Human-centred radiological software techniques supporting improved nuclear safety

SZŐKE István[1], and JOHNSEN Terje[1]

1. Software Engineering Department, Man Technology Organisation, Institute for Energy Technology, Os Alle 5, NO-1777 Halden, Norway (Istvan.Szoke@hrp.no)

Abstract: The Institute for Energy Technology (IFE) is an international research foundation for energy and nuclear technology. IFE is also the host for the international OECD Halden Reactor Project. The Software Engineering department in the Man Technology Organisation at IFE is a leading international centre of competence for the development and evaluation of human-centred technologies, process visualisation, and the lifecycle of high integrity software important to safety. This paper is an attempt to give a general overview of the current, and some of the foreseen, research and development of human-centred radiological software technologies at the Software Engineering department to meet with the need of improved radiological safety for not only nuclear industry but also other industries around the world.

Keyword: radiological software; 3D simulation; human-centred technology; virtual reality

1 Introduction

The Institute for Energy Technology (IFE) is an international research foundation for energy and nuclear technology. The Software Engineering department in the Man Technology Organisation (MTO) at IFE is a leading international centre of competence for the development and evaluation of human-centred technologies, process visualisation, and the lifecycle of high integrity software important to safety. Since the beginning of the 1990s IFE has been involved in research and development of human-centred technologies for increasing the safety of peaceful utilisation of nuclear technologies. The technologies have partly been developed within the OECD Halden Reactor Project (HRP), an international cooperation, hosted by IFE, focusing on safe and reliable operation of nuclear power plants. In addition, IFE has contributed to successful completion of a number of assistance projects with the Chernobyl Nuclear Power Plant in Ukraine, with the Leningrad Nuclear Plant and in the Andreeva Bay area in Russia, and with Eastern Europe, in accordance with the Norwegian government's action plan that has been funded and administrated by the Norwegian Ministry of Foreign Affairs.

This paper is an attempt to give a general overview of the current, and some of the foreseen, research and development of human-centred radiological software technologies at the Software Engineering department to meet with the need of improved radiological safety not only nuclear industry but also other industries around the world.

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2 Background

The Software Engineering department of IFE has, for many years, been involved in research and development of human-centred technologies for increasing nuclear safety. In connection with human-centred technologies the main current areas of interest are the following ones:

(i) Efficient recording and analyses (including *in-situ* and on-the-fly) of data, relevant for radiological safety, by using 3D and 2D (three and two dimension graphics based) human-system interfaces. Data, in this context, may refer to radiological data, *e.g.* activities, dose-rates, spectrums or signatures, surface and sub-surface contamination, contamination in air, liquids, structures, pipes, *etc.*, or relevant non-radiological parameters, *e.g.* material properties, concentration of particulate matter in air, *etc*.

(ii) Planning (optimising costs and safety), and demonstrating work protocols, with real-time risk analyses and visualisation. Risk, in this context, mainly refers to risk from radiation dose from external exposure. However, it is planned to widen the focus of risk analyses by including risk from internal radiation exposure, to chemically dangerous liquids and gasses, physical dangers (of hits and burns), *etc*.

(iii) Training workers well and cost efficiently, through using advanced 3D simulation and virtual reality (VR) technology. This mainly means providing realistic interactive VR based environments, which are enhanced with real-time visualisation of radiation danger and consequences of worker actions, for workers to practice work protocols before entering the real environment.

There are two of the most important current projects within which these developments are carried out; They are (i) a project entitled "Visualisation technologies to support decommissioning activities", which is a part of the OECD Halden Reactor Project, and (ii) a collaborative project between the Norwegian Radiation Protection Authority, Institute for Energy Technology, and the Burnasyan Federal Medical Biophysical Centre (FMBC) in Russia. The later project is titled Dynamic RadIation Visualisation Engine (DRIVE), which aims at improving regulatory supervision and safety in the Andreeva Bay Storage Base on the Kola Peninsula. Today, the Andreeva Bay is a site of temporary storage, where the operating company SevRAO is carrying out some urgent operations concerning the spent nuclear fuel and radioactive waste management. The operations are being performed under conditions of degraded and continuing degradation of containment barriers. The planned operations are aiming at stabilising the radio-ecological situation at the site by bringing the hazardous buildings and areas into compliance with regulatory requirements. As a follow-up of earlier Russian-Norwegian projects, the DRIVE project will utilize experience and technologies developed at IFE for 3D work planning and virtual reality based training at the Leningrad Nuclear Power Plant and the Chernobyl Nuclear Power Plant. This is conducted as a part of the Norwegian nuclear safety assistance program.

