E.2 New software tool for dynamic radiological characterisation and monitoring in nuclear sites

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The Halden Reactor Project (HRP) is a jointly sponsored international cooperation, under the aegis of the Organisation for Economic Co-operation and Development - Nuclear Energy Agency. Extensive and valuable guidance and tools, connected to safe and reliable operation of nuclear facilities, has been elaborated throughout the years within the frame of this programme. The HRP has particularly high level results in virtual-reality based tools for real-time areal and personal monitoring. The techniques, developed earlier, are now being supplemented to enhance the planning and monitoring capabilities, and support general radiological characterisation connected to nuclear sites and facilities.

Due to the complexity and abundance of the input information required, software tools, dedicated to the radiological characterization of contaminated materials, buildings, land and groundwater, are applied to review, evaluate and visualize the data. Characterisation of the radiation situation in a realistic environment can be very complex, and efficient visualisation of the data to the user is not straight forward. The monitoring and planning tools elaborated in the frame of the HRP feature very sophisticated three-dimensional (3D) high definition visualisation and user interfaces to promote easy interpretation of the input data. The visualisation tools permit dynamic visualisation of radiation fields in virtual or augmented reality by various techniques and real-time personal monitoring of humanoid models. In addition new techniques are being elaborated to visualise the 3D distribution of activities in structures and materials.

The dosimetric algorithms, feeding information to the visualisation and user interface of these planning tools, include deterministic radiation transport techniques suitable for fast photon dose estimates, in case physical and radio- and spectrometric characteristics of the gamma sources are known. The basic deterministic model, implemented in earlier versions of these tools, is suitable for quick estimates in simple irradiation situations. Through joint research of member institutions of the HRP, an additional deterministic Point Kernel based dosimetric algorithm has been developed and implemented, to supplement the basic approach. The new model is more accurate and suitable for better estimates in more complex environments.

Furthermore, additional methods dedicated to the geostatistical analysis and processing (kriging) of the data measured, and other dosimetric methods are being added, to extend the software tools for cases when less other type on input information is provided.

In this paper, the visualisation and dosimetric algorithms implemented in the complex software tools, developed within the HRP, for radiological panning, monitoring and characterisation are presented.

New software tools for dynamic radiological characterisation and monitoring in nuclear sites

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Introduction

The Institute for Energy Technology (IFE) is the host of the Halden Reactor Project (HRP), which is a jointly sponsored international cooperation, under the aegis of the Organisation for Economic Co-operation and Development (OECD) - Nuclear Energy Agency (NEA). The OECD Halden Reactor Project links many important centres of expertise, promoting collaboration and dissemination of knowledge within the nuclear community. Extensive valuable guidance, connected to safe and reliable operation of nuclear facilities, has been elaborated throughout the years within the frame of this programme. Among many others, the HRP has particularly high level results in the area of virtual-reality (VR) based tools for real-time characterisation of nuclear sites and personal monitoring in modelled environments. These tools are especially useful for planning work, e.g. dismantling, carried out in virtual models of different facilities, permitting real-time design of protection for the workers involved, in case it's needed. Numerous reports, describing recommendations withdrawn from experience attained during development of these computerised tools, have been elaborated (3, 4, 7). The planning and monitoring techniques, developed earlier, are now being supplemented by series of additional methods to enhance the planning and monitoring capabilities of the complex software tools, and make them suitable for more general radiological characterisation, connected to common types of nuclear environments and activities performed in them.

In this paper, the visualisation and dosimetric capabilities of the software tools, developed within the HRP, for radiological characterisation, monitoring and panning are described.

Methods

Radiological characterisation is needed in all stages of a decommissioning process of a radiological facility (e.g. reactor facilities, nuclear fuel cycle facilities, radiochemical laboratories, irradiation facilities etc.), i.e. radiological evaluation prior to dismantling, surveillance throughout the dismantling process, characterisation of the site after dismantling, during possible rehabilitation procedure of the site, and characterisation before final release of the site. A large variety of measuring instruments and techniques are available in the market to help acquire the data necessary for a thorough radiological characterization of contaminated materials, buildings, land and groundwater. Due to the complexity and abundance of the data, related to a decommissioning site, software tools, dedicated to the radiological characterization of contaminated areas, are applied to review, evaluate and visualize the data obtained. The database characterizing the nuclear environment usually contains abundant information on the mass, volume, quantity and type of radionuclides present. In addition, lateral (e.g. on building surfaces or on grounds) and in-depth (e.g. penetration into material) distribution of the activities is crucial for adequate description of the nuclear conditions.

The Halden Planner:

Characterisation of the radiation situation in a realistic environment can be very complex, and efficient visualisation of the data to the user is not straight forward. A good visualisation and user interface must be suitable to provide a realistic, easily understandable, and thorough image of the nuclear and radiation situation in the scene. The Halden Planner, a real-time monitoring and planning tool elaborated in the frame of the HRP, features very sophisticated three-dimensional (3D) high definition visualisation and user interface to promote easy interpretation of the data transmitted to the user (Figure 1). The visualisation techniques implemented in the Halden Planner permit dynamic visualisation of radiological conditions in virtual or augmented reality in various ways, and real-time personal monitoring of humanoid models (manikins) imitating movement of real human workers. The overall purpose of the Halden Planner is to support protection of workers in the nuclear sector by facilitating the principle of ALARA (As Low As Reasonably Achievable), and to facilitate communication between stakeholders.

