

# Application of 3D radiological modelling in digital support systems

## The VRdose family

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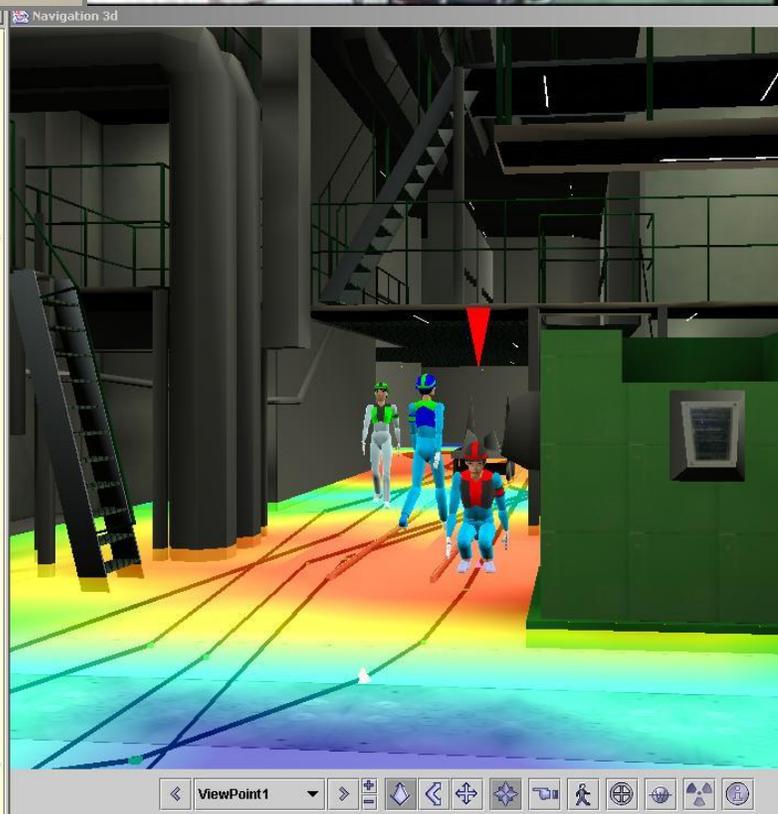
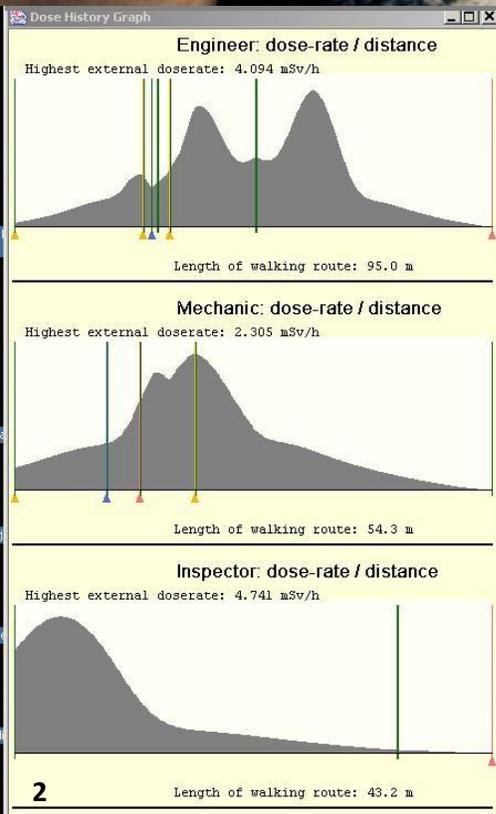
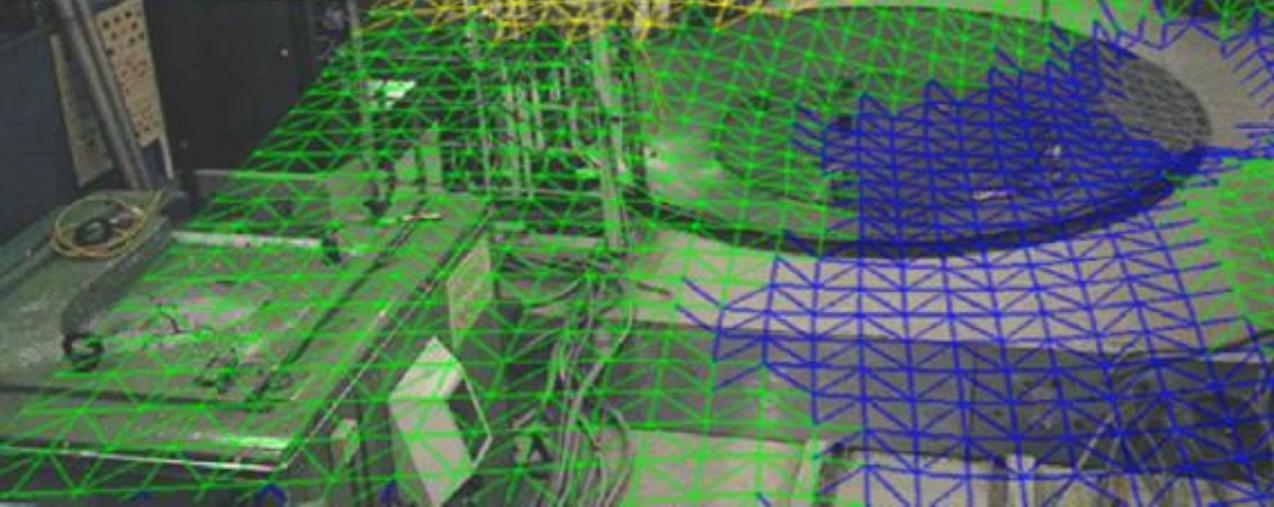
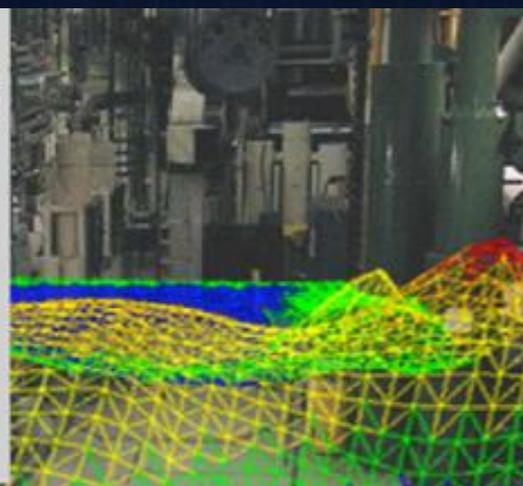
Institute for Energy Technology, Halden, Norway