The project called "Visualisation technologies to support decommissioning activities" is less specific customer oriented, and it is focusing on further developing, customising, and extending the human-centred technologies developed earlier to provide effective solutions to the most important decommissioning specific problems of the nuclear industry.
In the next chapters, the radiological tools that will be utilised as a base in the above described projects will be presented.

3 Human-centred radiological software techniques developed at IFE

The Halden VR Tools[1] have been developed for many years in the framework of the OECD Halden Reactor Project, and they are freely distributed among HRP members. Currently the Halden VR Tools primarily consist of the following ones:

(i) Halden Planner which is composed by a 3D simulation based tool for planning work (Planner), and presenting work scenarios, *i.e.* briefing personnel (Briefer), and
(ii) Halden Simulation Editor which is composed by a virtual reality based tool for composing (Editor), and undertaking (Viewer) interactive training.

Plans for further development of those tools have been regularly presented to the member organizations to ensure that developments are in line with general needs of the members.

The HVRC VRdose system[2] has been developed within collaboration projects mostly financed by bilateral customers. The VRdose system offers functionalities similar to those in the Halden Planner, and it is commercially available to customers.

3.1 The Halden Planner

The Halden Planner is a 3D real-time simulation tool that offers functionalities for:

- registration and visualisation of radiological data,
- analyses and visualization of radiation risks,
- design and optimisation (in terms of safety and cost) of work protocols, and
- documentation (reporting) of work protocols.

Figure 1 demonstrates the user interface of the Halden Planner. The features of user interface include (i) a 3D graphical window for showing a 3D model of the environment, (ii)3D models of workers (avatars) carrying out actions in the environment, (iii)physical information about the biological shields of concern, (iv)radiological data on the exposure conditions of the workers, and (v)distribution of the radiation risk (which is expressed by user selected quantity) within the whole environment. One of the most important features of the tool is that the radiological data (personal dose and radiation field) is updated in real-time. This allows dynamic optimisation of work protocols, by which the user will be informed in real-time about the consequences to the exposure conditions due to any change in the work protocol or the environment.

Designing an optimal work protocol for a given task is only the first step in ensuring that the task is addressed in an optimal way (as safe and as cost-effective as possible). Having an optimal work scenario design, it is important that participants of the work scenario (and especially field operators) have a deep understanding of the task, the planned work strategy, and the reasons for choosing the strategy in case, *i.e.* the consequences of suboptimal strategy.

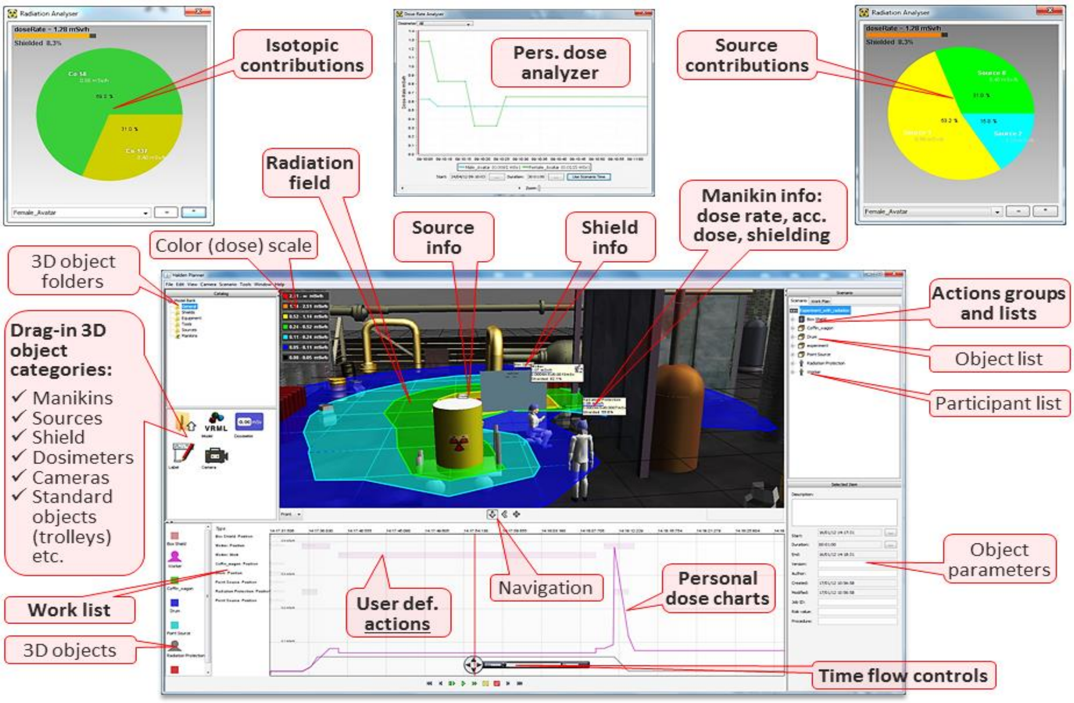

Fig.1 User interface of the Halden Planner.