Obviously, the reliability and abundance of the information visualised is just as important as the visualisation technique applied. The dosimetric algorithms, feeding information to the visualisation and user interface of the Halden Planner, include deterministic radiation transport techniques, suitable for fast photon dose estimates, taking into account shielding effect of objects present, in case physical and radio- and spectrometric characteristics of the sources of gamma radiation are known. The deterministic model, implemented in earlier versions, is a basic Point Kernel approach described in previous publications (7). The data supplied by this approach is suitable for quick estimates in simple irradiation situations (i.e. for certain photon energies, simple environment etc…). Through joint research of member institutions of the HRP, an additional deterministic Point Kernel based dosimetric algorithm has been developed and implemented in the Halden Planner, to supplement the basic approach. The new model is more accurate and suitable for better estimates in more complex environments. This novel model is based on up-to-date standard input data, and best practices in radiation shielding, reported in reference publications (1, 2, 5, 6).

In addition to the Point Kernel based deterministic methods described above, further dosimetric methods are being added to the Halden Planner, to extend its applicability and optimise its performance in cases where less or other type on input information is provided. These additional tools characterise the environment and exposure of humanoid models based on user supplied measurements, rather than calculate dose utilising the radiological parameters of the radiation sources supplied by the user. Hence, these techniques are especially useful and crucial when not all the required parameters of the radiation sources are known. These kinds of situations are quite frequent, and techniques permitting characterisation in these circumstances are very important, if we are to provide a general support for radiological characterisation for nuclear environments. In most cases the measures available are inadequate for a complete mapping and characterisation of the area and monitoring exposure of virtual workers in the zone. The dosimetric tools supporting decision making need to assess the radiation situation in areas where no real measurements are available based on the measures supplied. Depending on what additional information is at disposal, the Halden Planner applies different types of sophisticated techniques to infer the radiation conditions at locations where no user data is available.

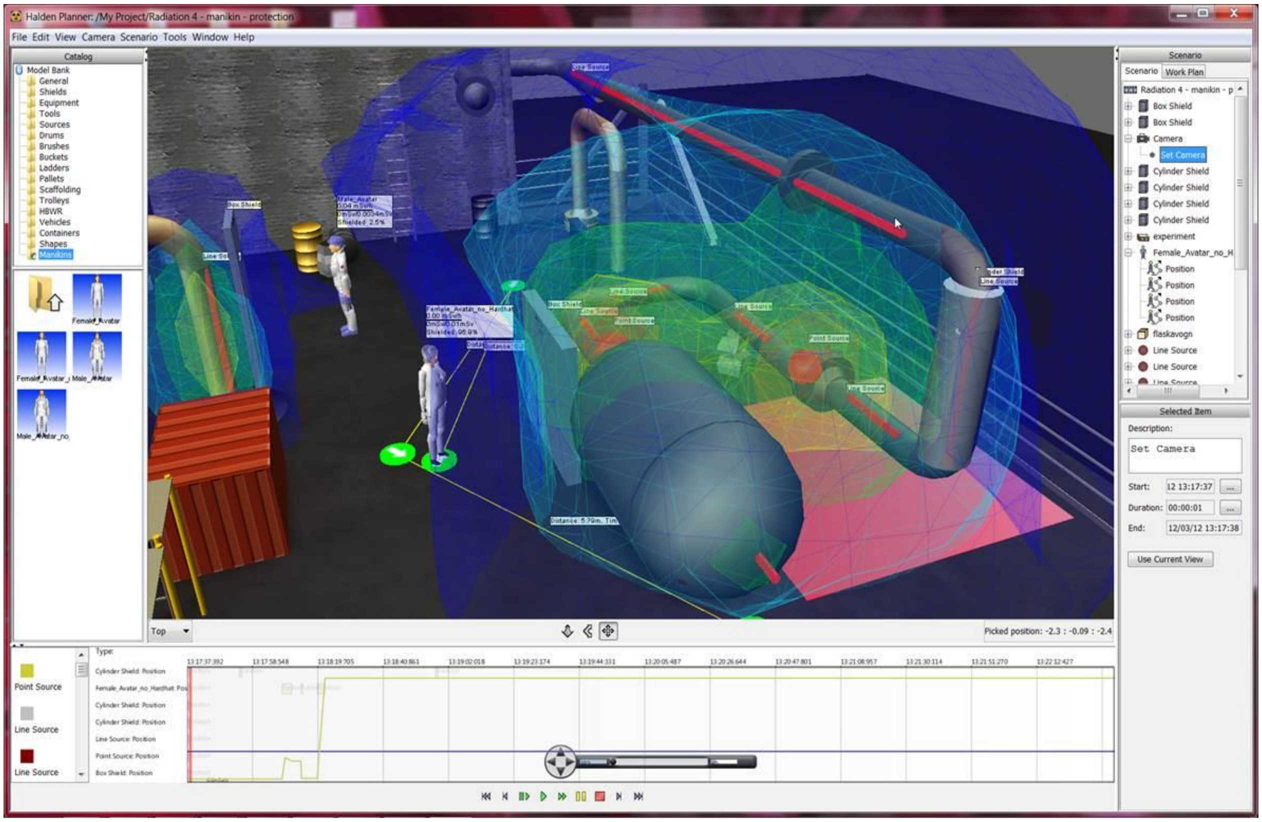

Figure 1 Halden Planner screenshot.