Interregional Workshop on Optimization of Technology Selection  
for Decommissioning of Large and Small Nuclear Installations

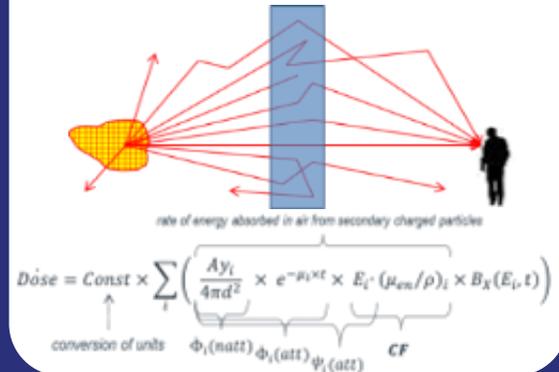
2019 Sep 9-13 Miami

# Digital support concepts in nuclear environments (since 1996 till today)

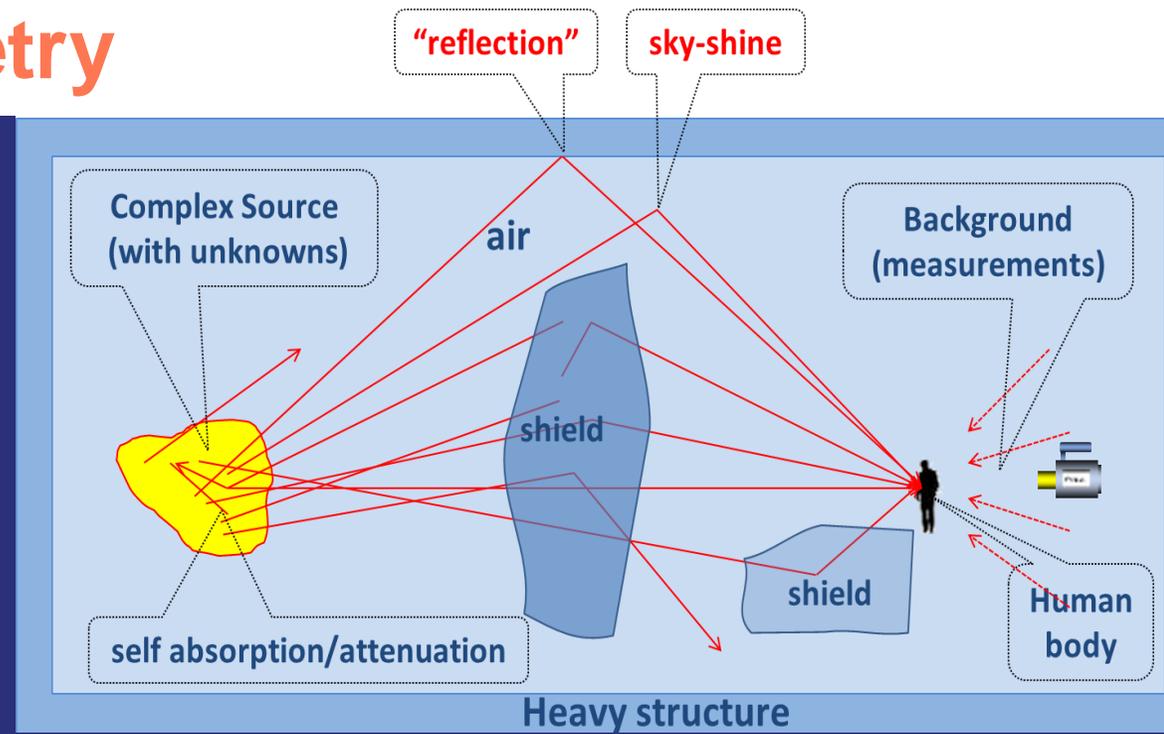
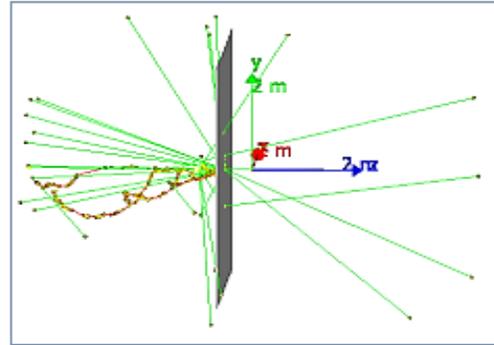


# Radiation transport and dosimetry

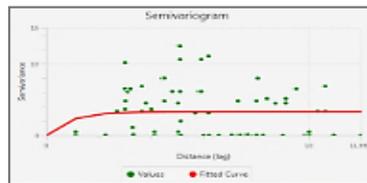
## Real-time (Point Kernel) radiation transport



## MC radiation transport (MCNP, GEANT4)



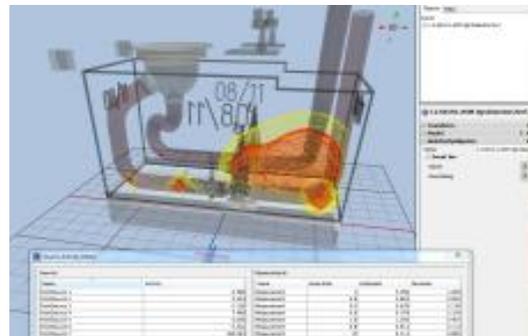
## Interpolation, Geostatistics



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

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

## Source deconvolution

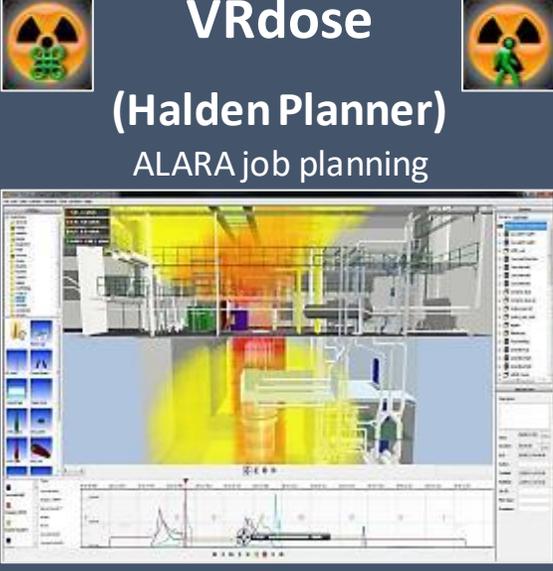


## Atmospheric dispersion

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

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

# Tools/ techniques (3D, interactive, efficient)



**VRdose**  
(Halden Planner)  
ALARA job planning

The image shows a software interface for VRdose. It features a 3D model of an industrial facility with a yellow and orange color-coded overlay representing radiation dose distribution. The interface includes various toolbars, a sidebar with icons, and a bottom panel with a graph and data tables.