3.1.1 The Halden Briefer

The Halden Planner also offers a briefing tool (Halden Briefer) as a 3D user interface. This is similar to that of the planning tool specifically designed for briefing (Figure 2). This tool has such functionalities as for work protocol visualisation (scenario playback) which is enhanced with dynamic visualisation of radiation risks. The employed technique greatly enhances the understanding of a work scenario and its context to the environment, by simulating real life actions by the help of humanoid avatar movements in realistic models of the targeted environment. In addition, dynamic 3D visualisation of radiation risks provides a unique understanding of the involved radiation risks (such as by the choice of the strategy and consequences of deviation from the plan). Previous investigations showed that some very common situations create very special exposure conditions in which workers who follow basic principles of radiation protection but rely only on their naked eyes, may result in unnecessary exposure. Gamma radiation, for example, is, by its nature, invisible to the human eye. In some situations, even with deep expertise in radiation transport, achieving good situation awareness is very difficult without "visualising the invisible".

3.2 The Halden Simulation Editor

The Halden Simulation Editor has been designed for interactive training in nuclear environments. This tool can be perceived as the first-person mode of the Halden Planner. While the user in the Halden Planner, he/she plays the role of the puppet master planning or viewing a work scenario. Whereas the user in the Simulation Editor, he/she can assume the role of any of the participants of a work scenario and experience the work steps first hand. This technique offers a much safer and cost effective way of training field operators for important tasks. Field operators can practice in a safe environment without the risk of being exposed to radiation and without disturbing normal operation while training.

Fig.2 User interface of the Halden Briefer.

Compared to using physical mock-ups VR based techniques offer a much cheaper solution. Creating a realistic virtual model of an environment is cheaper than building physical models. In addition, a virtual model is transportable, reusable as many times as required, easily modifiable (adaptable to alternative situations), and places no limit over the number of participants that can practice in parallel.

In addition to the advantages provided by a virtual mock-up alone (described above), additional training effectiveness can be achieved with the help of the technologies implemented in the Simulation Editor for work scenario guidance, radiation risk visualisation, and user performance evaluation. 3D visualisation of radiation (similar to that in the Halden Planer and Halden Briefer) helps increasing the understanding of the irradiation conditions both by expert and especially non-expert users. While this technique is also important from an academic point of view, it also helps trainees to better understanding of the knowledge on radiation transport. Therefore this technique is very efficient in reducing radiation dose to field operators.

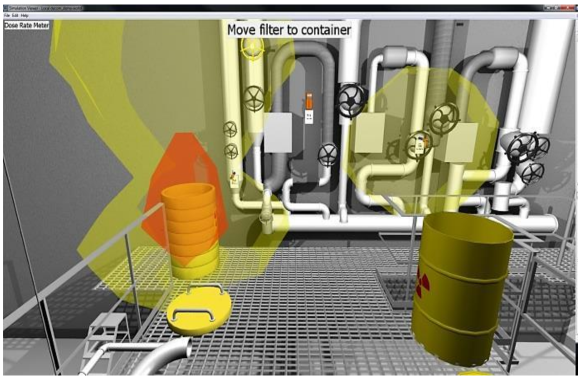

Fig.3 User interface of the Simulation Editor.

3.3 Radiation transport simulation

The literature on radiation transport is quite vast, and the international market offers a large selection of tools for radiation transport calculations. However, as stated above, the most important advantages of the tools developed at IFE originate from their real-time capability.

Real-time compatibility is a feature that grants very efficient optimisation capability for the Halden VR system, by which the users are able to investigate alternative solutions (*e.g.* biological shielding configurations) in real-time. This capability also offers a unique opportunity for virtual reality based training, where the trainees are able to see the consequences of any of their actions to the exposure conditions in real-time.