Radiological characterisation for large outdoor areas:

While the size of the environment to which the Halden Planner is applied to is only restricted by the available computer power, the Halden Planner has, in principle, been created for application in geographically small areas, e.g. a nuclear installation. In addition, new techniques are being elaborated within the HRP to visualise the areal distribution of different radiological parameters within large outdoor areas (Figure 2). This involves dynamic geographic representation of scattered radiological data (measures), aided by high resolution model of the landscape, to facilitate better understanding of the

- distribution of the radiological parameters,
- evolution of the radiological situation in time,
- origins of the dose rates at key locations within the area,
- accumulated and collective dose of workers walking user defined paths through the monitored area,

- and measures required by protection of workers in the area and rehabilitation of the site before final release.

The dosimetric techniques applied by tools developed for radiological characterisation and monitoring of large outdoor areas are based on scattered measurements provided by the user, either automatically through a databank or via a user interface. As a consequence inter- and extrapolation of the supplied values is required for a smooth mapping of the area and personal monitoring within the site. The suitable inter- and extrapolation method depends on the nature of the input data supplied. For example interpolation based on measured dose rate values (e.g. rate of ambient dose equivalent H*(10)) is not simple or straight forward, due to the high skeweness of the data and the expected dose rate map, which follows from the exponential decrease of the dose by distance from a radiation source. In this particular case, based on the related literature, geostatistical analyses of the data has proven to perform very well, and, thus, will be adopted in the tools developed within the HRP.

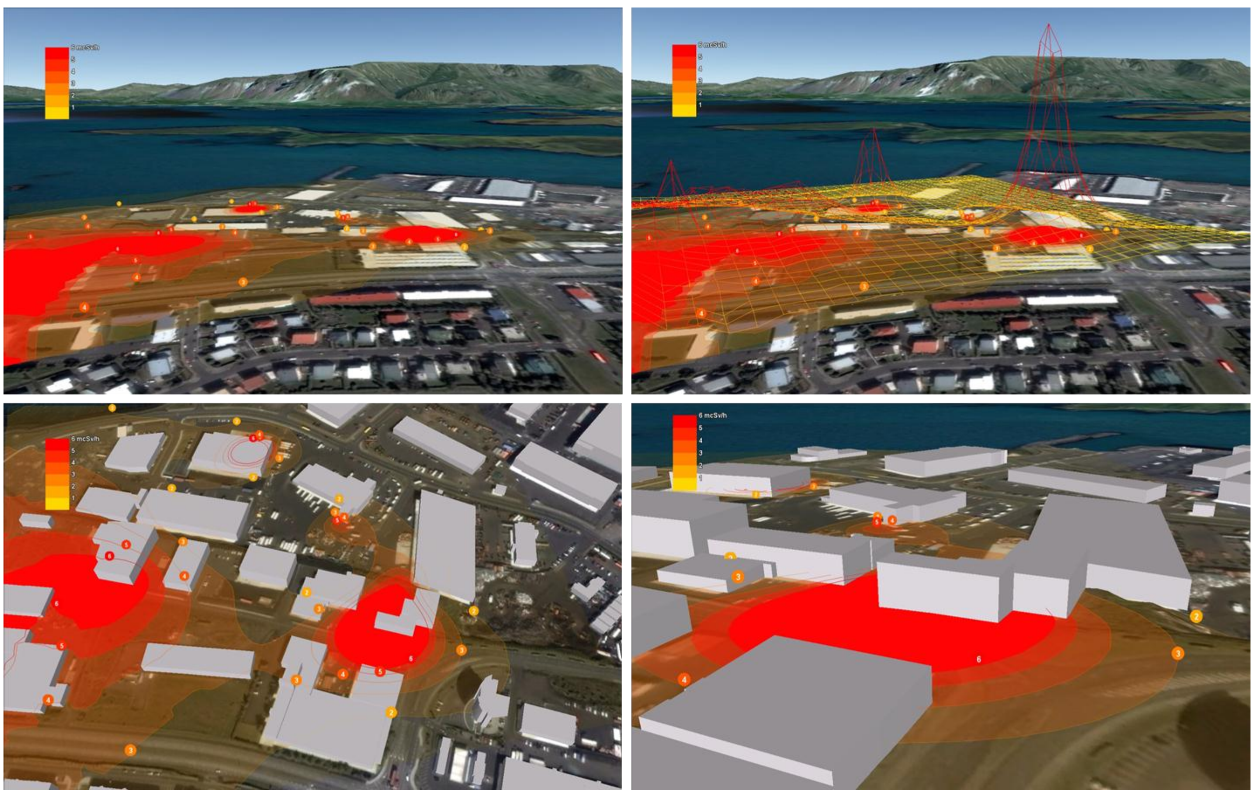

Figure 2 Radiological characterisation for large outdoor areas.