Virtual Reality (VR) *immersive vis.*



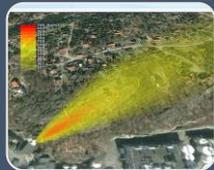
Mobile & ubiquitous computing



Augmented Reality (AR)



Advanced UI (touch screens)



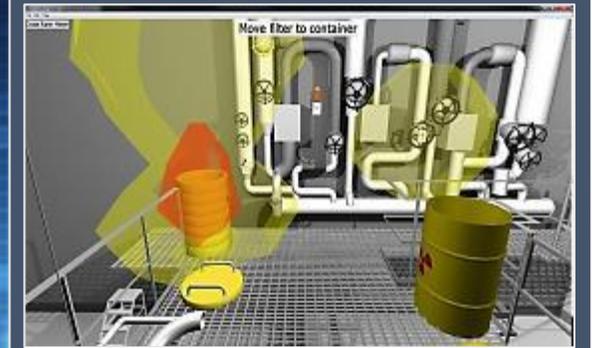
Geographical Info. Systems



**Simulation  
Editor**

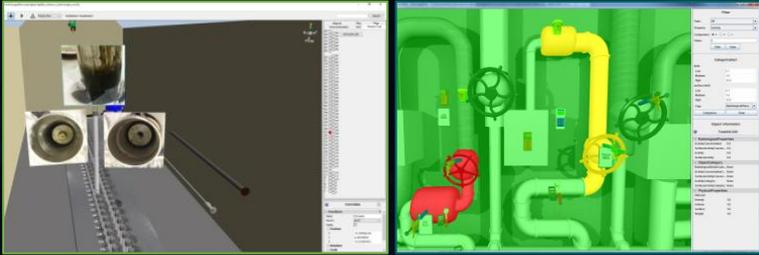


Virtual Reality based training

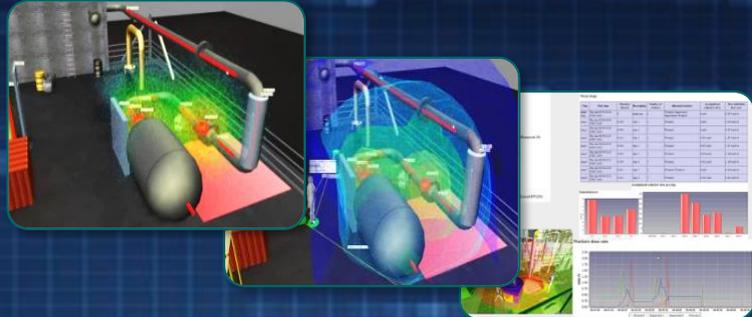


# SW tools and services

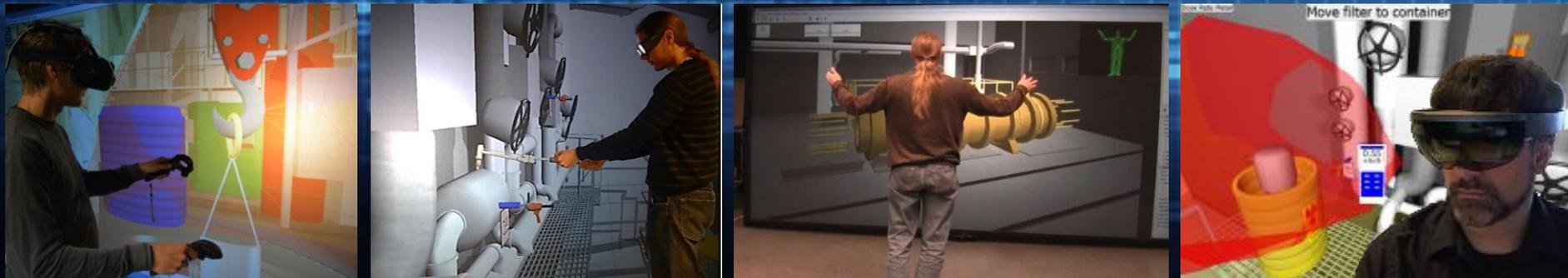
RadPIM



VRdose & Pro



Immersive solutions



Information management

Job planning

Mixed reality training

In-the-field information

Safety evaluation and demonstration

Knowledge management

# HVRC VRdose<sup>®</sup>

## 3D ALARA Planning and Briefing Tools

vrdose-support@ife.no

<https://ife.no/en/Service/hvrc-vrdose/>



Planner



Briefer



# Basic Workflow

Characterise  
& Model  
Environment

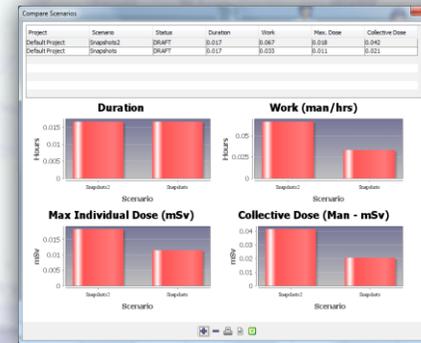
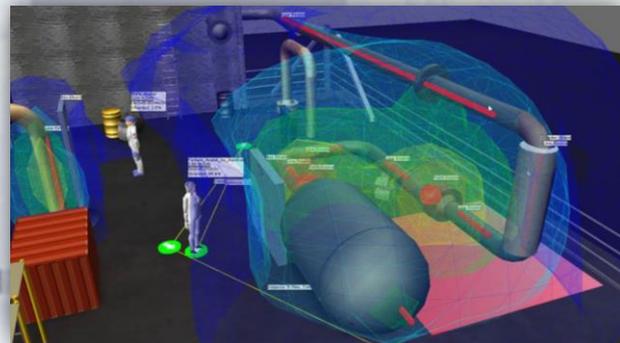
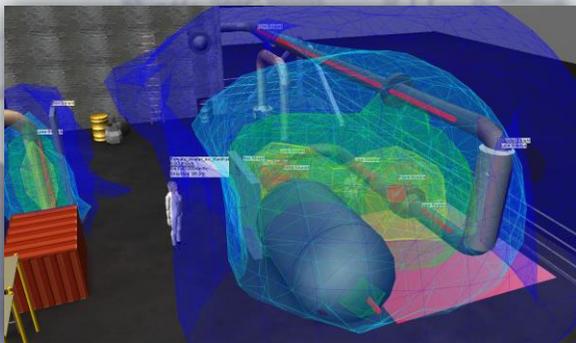
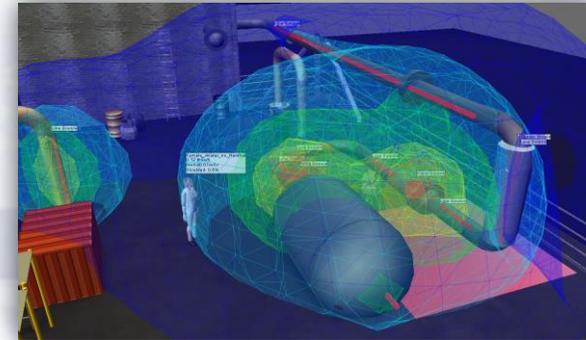
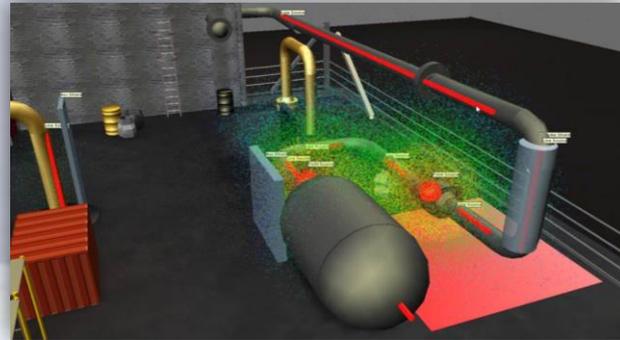
Plan Work  
Procedure

