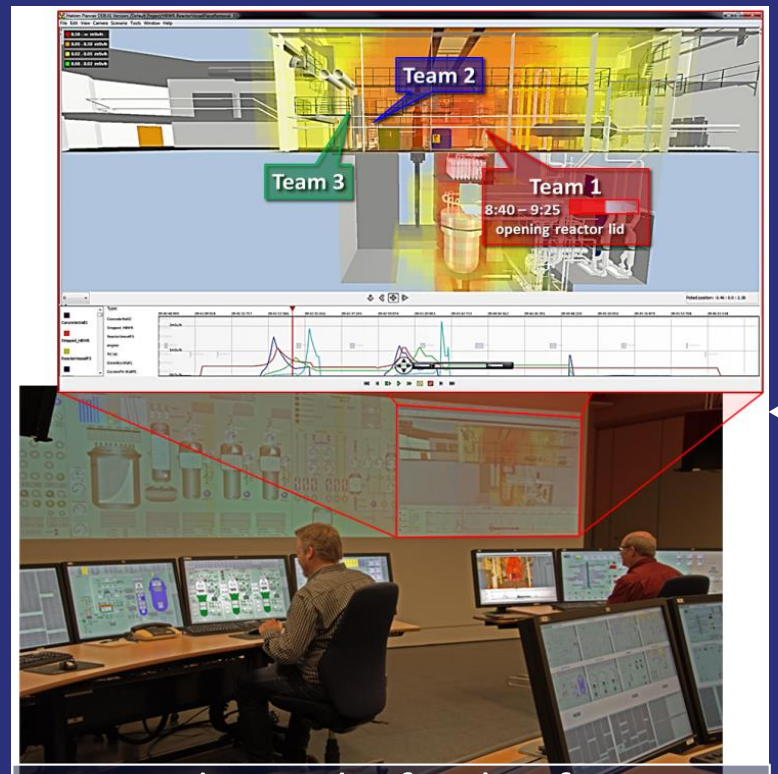


28

Attempts for integration

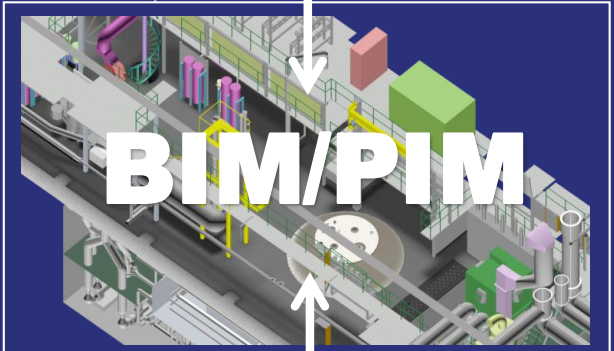


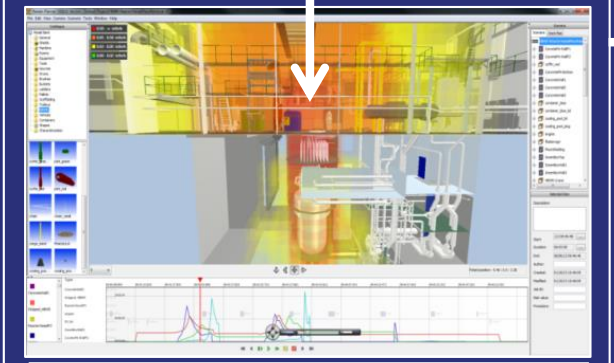
Training, briefing, control



Advanced safety briefing
and
control center

Sensors in the field





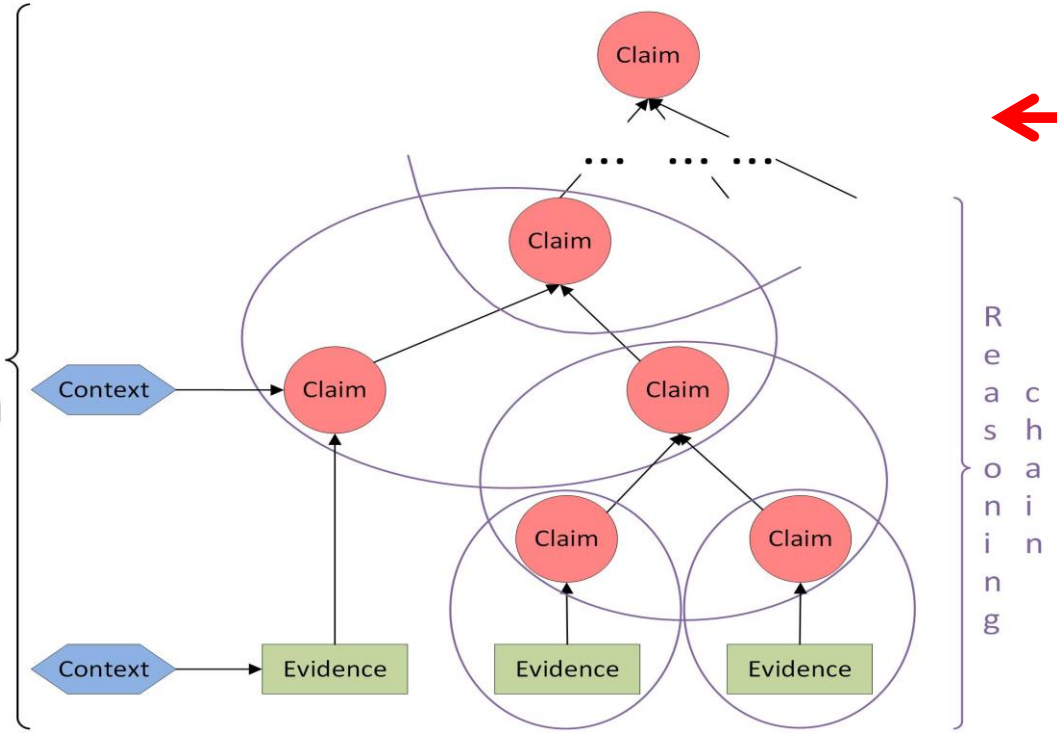
Analyses

VR based
safety training

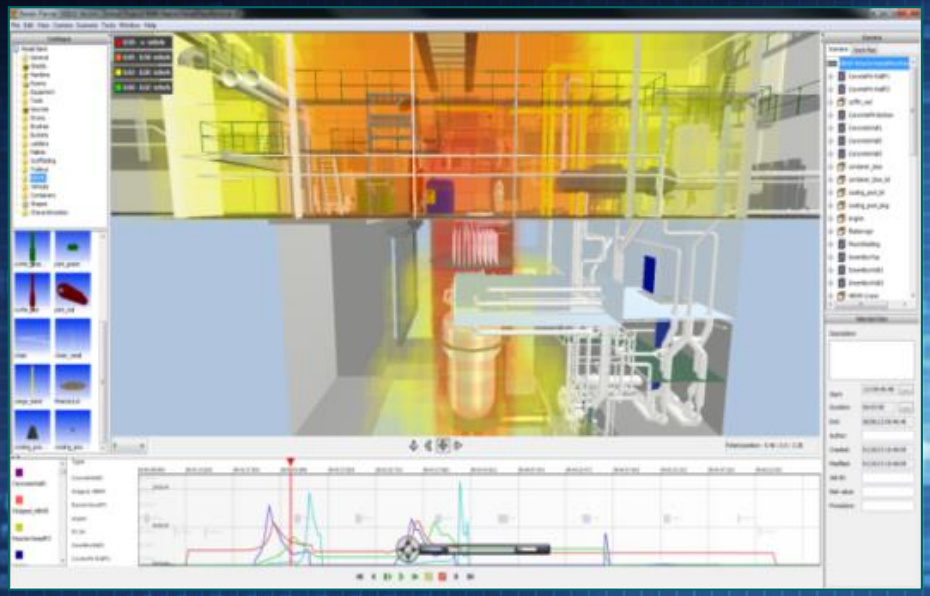