<u>In-situ radiological characterisation (using portable devices):</u>

As explained above, Halden Planner provides very efficient characterisation of nuclear environments and the exposure conditions within, based on the radiological features of the radiation sources present, user supplied measures or a combination of data of these kinds of data. If we are to provide a complete arsenal for general radiological characterisation, then additional tools have to be provided, which can be used by personnel involved in work involving radioactive materials. For example decommissioning of different nuclear facilities involves contaminated buildings or buildings having radiation sources inside, and requires radiological characterisation preceding, during and after the work commences. The execution of radiological characterisation, in this case, may include gathering and processing of a very large amount of data. This requires efficient (quick and reliable) data acquisition and processing tools to

- minimise presence of the workers performing the acquisition of the data in the hostile environment,
- and facilitate investigation of the data gathered for finding optimal solutions, minimising costs entailed and radiation exposure of both
  - the workers involved in decommissioning,
  - and residents who have a potential of being exposed to radiation from radioactive material released from the site.

Data acquisition many times requires presence in areas (rooms) with elevated level of radiation. Further, the possibility of analysing data in-situ and on-the-fly would therefore be very useful for

- protection of workers involved in acquisition of the data required,
- checking adequacy of the amount of data gathered for deliberated decision making,
- and inspection of the compliance of any kind of earlier data with the actual situation.

As a consequence emerging hand held devices have a huge potential in this area, due to their small size, capability of measuring different physical and even radiological (with special accessories) parameters and simplicity of use. Tools developed, and being developed by the HRP, are particularly useful for application on hand held devices in-situ (Figure 3). This means that by utilising these tools the workers involved

- gain a much better protection from radiation harm,
- have a better understanding of the radiological situation and thus are capable of making more deliberated decisions,
- and are relieved from having to carry a number of additional instruments and having to consecutively leave the area for data analyses and come back for additional measurements.

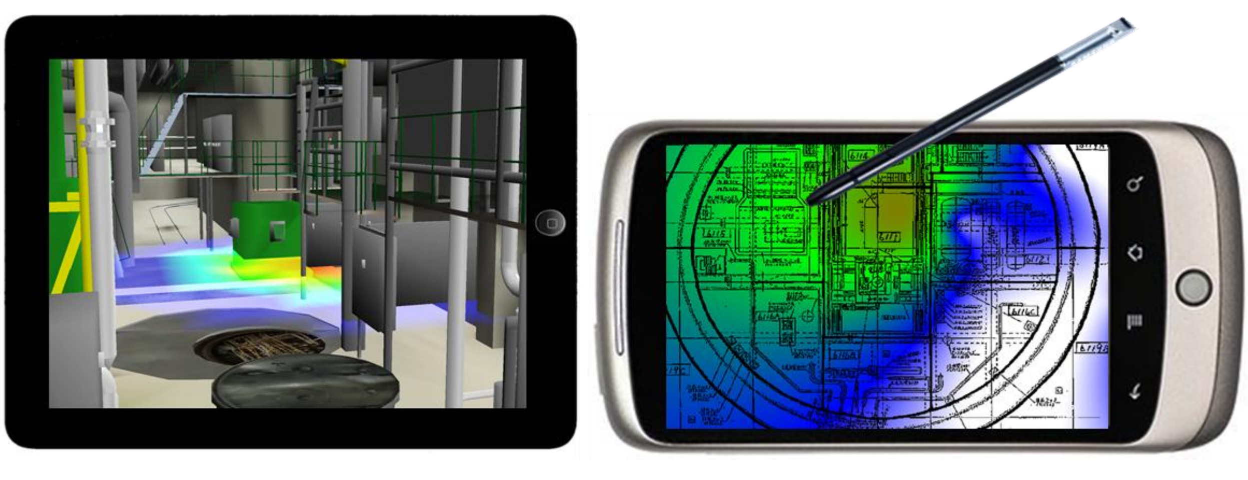

Figure 3 Indoor radiological characterisation for buildings.

Summary

Efficient (quick/real-time, easy to use, but reliable) radiological characterization is very important for decommissioning and other activities involving radioactive material. Since the tasks required are very diverse, workers and other personnel involved are compelled to resort to a series of different data gathering/processing, simulation and visualisation tools/methods. Some of the tools available today are very archaic and not especially suitable for the task. For example participants may have to bring into controlled areas and operate a large number of different devices, to measure physical and radiological parameters. Even worse, registering the data acquired many times involves paper and pencil. This, of course, makes it very hard to check, modify, transmit (e.g. to other participants of the work having no visual or audio contact) and analyse the data. On the other hand emerging technology has a huge potential in making this kind of work orders of magnitudes more efficient. Therefore, the complex nuclear toolkit developed, and being further extended and developed in the HRP, has a very good potential in becoming a general purpose, widely applied instrument in decommissioning and other activities involving radiative material.

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New software tools for dynamic radiological characterisation and monitoring in nuclear sites

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Overview

Decommissioning can greatly benefit from **flexible, easy-to-use but professional, quick/real-time but reliable**, 3D/2D radiological characterisation tools, since:

- the radiological conditions are dynamically changing,
- accidents, requiring quick intervention, may happen,
- realistic, easy to understand user interface is required for good situation awareness,
- communication between stakeholders and towards the authorities is very important for common understanding of the situation,
- decisions made may have severe health or financial consequences, etc.

The Halden Planner

is a real-time 3D software tool for:

- modelling & characterizing nuclear environments by
  - characterising radiological features,
  - and analysing exposure conditions,
- planning a sequence of activities,
- demonstrating, teaching and rehearsing work protocols,
- producing job plan reports,
- producing post-work review reports,
- presenting information.