Review &  
Schedule

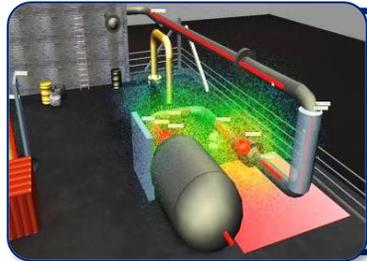
Brief

Execute

Evaluate &  
Report

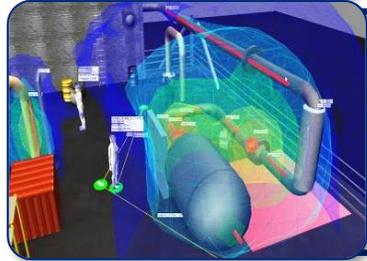


# The IFE VRdose™ family



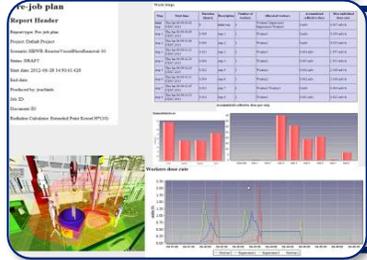
## Visualize

- 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

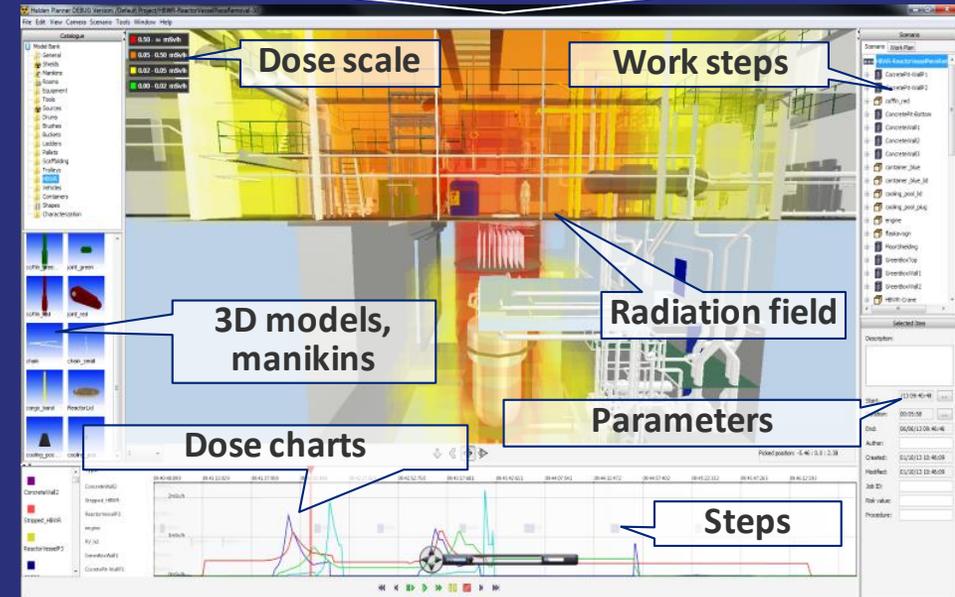
- Mobile and interactive material
- Augmented / mixed reality

User(s)

Info.  
systems

Sensors

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



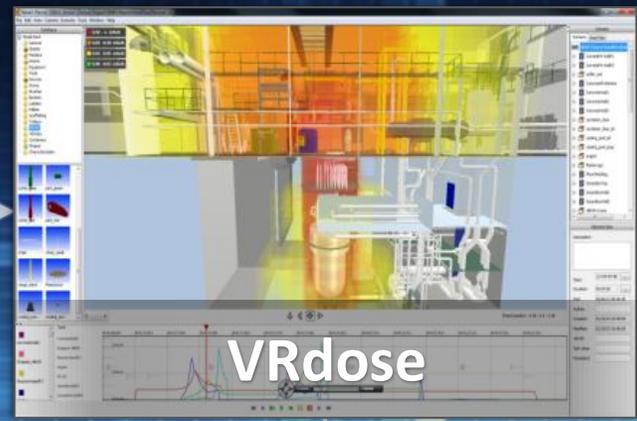
Optimal work procedure, Worker  
dose/risks, Comparison of  
alternatives, Documentation,  
Demonstrations,  
Training material