Safety assurance

Argumentation based textual

Structured Argument

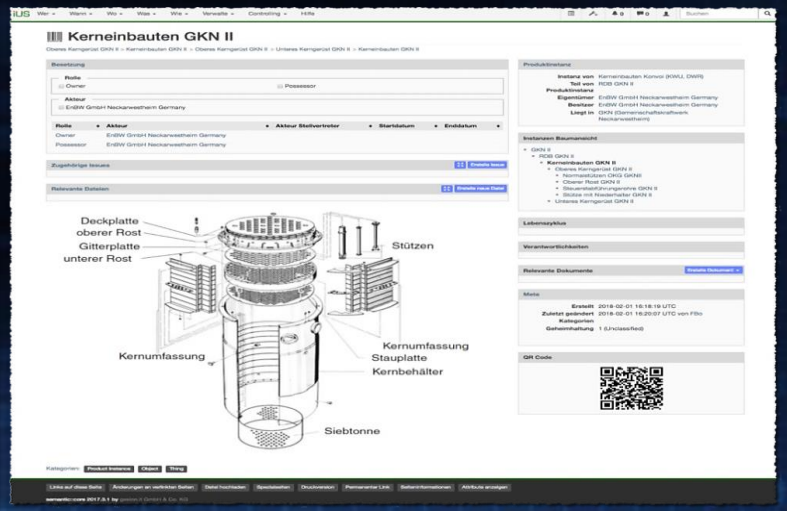


3D Digital



Safety analyses – HAZOP…
3D simulation supported

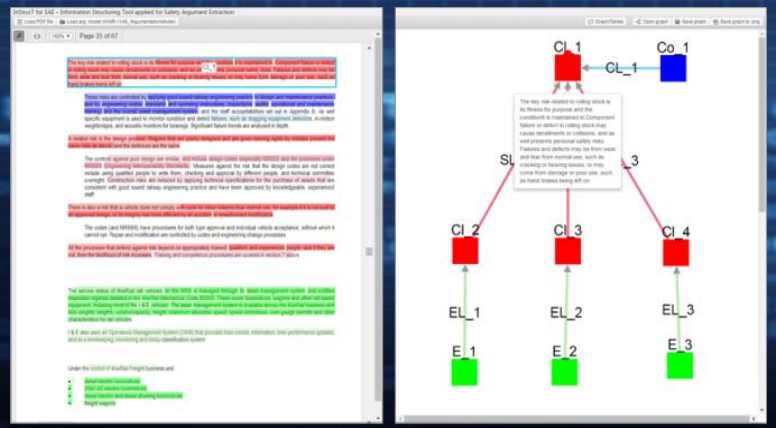
Safety management and assurance in decom



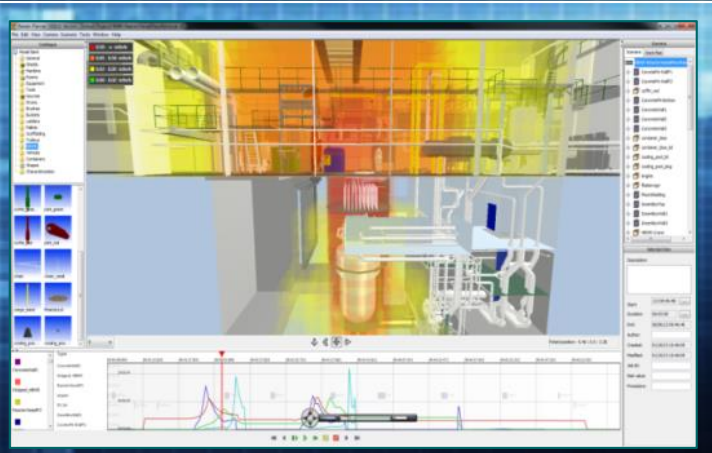
Documentation
semantically re-organized

?