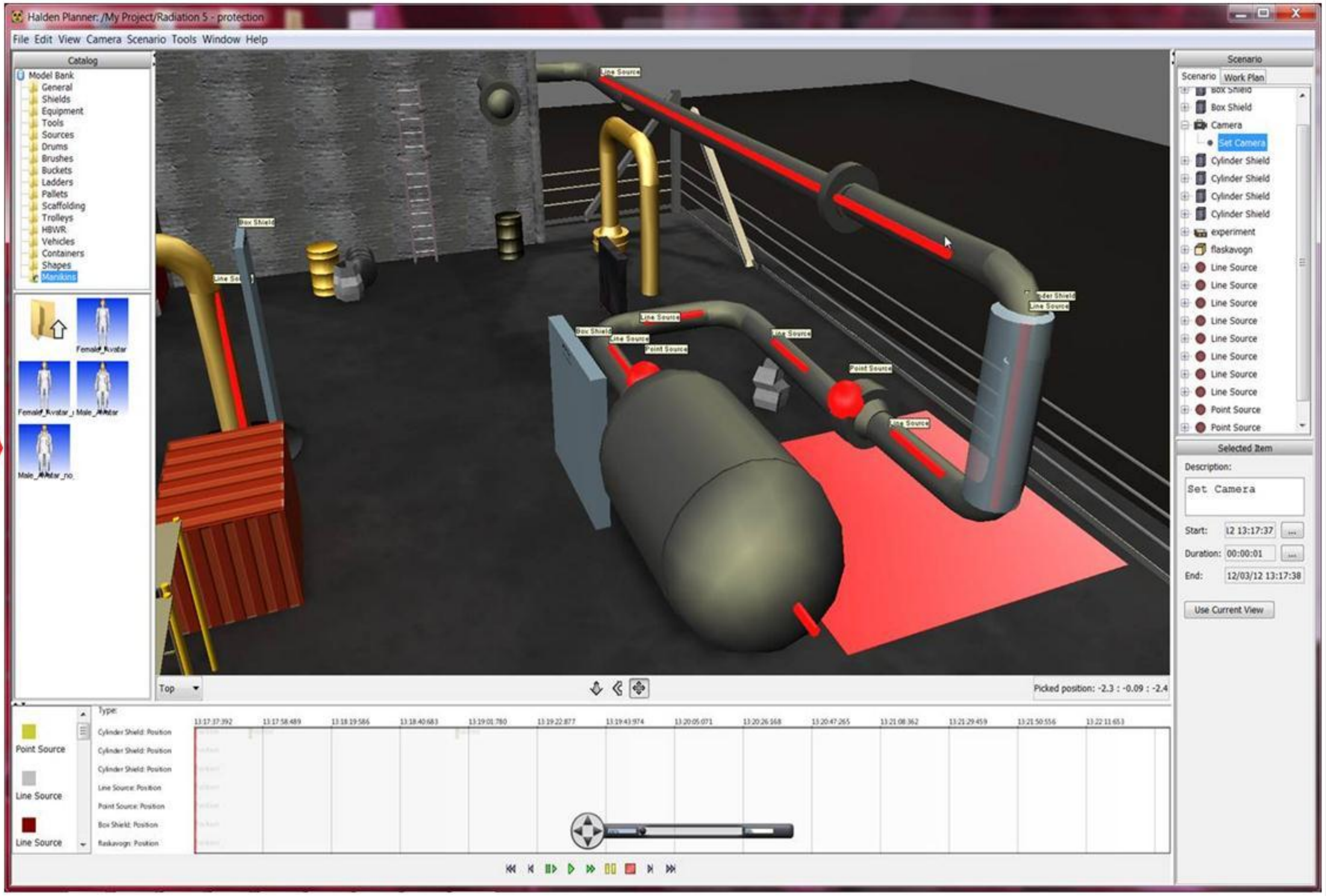
Characterising radiological features

(The Halden Planner).

INPUT

- 3D model of the scene.
- Radiological data:
  - position and shape,
  - isot. composition,
  - activity / activity concentration

  of rad. sources / hot spots,
  - type & energy spectrum of rad. emitted (γ),
  - scattered measurements, etc.
- Other data
  - **the work plan** (activities, paths, speed, etc.)



Analysing exposure conditions

(The Halden Planner)

INPUT

DOSIMETRIC PACKAGE

- Deterministic radiation transport
- Mapping based on measurements
- Other dosimetric tools
- User defined tools
- Mixture of tools