Real-time compatibility, on the other hand, places very strong requirements on the performance of the radiation transport techniques applied, limiting the possibilities to those capable of very high speed calculation while still yielding reliable results. This requirement effectively rules out sophisticated Monte Carlo radiation transport models, and places strong constraints even on deterministic radiation transport techniques. The radiological tools developed at IFE adopt Point Kernel based radiation transport models enhanced by a series of programming and modeling techniques to enhance the speed of the calculations. More details about the applied radiation transport methods developed earlier[3], and new radiation transport techniques[4] can be found in the international literatures and HRP work reports (available only to HRP members).

In addition to deterministic radiation transport techniques, the specific features of radiological tools developed at IFE are also interpolation techniques and other (mixed) methodologies. The reason for completing the deterministic radiation transport techniques by suitable interpolation methodologies is twofold. First, radiation transport simulation requires adequate knowledge about the radiation sources in the scene. In situations where this kind of data is missing, radiation risk assessment during work simulation is still possible, if a suitable number of scattered dose measurements are provided by the user. Second, deterministic radiation transport techniques become increasingly unreliable for calculating dose with increasing contribution to dose from scattered radiation. In situation where distribution of the scattered radiation is constant, a radiation background, generated by multiply scattered photons, can be superposed onto the dose calculated by the point kernel methodology.

Based on the previous discussions, real-time tools become more suitable for optimisation of work scenarios, shielding design, and realistic interactive training in radiological environments. In addition, real-time tools also hold strong advantage over non-real-time tools in supporting radiation risk assessment in dynamically changing environments, where the radiation situation is dynamically altered by the changes of radiation sources and biological shields. While this situation may occur in many situations, it is worth noting that decommissioning of nuclear facilities is one of the situations where dynamic risk assessment is strongly required.

The other real life example when quick and real-time risk assessment may save human lives is supporting decision making in stressful situations caused by radiological accidents.

3.4 In-situ radiological software support

When it comes to the applicability of the radiological tools developed at IFE, one of the most important questions is: How to provide data to the tools in real-life situations? First of all, the tools presented above are based on 3D virtual representation of the environment. For most of the nuclear installations (*e.g.* nuclear power plants) 3D computer aided design (CAD) models are created even before the process of building starts. In addition, emerging 3D scanning technology and the software support make it very easy to generate 3D virtual models of complex environments. The radiological tools developed at IFE are based on imported 3D CAD models as a starting point.

In addition to the model of the environment, radiation risk assessment requires suitable radiological data. Efficient recording and analyses of radiological data in complex environments is actually an important issue of the nuclear industry. Radiological survey is a costly and possibly danger prone process. Since any job targeting a nuclear environment must begin with radiological characterisation of the environment, minimising the cost of radiological surveys and risk to humans during the process is a key issue. The 3D user interface of the Halden Planner provides especially user friendly and easy to understand presentation of radiological data in the context of the 3D environment.

Making this kind of information available to the field operators while making radiological surveys, would greatly help field operators in analyzing data already acquired and acquiring additional data. Hence, IFE is experimenting with transporting some of the functionalities of the Halden VR Tools to hand held and other portable devices.

3.5 Large scale dynamic radiological mapping

The radiological tools and technologies presented so far are very suitable for simulating smaller environments like a nuclear installation, or a complex of multiple nuclear installations. However, these tools are not suitable for simulations affecting a much larger area, like a whole country or more. In the framework of the DRIVE project, IFE has developed a wide scale dynamic radiological mapping tool that can be coupled with commercially available geographical information systems (GIS). The initial aim of the tool was improving regulatory supervision by visualising the temporal evolution of the radiological conditions in the Adreeva Bay area, in order to help decision making. The same methodology is easily adopted to show the distribution of any kind of radiological (and non-radiological) parameters over wide geographical eras, for example, results of atmospheric and other dispersion calculations.

Fig.4 The Halden VR Tools on hand-held.

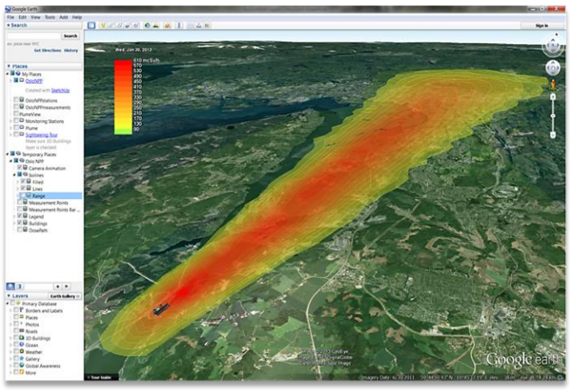

Fig.5 Radiological mapping with Google Earth.