Actual conditions
with 3D scanning and rad. mapping



Safety requirements / arguments
structured

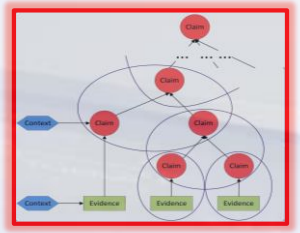


Safety analyses – HAZOP…
3D simulation supported

Holistic safety assurance in decom

Regulation

Safety Requirements (texts)

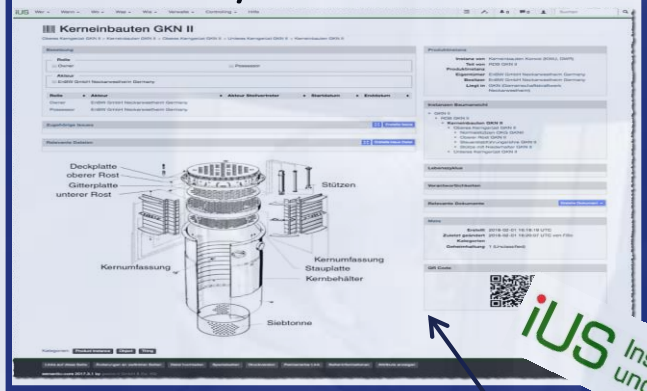


Safety Analyses Report(s)

Tenders/ Contracts

?

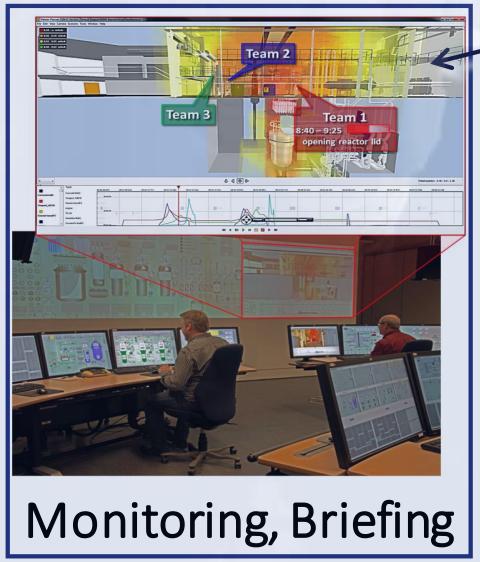
Central info portal structured info/data access



iUS Institut für Umwelttechnologien und Strahlenschutz GmbH

Digital twin

Project planning system



Monitoring, Briefing

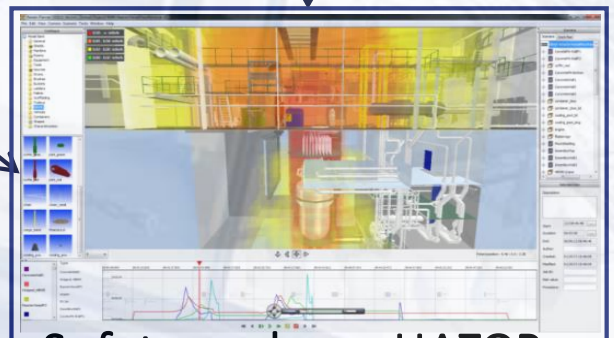
Other Docs

Historical Database(s) with info on SSC

Analyses codes

3D CAD model(s)

Sensors in the field



Safety analyses: HAZOP… 3D simulation supported

Work protocols

Safety (HAZOP) documents

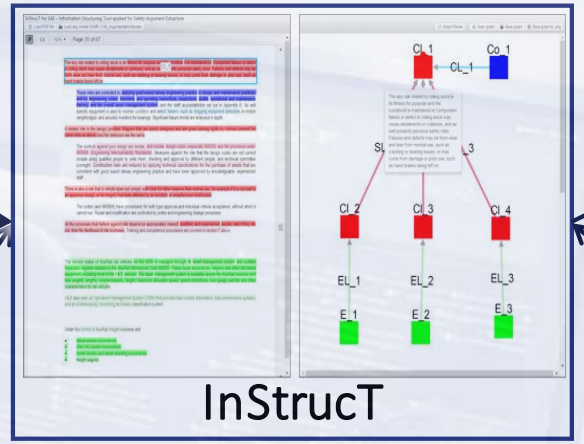
Safety assurance in decom

Text

Regulation

Safety Requirements (texts)

Other Supporting Docs



Safety Analyses Report(s)

Tenders/ Contracts

Safety (HAZOP) docs

Work protocols

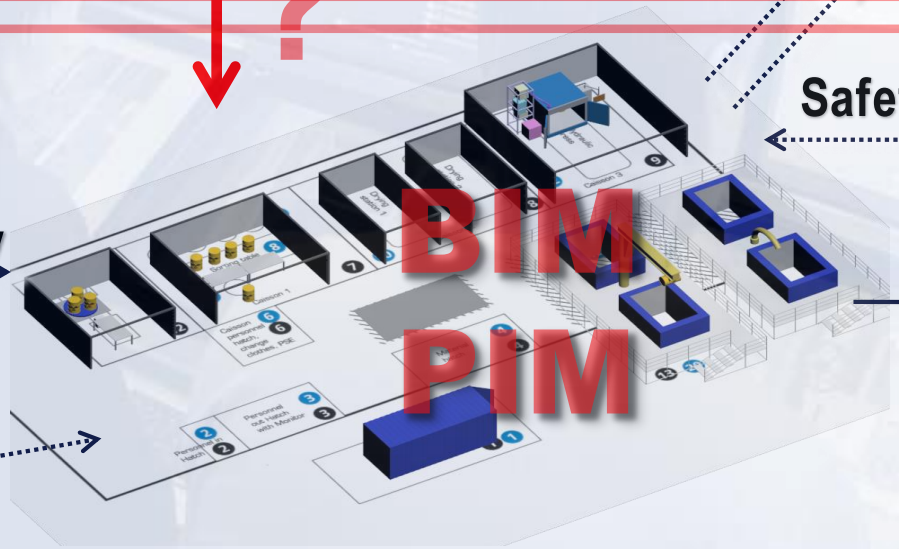
?