# Integrated system

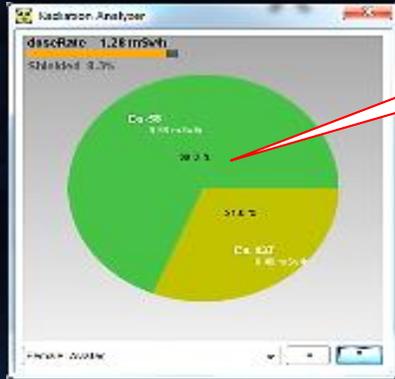
Sensors, detectors

3D design production

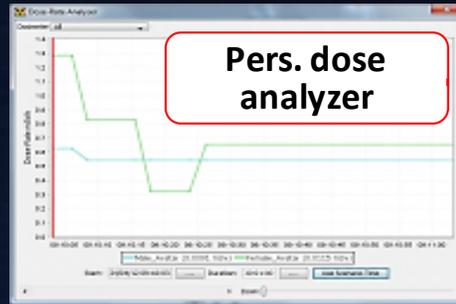
MRO/EPR



# VRdose UI

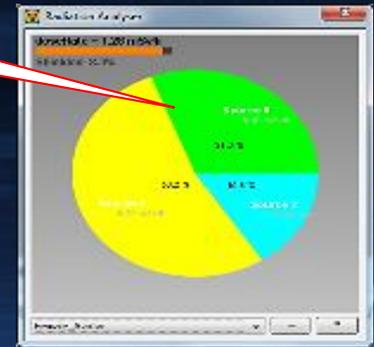


Isotopic contributions



Pers. dose analyzer

Source contributions



Radiation field

Color (dose) scale

Source info

Shield info

Manikin info: dose rate, acc. dose, shielding

3D object folders

- Drag-in 3D object categories:
- ✓ Manikins
  - ✓ Sources
  - ✓ Shield
  - ✓ Dosimeters
  - ✓ Cameras
  - ✓ Standard objects (trolleys) etc.

The main 3D visualization window displays a simulated radiation field. A central yellow cylindrical source is surrounded by a blue and green radiation field. A manikin is positioned in the field. The interface includes a 'Hidden Planner' panel on the left with a tree view of objects, a 'Work list' and '3D objects' panel at the bottom left, and a 'Participant list' and 'Object list' panel on the right. A 'Personal dose charts' window is overlaid at the bottom, showing dose rate and accumulated dose over time. A 'Time flow controls' bar is at the very bottom.

Actions groups and lists

Object list

Participant list

User def. actions

Navigation

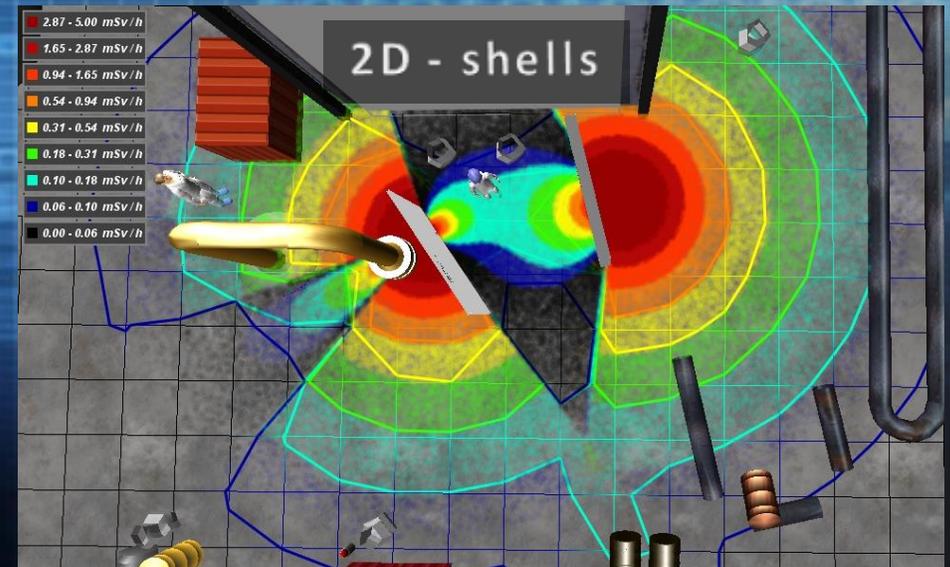
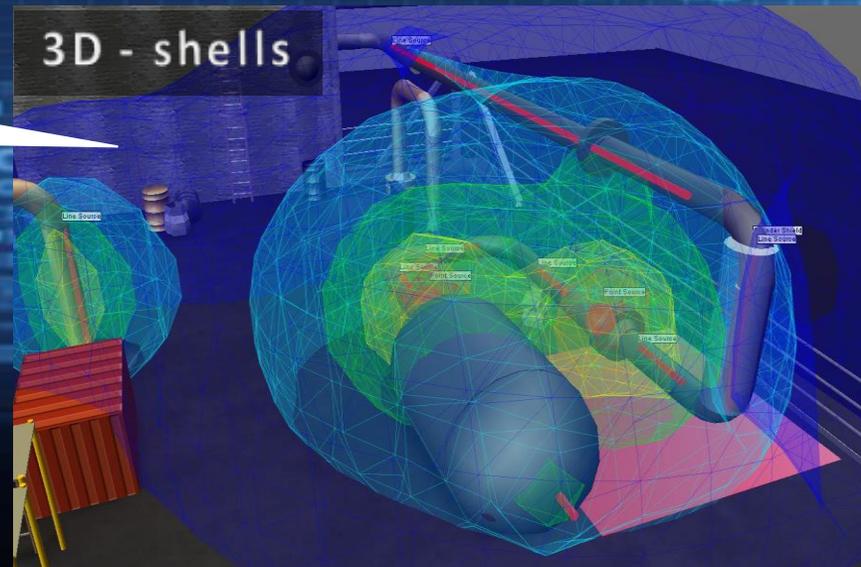
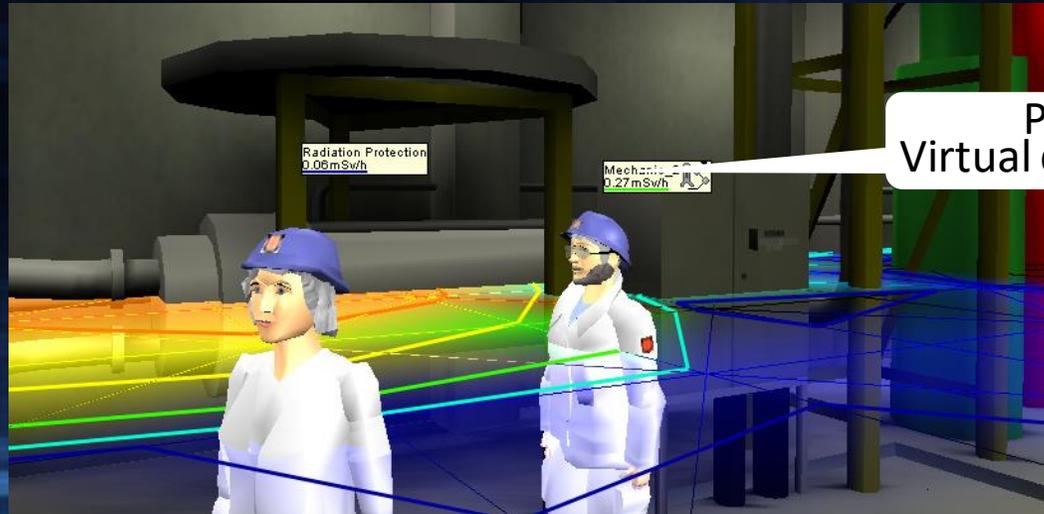
Personal dose charts