While the selection of radiological mapping tools and radiological dispersion models is widely possible, the technology would provide a very useful addition to the systems which lack advanced visualisation methods for showing radiological data. In addition, the fact that the tool can be coupled with any GIS system may provide additional advantages to such systems that already have graphical visualisation output.

GIS systems, like Google Earth, are familiar to many users around the world. In addition, these systems already have many features at the users' disposal, and they are constantly improved. Furthermore, in order to offer some default environmental consequence analyses methods, the system is being enhanced with a simple atmospheric dispersion model, suitable for estimating consequences of short emissions in a few kilometre vicinity of an emission point.

4 Application areas

Obviously the most important area of application of the radiological tools presented above is the nuclear industry. The radiological tools developed at IFE are primarily meant for improving nuclear safety of nuclear power plants during their operation, and the radiation safety of the workers during maintenance jobs. The techniques are now being adopted to support characterization and remediation of contaminated installations (and sites) in general, through supporting planning and monitoring radiological surveys, and registration and analyses of radiological data. Hence, the tools will be suitable for providing wider assistance for work in nuclear environments through supporting the following functions.

(i) Data acquisition: Record, inspect and update (on-the-fly) radiological data,
(ii) Data analyses: Visualise data and provide risk assessments for decision making,
(iii) Planning: Design and optimise work strategy by taking into account regulation, costs and risks,
(iv) Obtaining permissions: Communicate plans and radiological conditions to authorities and stakeholders,
(v) Preparations for work: Brief and train personnel (including training for possible accidents),
(vi) Execution of work: Enhance communication between field operators and the control room, and
(vii) Post-work phase: Documenting initial work plans. Evaluate and report on successfulness of work strategy and reasons for failures, if any.

In addition, the technologies have great potential in supporting nuclear installations throughout their whole lifecycle; beginning with the design and building up phase, and concluding with decommissioning.

The highly user friendly interface designs and the realistic (easy to interpret) 3D real-time output information make the technology especially suitable for supporting the following areas:

(i) Regulatory supervision of legacy sites,
(ii) Enhancing safety culture by preserving knowledge (experience),
(iii) Crisis management, and
(iv) Education of future workers.

This evidently enlarges the area of application of the technologies by including authorities (regulatory bodies) and educational institutions.

In addition, it is worth mentioning that while the nuclear industry is the main target of utilisation, other industries, like the oil and gas industry, may also benefit from application of the technology. First, the nuclear industry is not the only industry where exposure of workers to radiation is possible. For example, strong gamma sources are used in other industries for expecting welding and seeing through metallic structures. Second, the techniques developed for simulating work in nuclear environments and visualising radiation danger can easily be adapted to simulating work in other industries and visualising other kinds of dangers.

Finally it should be mentioned that the IFE had cooperation with the space industry for visualising radiation fields in and around space stations, and the opportunities in using this technology for supporting the space industry (*e.g.* manned space missions) are far from being fully exploited.

4.1 Nuclear decommissioning

As mentioned above, efforts towards providing a whole lifecycle support for nuclear installations are being made at IFE, based on the technology initially developed for supporting maintenance and outage work.. Nuclear decommissioning has gained increased focus as more and more installations approach their natural end of lifecycle. In addition, unplanned decommissioning projects have been initiated by political decisions and unfortunate events.

Due to the high interest of the HRP members in this topic, research and development has been initiated for adopting and further developing IFE's existing software technologies for supporting nuclear decommissioning[5]. While many of the technologies developed earlier are very useful in decommissioning, decommissioning also poses some more specific requirements due to the difference in objectives, and radiological and organisational conditions. More results of these new developments will be elaborated in future publications.

5 Concluding remarks

Application of innovative solutions based on real-time 3D simulation and virtual reality for work planning, risk analyses, complex data registration and visualisation, training, and communication is becoming increasingly exploited in the international nuclear industry. IFE has been involved in research and development of 3D simulation and VR aided solutions for many years. Results achieved during research and development of innovative solutions for scheduling and sharing work tasks, monitoring work progress, and GIS based technology for radiological mapping and monitoring complete IFE's experience and software testbed in human-centred technologies for the nuclear industry. In addition, IFE has achieved broad experience from human and organisational factors research. This enables IFE to address issues of the nuclear industry from a general perspective instead of tacking individual features of the problems without considering all associated aspects contributing the failures of inefficiencies.

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