Data/info centric

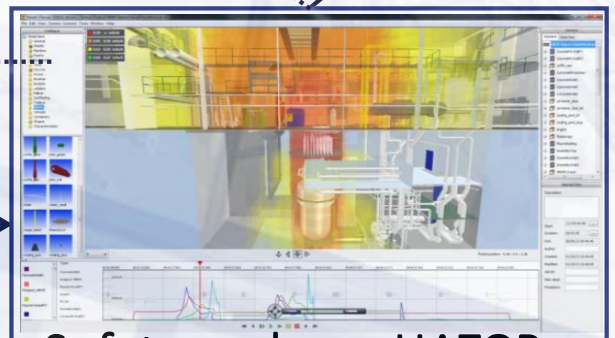
Historical Database(s) with info on SSC

Incl. safety info

Analyses codes

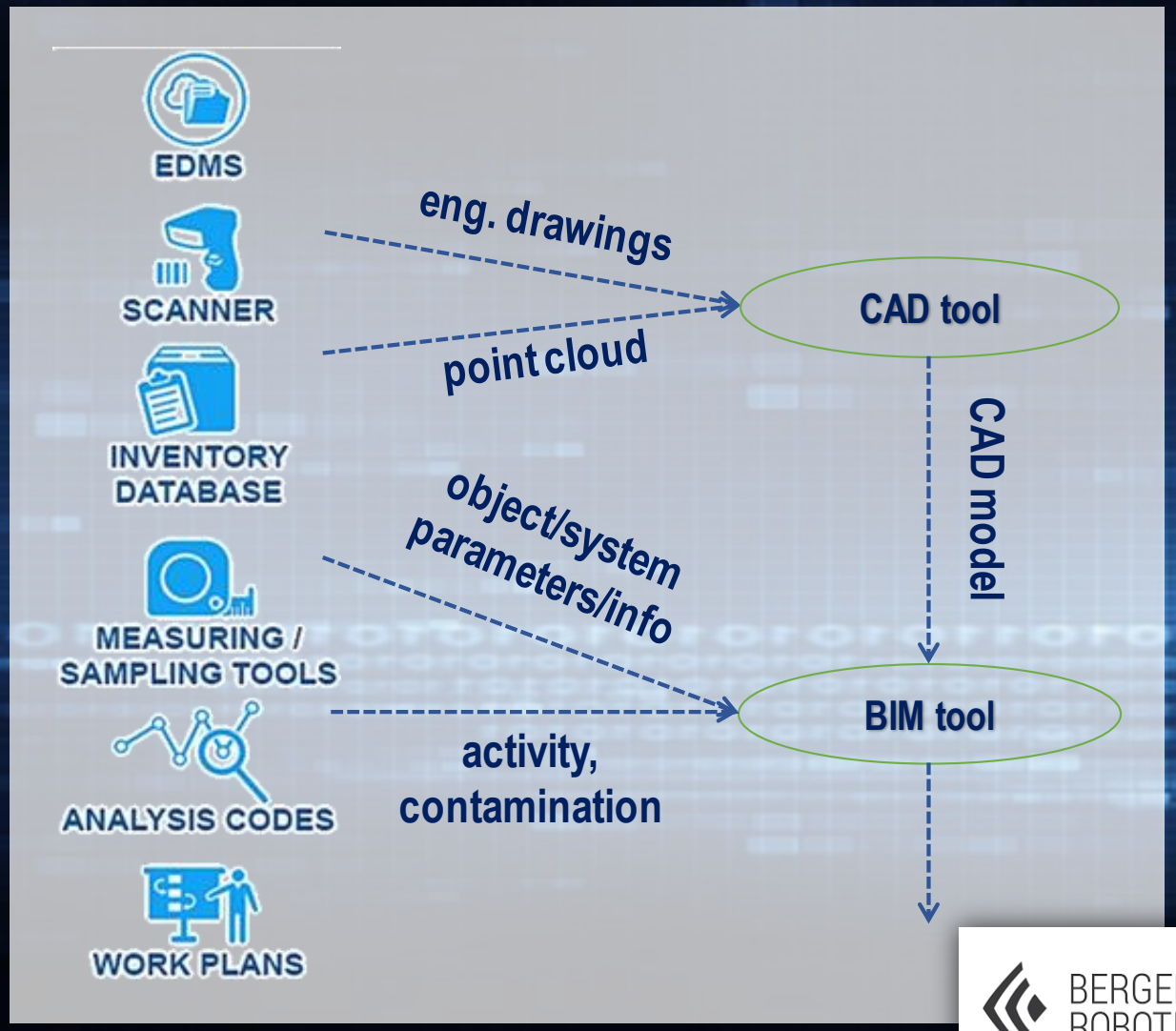


Safety info



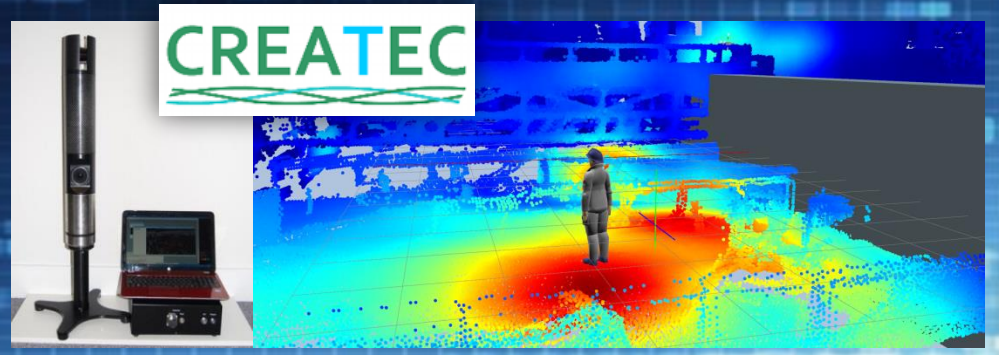
Safety analyses: HAZOP… 3D simulation supported