Time flow controls

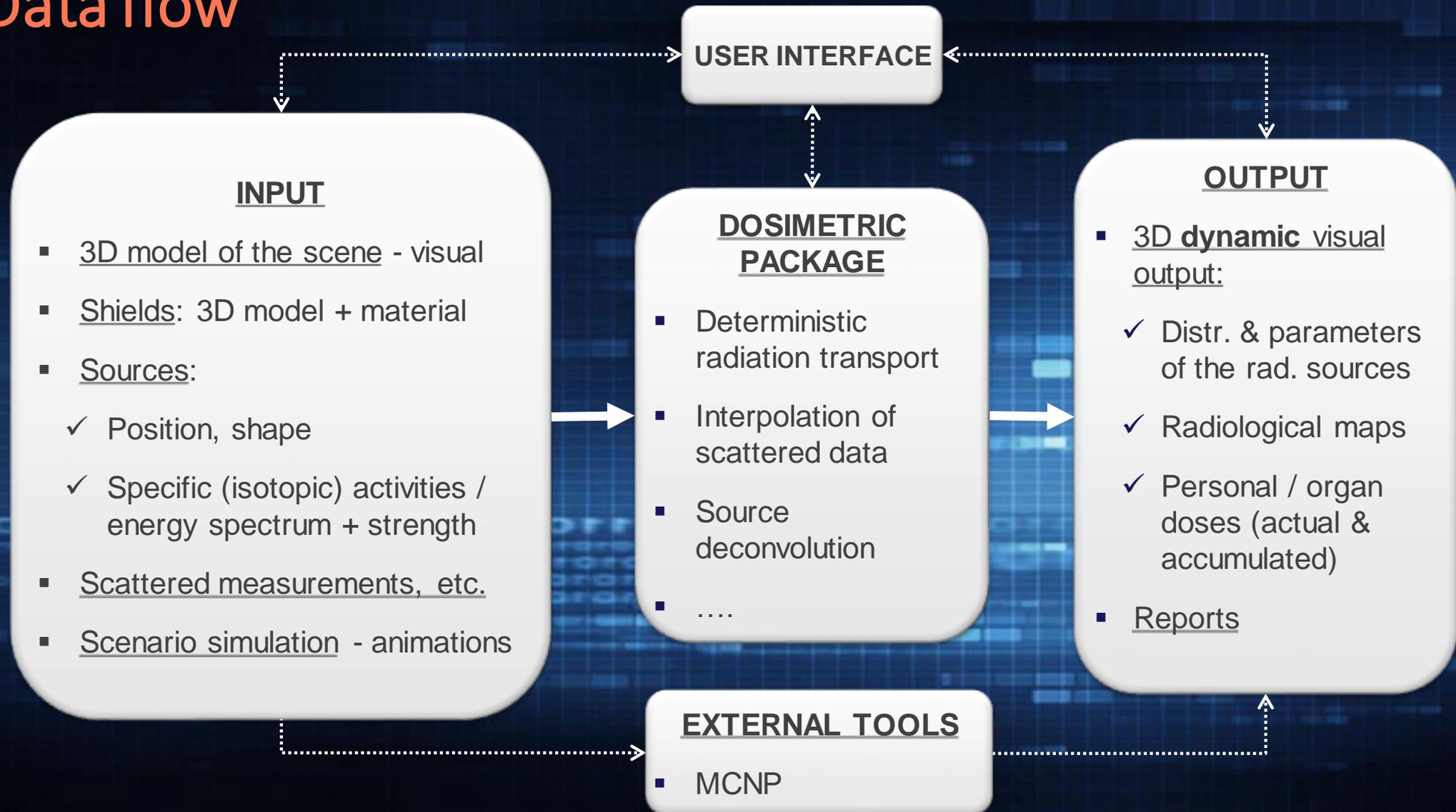
Object parameters



# Radiation Visualisation – real-time



# Data flow





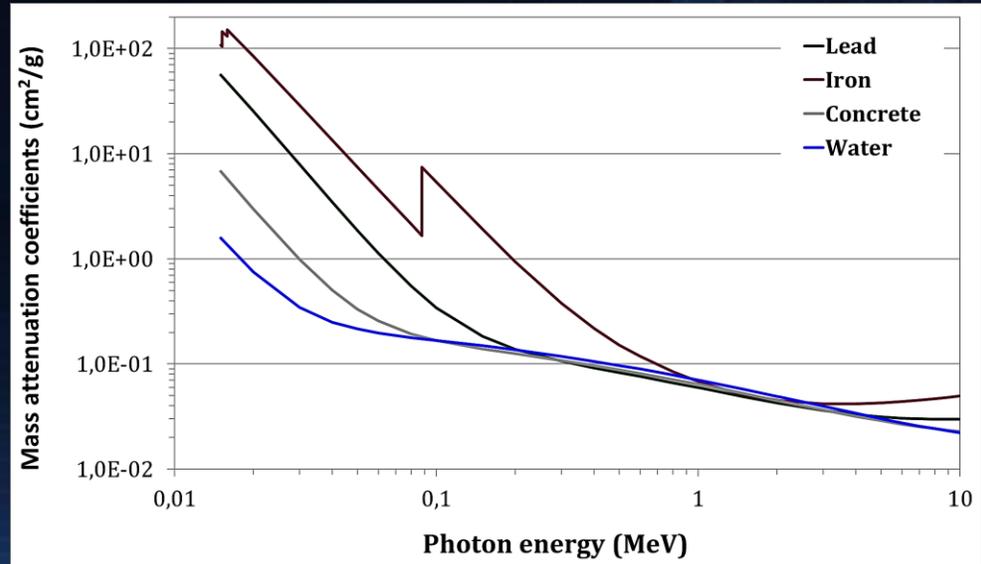
# Sources and shields

117 isotopes from the IAEA INDC(NDS)-053,  
Handbook of nuclear data for safeguards: Database extensions. August 2008