USER INTERFACE

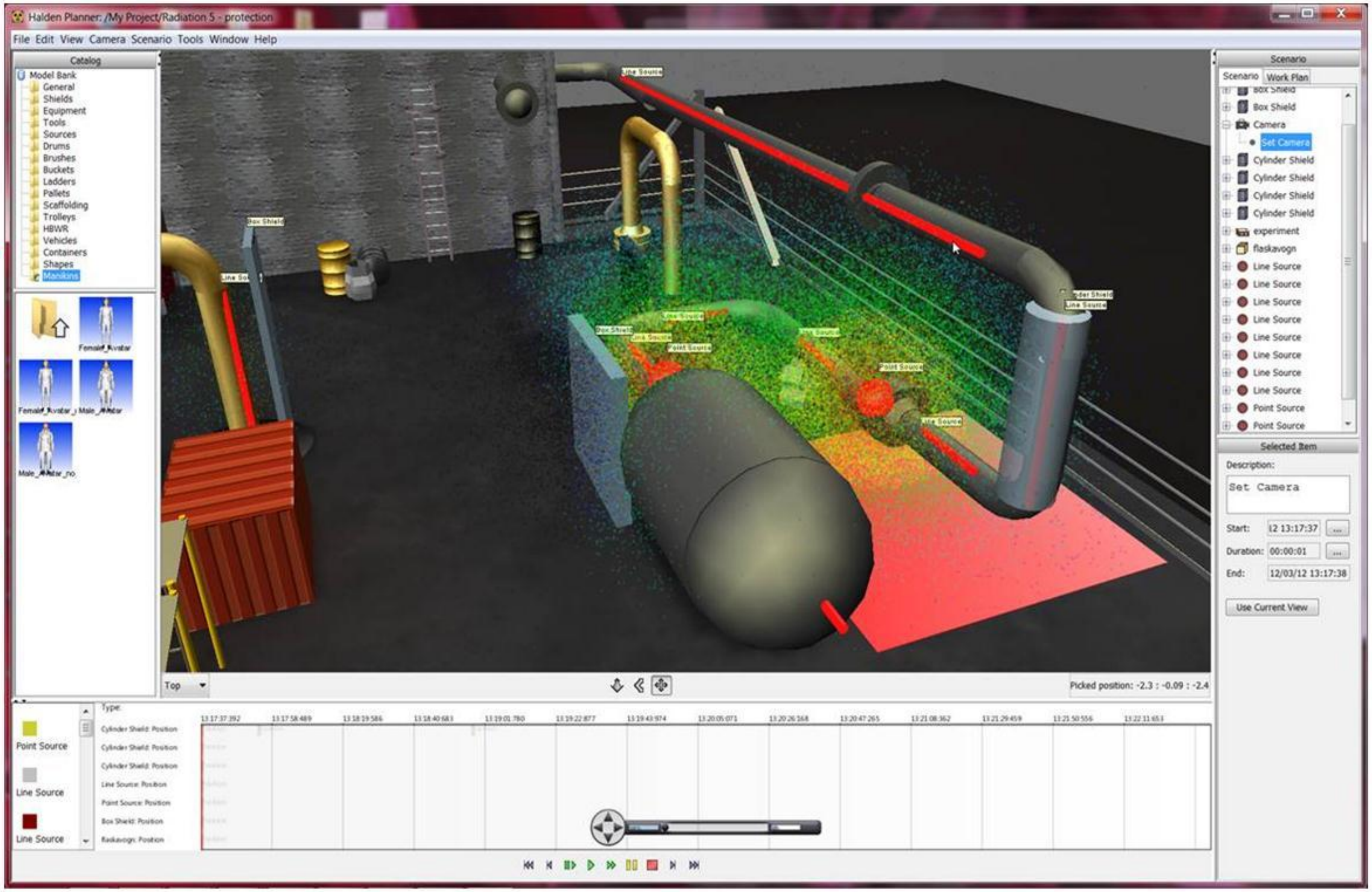
OUTPUT

3D visual output:

- Distr. & param. of the rad. sources
- Radiological maps
- Personal/organ doses (actual & accumulated)

Reports

Dynamic radiological mapping.



Planning a sequence of activities
(The Halden Planner)

INPUT

DOSIMETRIC PACKAGE

- Deterministic radiation transport
- Mapping based on measurements
- Other dosimetric tools
- User defined tools
- Mixture of tools