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,

nLink

BERGEN ROBOTICS

MARITIME ROBOTICS

The industry need

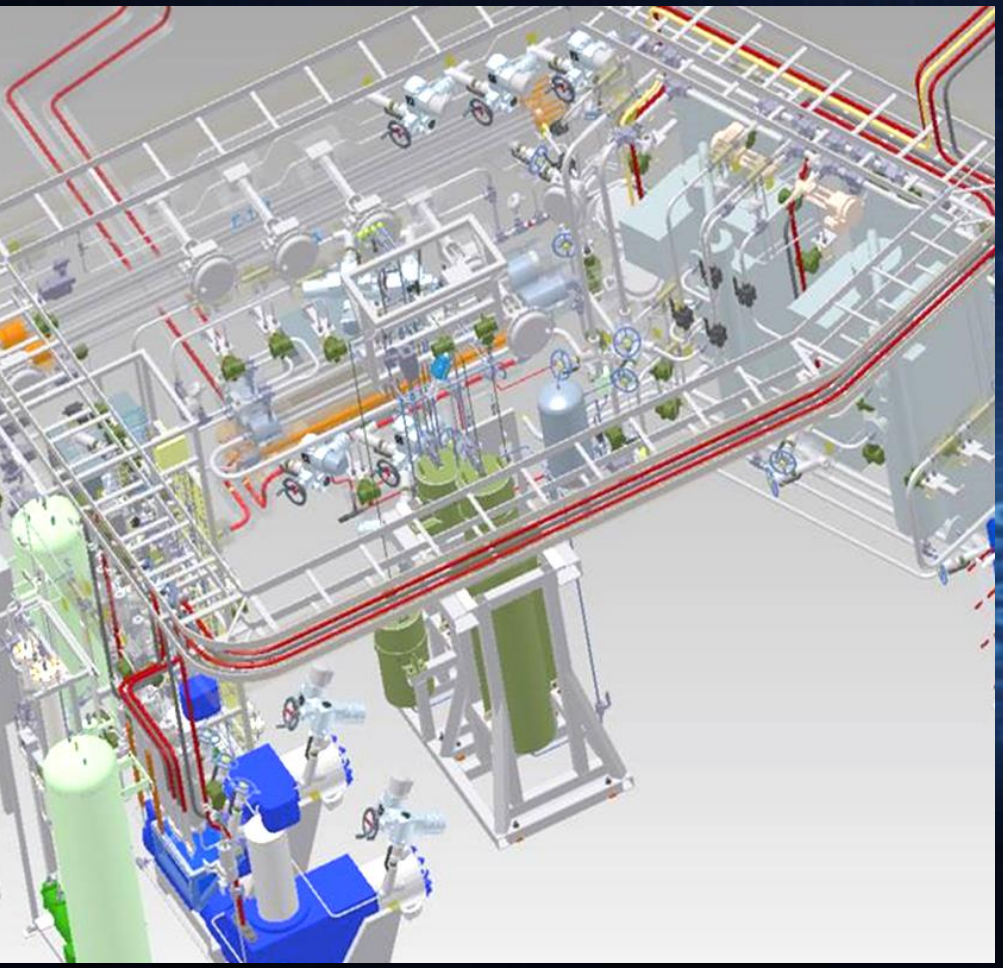
Automation of work processes is and industrial reality, especially when elevated risk to humans.

Some challenges:

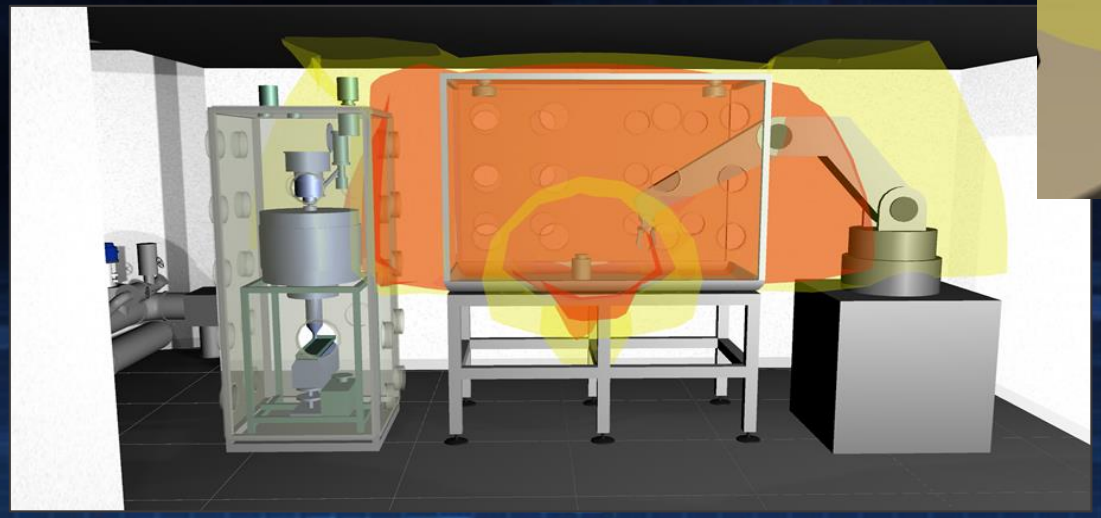
- Purpose-built solutions, initially developed for other purposes => adoption is challenging
- Initial adoption is still costly => proof of efficiency is needed
- Suboptimal solution results in very high additional costs
- Safety has to be well demonstrated to authorities
- Training of operators is costly with traditional methods

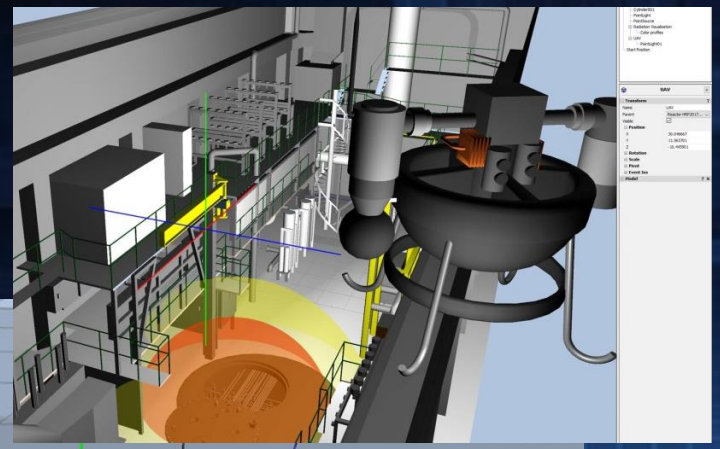
Cost effective solutions enabling low risk adoption of robotic techniques is needed!