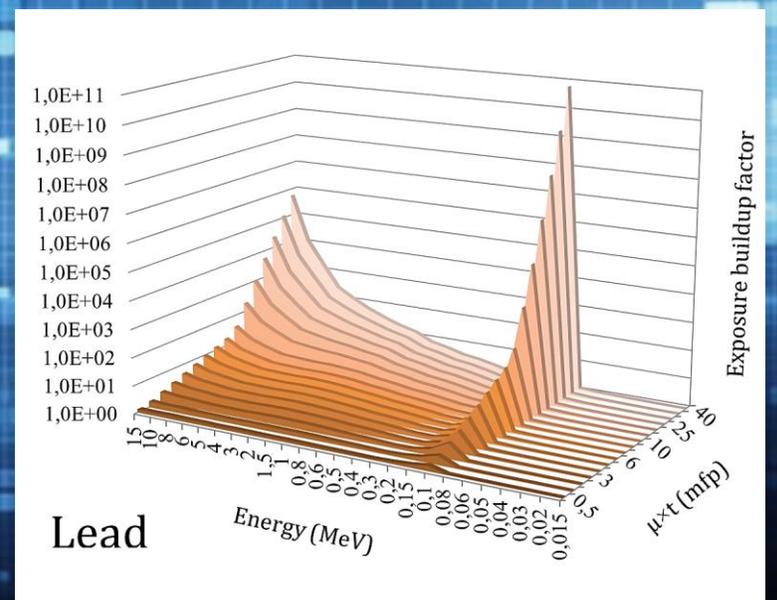
Isotope	T1/2		Energy (keV)	Yield (%)
6-C-15	2,449	s	5297,817	63,2
7-N-16	7,13	s	6128,63	67
			7115,15	4,9
8-O-19	26,88	s	109,894	2,54
			197,142	95,9
			1356,843	50,4
			1444,085	2,64
			1553,97	1,39
11-Na-22	950,57	d	511	179,8
			1274,537	99,94
11-Na-24	0,62329	d	1368,626	99,9935
			2754,007	99,872
12-Mg-27	9,458	m	170,686	0,8
			843,76	71,8
			1014,44	28
13-Al-265	717000	y	511	163,5
			1129,67	2,5
			1808,65	99,76
			2938	0,24
18-Ar-41	109,61	m	1293,64	99,16
19-K-40	4,563E+11	d	1460,822	10,66

+ Custom

+ Custom



Lead  
Iron  
Concrete  
Water  
Air  
+ Custom



# Radiation transport models

## Basic Point Kernel model (simple & fast approximation):

*rate of energy absorbed in air from secondary charged particles*

$$\dot{D}ose = Const \times \sum_i \left( \underbrace{\frac{Ay_i}{4\pi d^2}}_{\Phi_i(natt)} \times \underbrace{e^{-\mu_i \times t}}_{\Phi_i(att)} \times \underbrace{E_i}_{\Psi_i(att)} \cdot \underbrace{(\mu_{en}/\rho)_i}_{CF} \times B_X(E_i, t) \right)$$

*conversion of units*

## Extended Point Kernel model (greater accuracy and extensibility & thus a little slower than the basic model):

$$\dot{D} = \sum_i \left( \frac{Ay_i}{4\pi d^2} \times e^{-\mu_i \times t} \times CF(E_i) \times B(E_i, t) \right)$$

**CF(E<sub>i</sub>)** depends on:

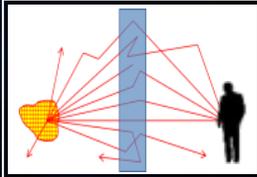
1. photon energy
2. irradiation geometry
3. detector response (quantity)

**B(E<sub>i</sub>, r)** depends on:

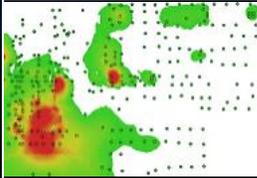
1. shield material
2. photon energy
3. shield thickness
4. detector response
5. shielding composition
6. angle of incidence
7. shield geometry

→ accuracy and flexibility

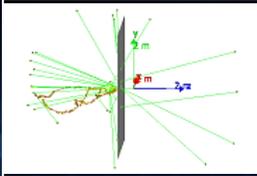
- extended database → applicability
- updated database → accuracy
- open input database → updatable
- improved interpolation → accuracy
- improved extrapolation → applicability
- improved source splitting → close distances
- etc...



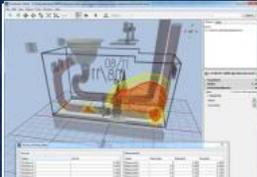
**Improved deterministic radiation transport**  
Accuracy, applicability, output detail



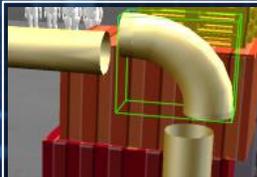
**Geostatistical analyses of radiation data**  
Kriging and other interpolation techniques



**Monte Carlo radiation transport modelling**  
Interface with MCNP



**Source deconvolution**  
Find activities and positions of radiation sources



**3D modelling functions**  
Model splitting and cutting functionalities



**Constructive solid geometry (CSG) editor**  
Complex shaped radiation sources and shields

Diffuse radiation sources, enhanced reporting, import functionalities, ...



**VRdose Pro**

**Main VRdose based solution users:**

- Chernobyl Nuclear Power Plant, Ukraine
- CNPO - China Nuclear Power Operation Technology Corporation, Ltd., China
- Chubu Electric Power Company, Japan
- Fugen Nuclear Power Plant, Japan
- INER - Institute of Nuclear Energy Research, Taiwan
- JAEA - Japan Atomic Energy Agency, Japan
- Leningrad Nuclear Power Plant, Russia
- NNL - National Nuclear Lab, UK
- PartDB Co., LTD., Korea
- SevRAO Andreeva Bay, Russia
- SRCFMBC, Russia
- EC Joint Research Centre in Ispra, Italy
- Exitech Corporation, US
- NUVIA, France
- Halden Boiling Water Reactor, Norway
- IFE Radioactive Waste sector, Norway