USER INTERFACE

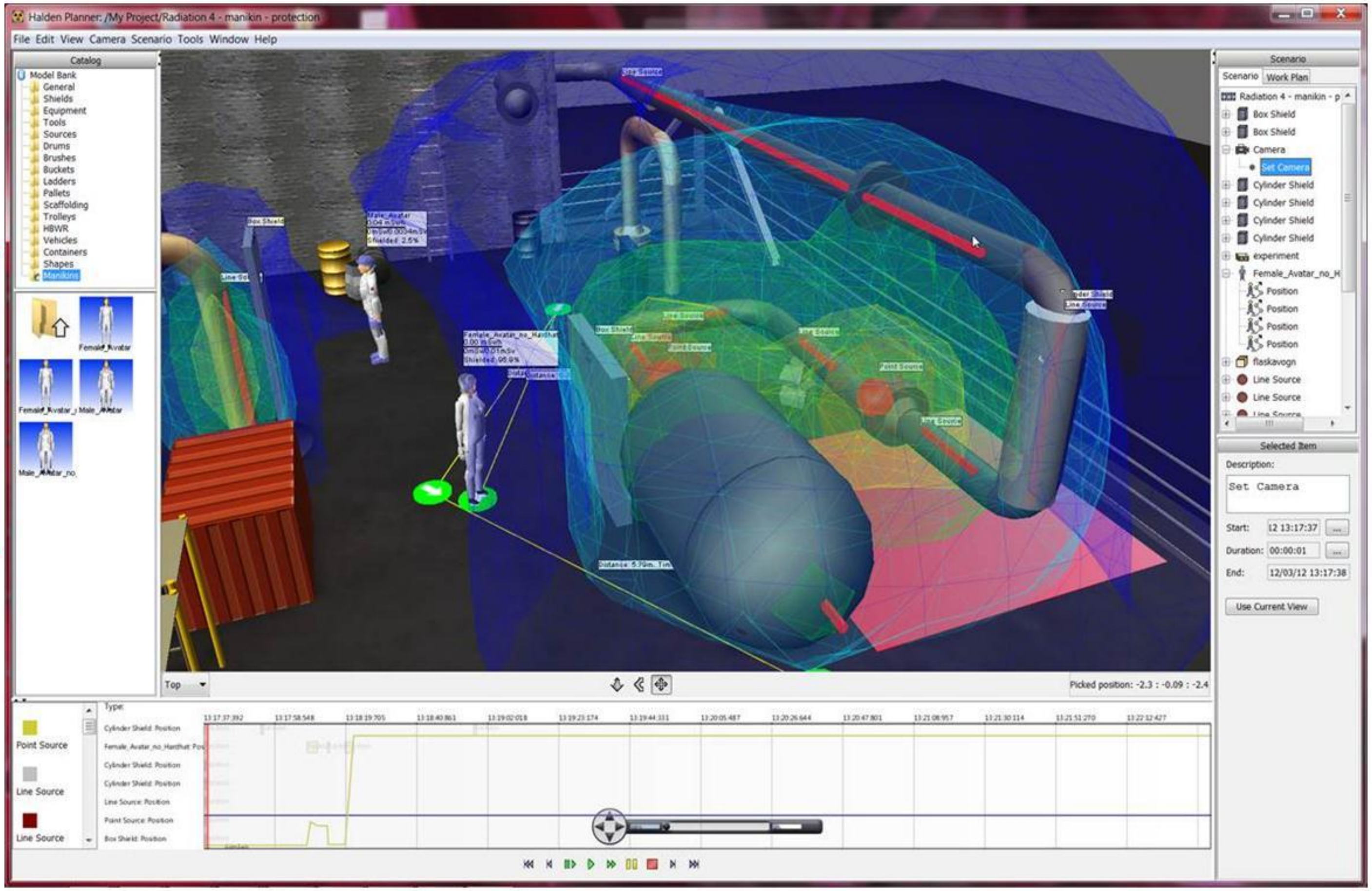
OUTPUT

3D visual output:

- Distr. & param. of the rad. sources
- Radiological maps
- Personal/organ doses (actual & accumulated)

Reports

Real-time design of protection.



Reporting and communication
(The Halden Planner)

- producing job plan reports describing
  - characterisation of the environment (rad. maps),
  - the consecutive steps of the work,
  - the entailed radiation exposure (personal, collective), etc...
- producing post-work review reports,
  - containing additional user input (e.g. real measurements).
  - suitable for final documentation of the work.
- presenting information to different types of users, thus serving as an aid to
  - communication between stakeholders,
  - reporting towards the authorities, etc...

Other software developed / to be developed at IFE

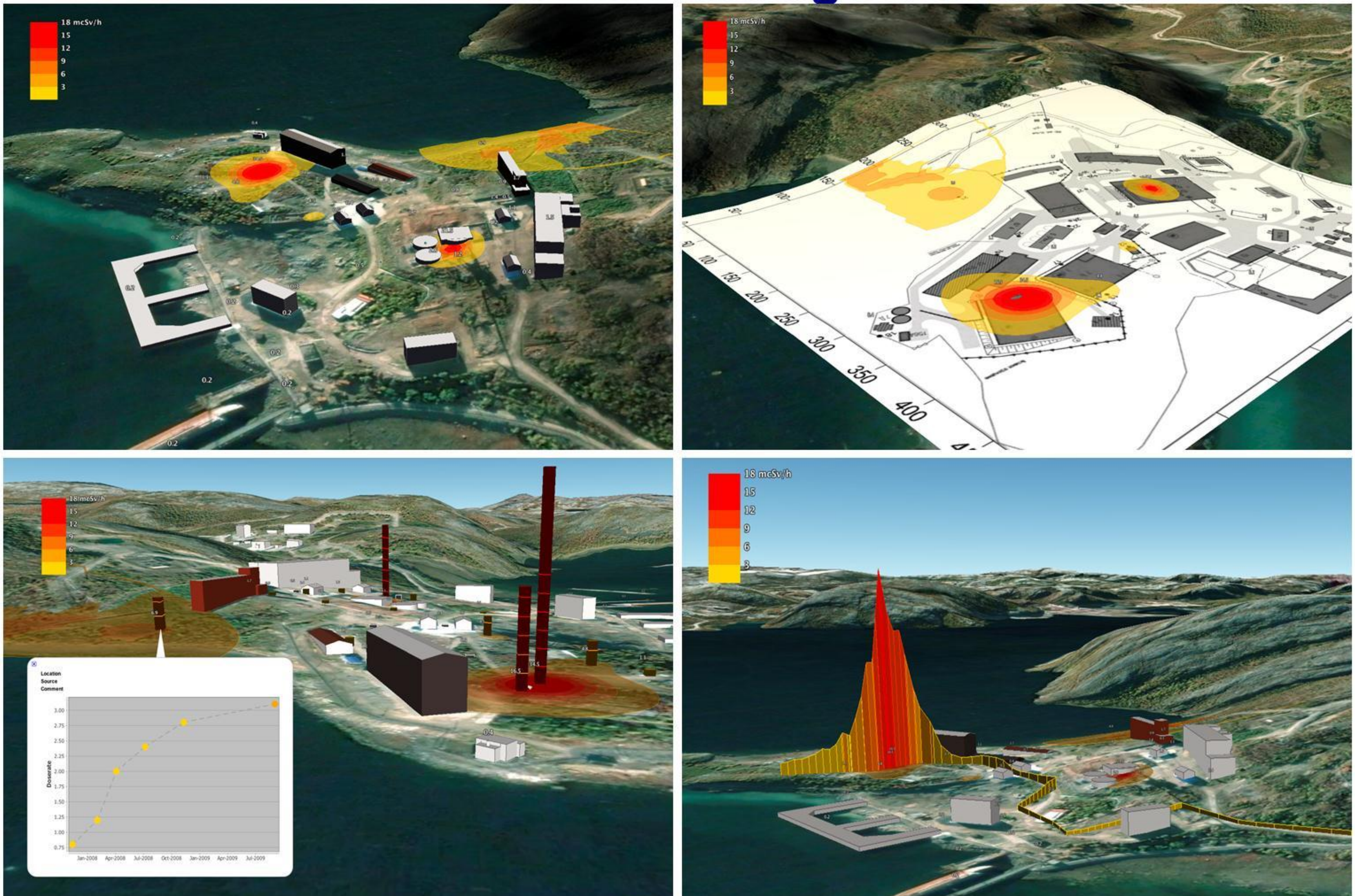
include tools for:

- radiological characterisation of large outdoor areas,
- in-situ radiological characterisation (using portable devices),
- etc.

Radiological characterisation of large outdoor areas (Terrain Viewer)

- High definition 3D visualisation of the environment (landscape, buildings, 2D overlay maps, etc.).
- Real-time 3D radiological mapping (areal distribution along the surface, vertical dispersion).
- Dynamic analyses of the exposure based on user defined paths.
- *Interactive assessment of the costs entailed by remediation*.
- Etc.

Rad. characterisation of large outdoor areas



In-situ radiological characterisation (using portable devices)

Huge potential in hand-held devices!

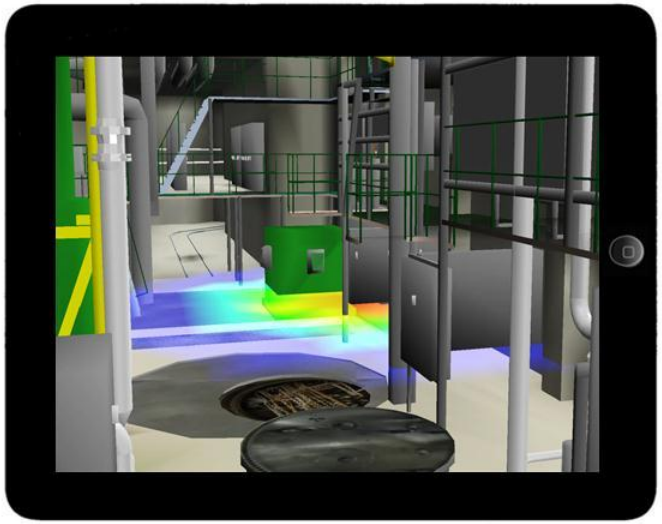
- Registering - radiological data using - 3D models and/or
  - other
  - 2D maps and/or
  - drawings and/or
  - photos.
- On-the-fly processing, checking and comparison (e.g. to calculated) of acquired data.
- Note deviances (and on-the-fly update) of 3D models, maps and drawings based on real measurements.

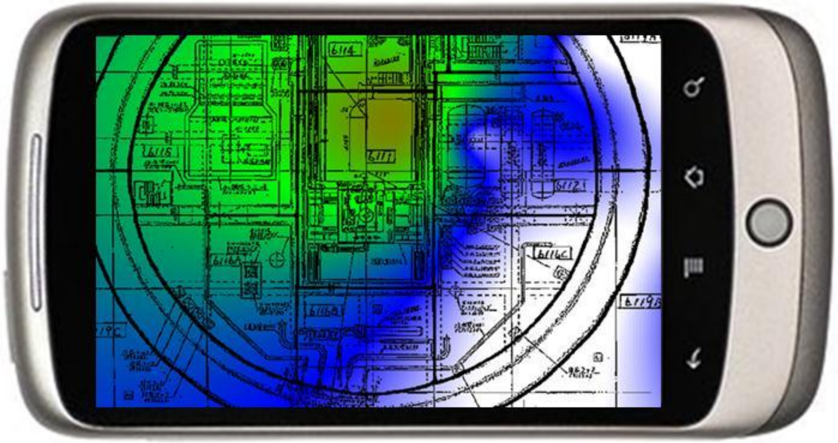
Minimise presence in hostile areas.

Registering data in-situ

On-the-fly processing, checking and comparison of acquired data

e.g. comparison to calculated





Summary

Use different data gathering/processing, simulation and visualisation tools/methods (some very archaic).

Efficient (quick/real-time, easy to use, but reliable) radiological characterization for decommissioning (or other purpose) is needed?

IFE nuclear toolkit!