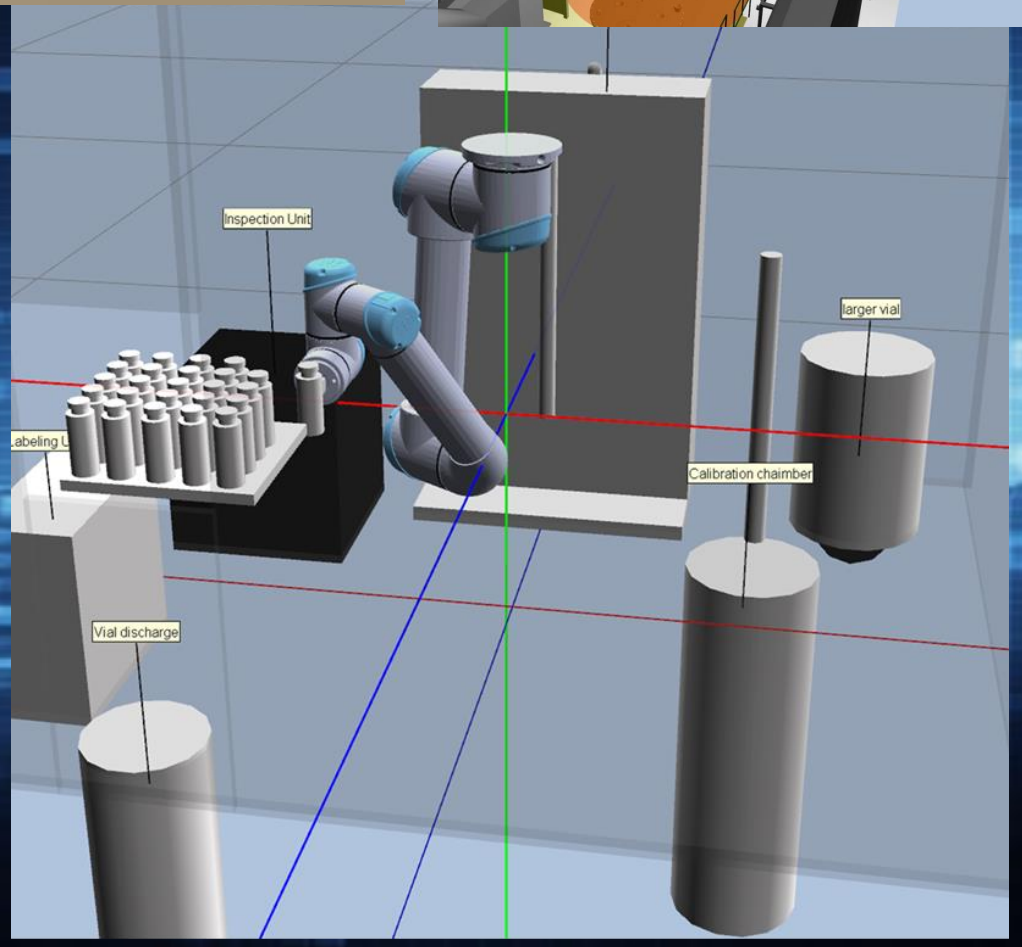
Digital twins



Digital twins - robotics



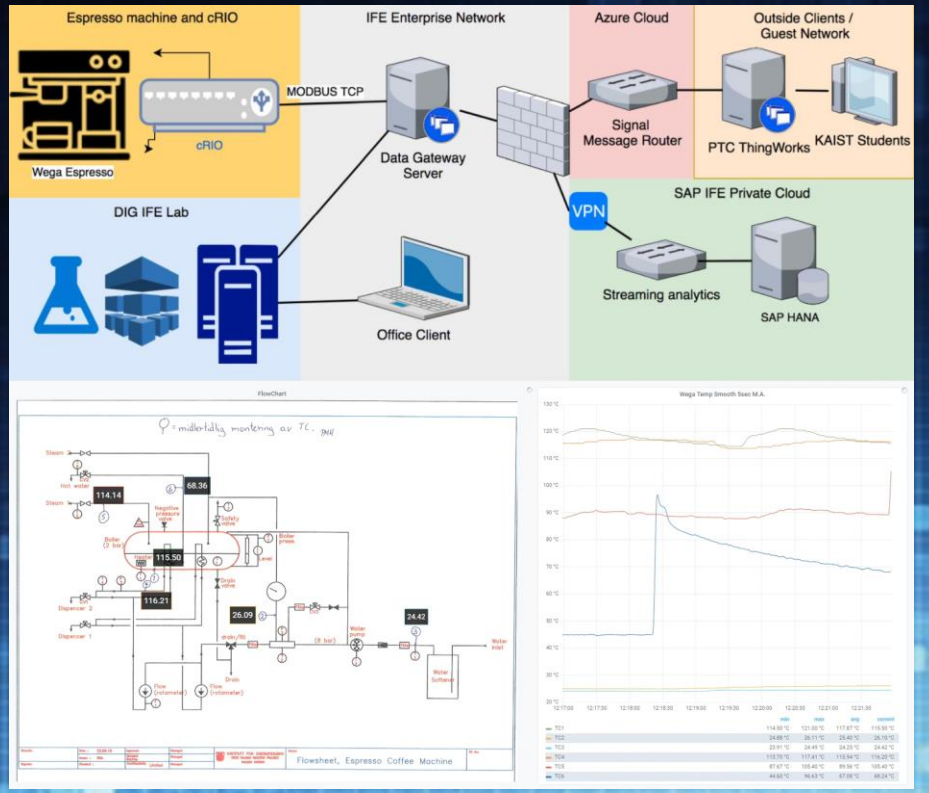




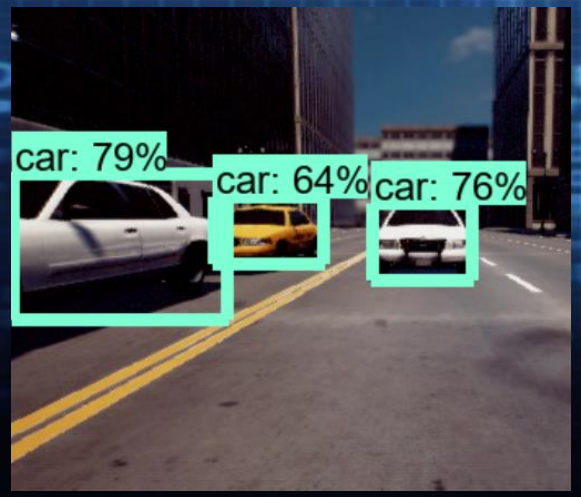
Machine learning and AI

Rust

Clean



Virtual

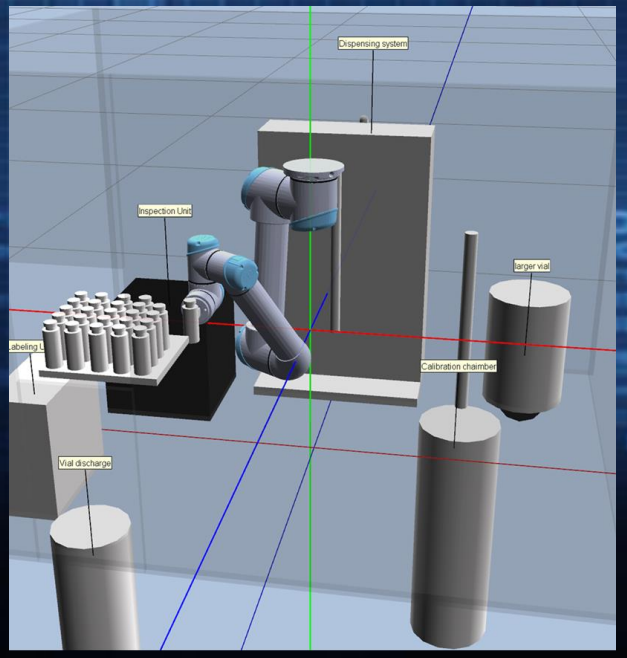


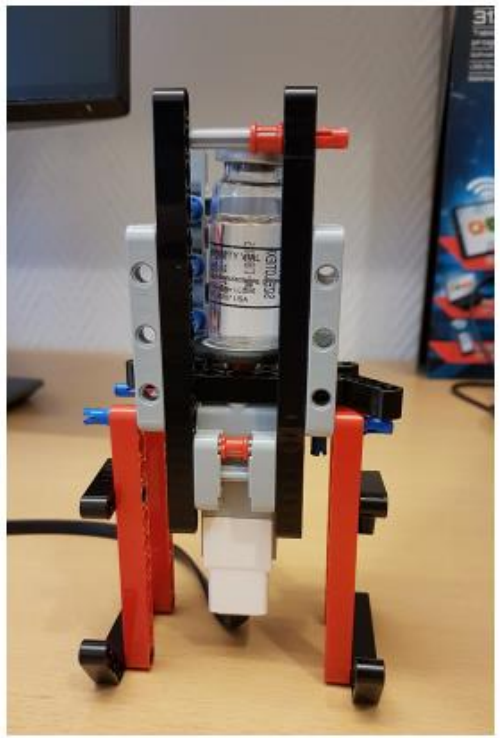
Real

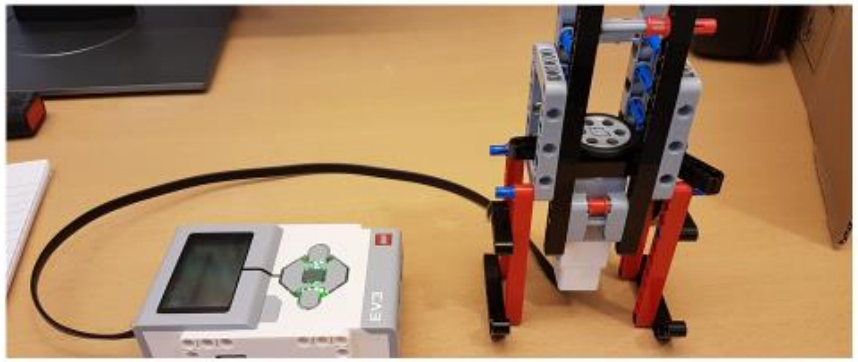
Potholes and cracks

Machine learning – visual inspection

Visual quality inspection for radiopharmaceuticals







Lego Mindstorms device to create motion in the vials

IFE is an International Collaborating Centre of the IAEA

for the digitalisation of knowledge management for nuclear decommissioning

The IAEA and Norway's Institute for Energy Technology will work together on the use of digital technologies in decommissioning and nuclear knowledge management under an agreement signed by the two parties on the side-lines of the 62nd General Conference.

(Left to right) President of the Institute for Energy Technology Nils Morten Huseby signs the Practical Arrangement with IAEA Deputy Director General and Head of the Department of Nuclear Energy Mikhail Chudakov. (Photo: IAEA)

www.iaea.org/newscenter/news/general-conference-day-2-highlights-18-september-2018

Institute for Energy Technology

IAEA International Atomic Energy Agency

NEA Nuclear Energy Agency

DigiDecom2017 (7-9 Feb. 2017)

Current and Emerging Methods for Optimising Safety and Efficiency in Nuclear Decommissioning

www.ife.no/digidecom2017

Institute for Energy Technology

IAEA International Atomic Energy Agency

NEA Nuclear Energy Agency

www.ife.no/digidecom2017

Day 1 Group Discussion: Needs and Opportunities for Improving Decommissioning Practices

1 Which areas of decommissioning have developed and improved fastest, and which areas are lagging to adopt?

Developed fast:

- Technologies, techniques and tools
- Characterization: start as early as possible
- Recent development early and thorough planning, learning, experience exchange
- The number of decommissioning companies
- Modeling of decommissioning
- Mature dismantling techniques
- Use of gamma cameras and portable spectrometers
- Remote operations (but still expensive and limited)

Still lagging:

- Criteria for final clearance of sites
- General harmonization of e.g. international standards for packaging and clearance levels in general
- Requirements for waste management for packaging for disposal sites
- Licensing of sites in general
- Remote operations (but still expensive and limited)
- General project management and quality assurance
- Human factors
- Automation

...