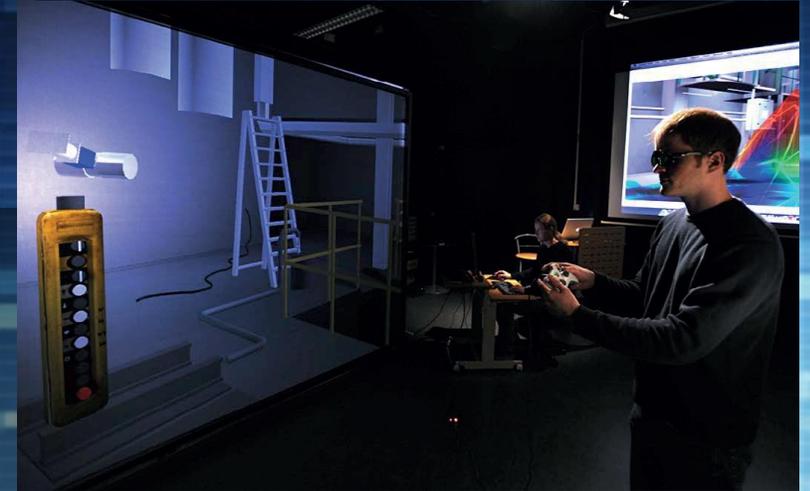
# Halden Simulation Editor

## 3D Procedure Creation & Training Toolkit

vr-info@ife.no

### Key Features

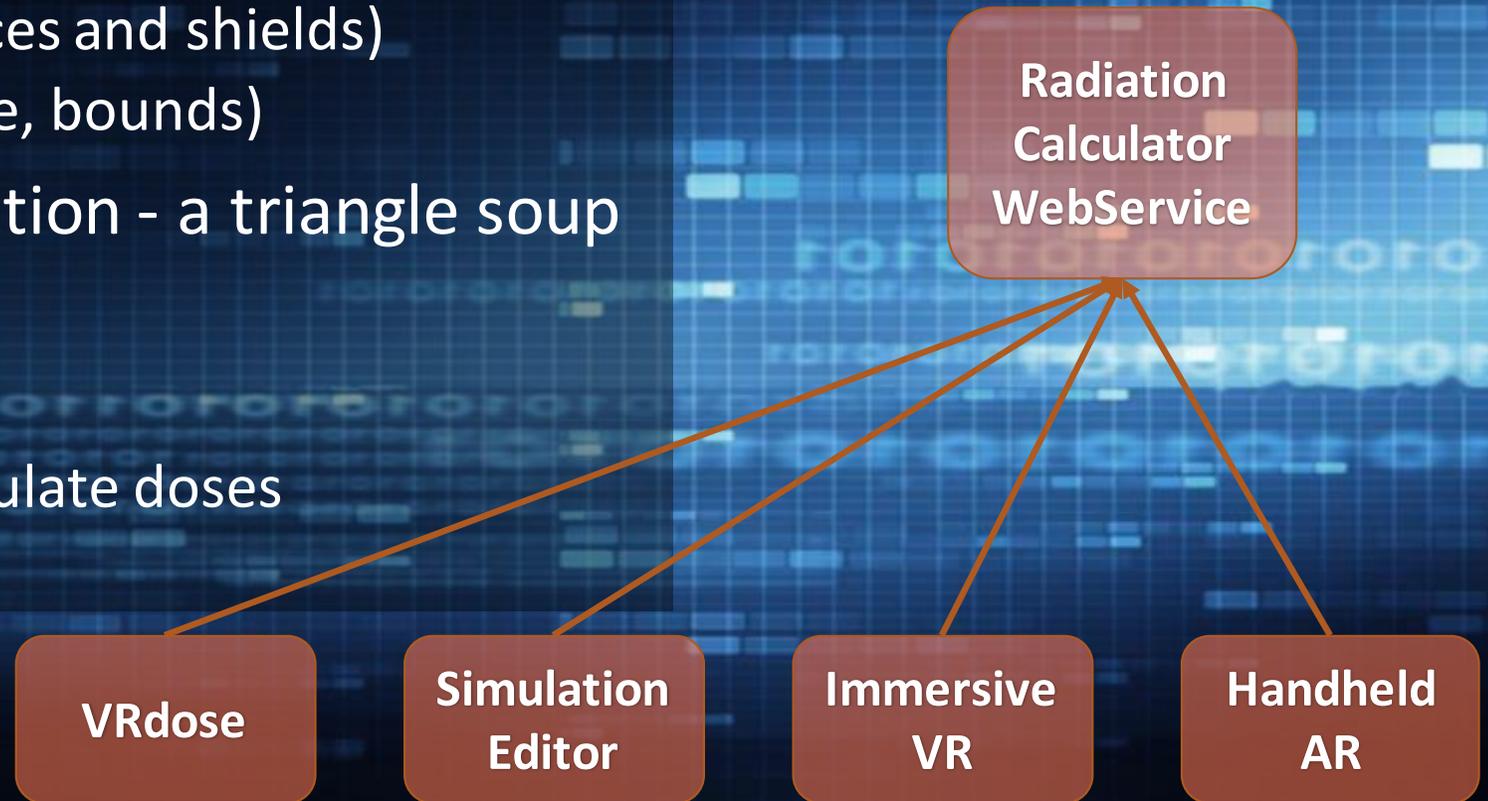
- Animation tools
- Newtonian physics simulation
- Scripting language support for complex behaviours
- Multiple possibilities for interaction design and input devices
- Multi-user support for teamwork training
- Radiation simulation for nuclear power applications
- 3D model input and customisable built-in geometries



# Point-kernel calculator as a webservice

Standalone, plug-in module via web

- Input to the service calls are
  - The radiological scene (sources and shields)
  - Rad. visualisation mode (type, bounds)
- Output is radiation visualisation - a triangle soup
- Will be extended to
  - Return raw dose-rate values
  - Support «animation» to calculate doses





# Managing the transition from operation to decommissioning

- Inadequate planning and management of decommissioning projects is a principal factor affecting success [IAEA].
- **Decommissioning is different** from operation:
  - The plant loses its mission, which is to generate electricity,
  - The staff lose their primary function, which is to operate the plant.
- Decommissioning is a period of great **uncertainty** and **unease** for both staff and management.
- The **transition** from operation to decommissioning **is a key moment** in decommissioning:
  - Failure to plan for and manage the transitional stage can result in loss of staff, loss of plant expertise and knowledge, degradation of the safety culture and increased costs.

## Transition Analysis & Planning

- IFE offers a **combined capability management and gap analysis approach** to:
  - Identify key capabilities for the entire decommissioning process, including evaluation of capability maturity
  - Perform a gap analysis to assess the difference between current and future capabilities
  - Work with the plan to develop a road map to address the gap and plan for the future
- This approach involves staff in the planning and organization of the decommissioning project, with the added benefit of:
  - Reducing uncertainty & rumours
  - Increasing engagement & buy-in
  - Capitalize on staff experience & knowledge
  - Identify opportunities for staff competence development