2 What are the main challenges we foresee in upcoming decommissioning work?

- Resources for decommissioning:
  - Market situation and contractors, increasing number of decom projects
  - Young generation in the business, needs training for decom

Day 2 Group Discussion: Needs and opportunities for OECD-HRP and international research into advanced technologies for decommissioning

1 Which new/emerging technologies may have significant impact on future decommissioning?

- Use of laser for cutting and decontamination work
- Vision guidance system for cutting, manipulators, decontamination
- Computer guided manipulation
- Automation of building surveys
- Reduced volume of abrasive cutting
- Laser guidance systems
- Robotics for decon, characterization, ...
- Creating a database that controls all information flow for decommissioning
- Waste based decom strategies
- Use of a AR to control work
- Waste management tracking
- Use of geo statistics and other sampling approaches
- Non-destructive characterization
- Using burn off technologies for coating removal
- Once space travel becomes reliable, send waste into space
- GPS based systems for locating stuff
- Total optimization: Combination of technologies
- Real time 3D gamma ray imaging
- Waste management, treating of graphite

2 How can R&D into new techniques for decommissioning be improved through international collaboration?

- Share problems, and not just report success stories
- Training of staff and experience exchange
- Knowledge management in general
- Avoid doing work twice, use what others have developed
- Encourage private companies to share knowledge and methods developed in public projects
- Jointly develop decommissioning technologies and make results available to all
- Develop a (generalized) model for how to conduct

Needs and opportunities for international research for advancing management of decommissioning

1 What are the biggest challenges for managing the transition from operation to decommissioning?

- How to keep the right (best) people – need to be quick in thinking of retaining these
- Mindset of the staff who leave – risk of unemployment in the area
- May not have the funds to invest in retraining, may have to let staff go
- Keeping people engaged and motivated, and keeping focus through a possibly long shutdown period
- Technical: Waste management, waste removed and not separated or segregated, with a mindset of being somebody else's problem..
- Going from repetitive work during operations to varied work during decommissioning – need to change mindset
- Making staff aware of new safety issues
- Managing transition from a line hierarchy to a project hierarchy
- Retain collective memory
- Timeline can change, challenging for the staff
- Post operational clean-out
- Inventorisation and characterization can be started during transition, also resolving decontamination
- Keeping operational data
- Do not forget offsite work; communication with community, retired staff

2 What are the best practices for managing the transition from operation to decommissioning?

- Can be useful if both management and regulator indicate that decommissioning should be discussed early, during operation
- Have HR plans in place even before announcement of shut-down
- Need to bring in external help with decommissioning experience for refining your plans
- Good to have both internal and external communication plans
- US: Public advisory committees set up by plant, running on their own

DigiDecom2018 (3-7 Dec. 2018)

Application of advanced plant information systems for nuclear decommissioning and life-cycle management

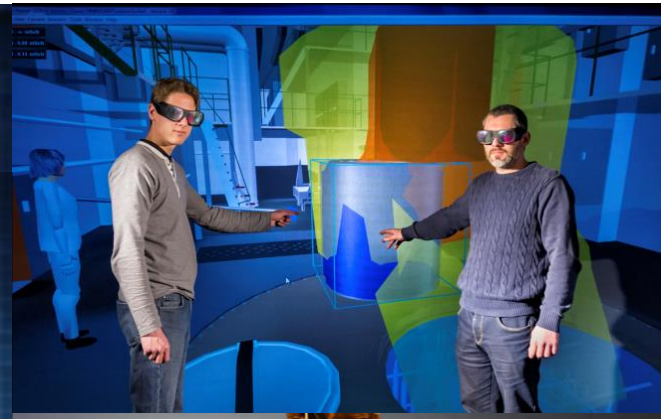


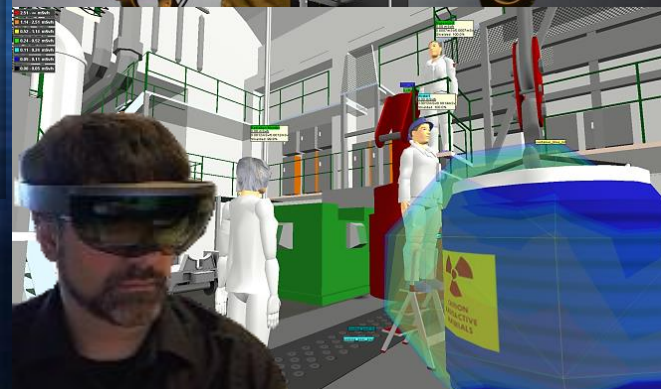


www.ife.no/digidecom2018

DigiDecom2019 (29-21 June 2019)

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





using technologies like **storytelling, serious games, 3D simulation, digital twin, and virtual/augmented reality.**

www.ife.no/digidecom2019

DigiDecom-Training 2018 - IAEA TC supported Workshop

on the Role of IT in Knowledge Management for Decommissioning

5-9 November 2018, Halden

…train **young professionals** in application of **innovative methods for various aspects of nuclear decommissioning** projects. A special focus will be on advanced, digitally-enhanced, techniques for enhanced *information and knowledge management, early strategic planning, detailed job and workforce planning, site and job specific training, radiological hazard management and emergency preparedness, site monitoring, in-situ information support, as well as communication and documentation*. The Workshop included digital simulation-based **practical exercises**.

DigiDecom-Training 2019
2020 Spring, Norway

ELINDER

Learning

- Radiation protection
- Worker safety
- Measuring and sampling
- Characterization
- Decom tasks (cutting)
- Using digital tools
- …

Using

- eLearning (pre-qualification and refresher)
- Immersive and interactive presence
- Serious gaming
- Mixed reality – AR augmented in physical training site
- Trainee performance measures
- Simulation based story telling

Through

- Real-life examples (of the instructors, …)
- Learning by doing – practical tasks (in VR and desktop)
- Possiblity for usign data and examples from the trainees (orgaisation)

iUS Institut für Umwelttechnologien und Strahlenschutz GmbH

Making Future.