

Institute for Energy Technology
Halden Virtual Reality Centre

User Documentation **HVRC VRdose** **System Overview**

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HVRC VRdose® Overview Issue 2 Revision 2
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Abstract

The HVRC VRdose® software comprises of a pair of tools:

- HVRC VRdose Planner: A tool for simulating work scenarios, with radiation visualisation and dose-rate charts for scenario participants
- HVRC VRdose Briefer: A tool for playback of scenarios created using the VRdose Planner, for training/briefing purposes

This document provides an overview of the HVRC VRdose system.

Citing this document

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Note that the Issue and Revision number of this document is not the same as the version number of the HVRC VRdose system it applies to, however all revisions of Issue 2 of this document apply to version 2.x of the software.

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1. INTRODUCTION

1.1 HVRC VRdose

HVRC VRdose is a real-time software tool for modelling radiological nuclear environments, planning a sequence of activities in the modelled environment, optimising protection against radiation, and producing job plan reports with dose estimates. HVRC VRdose offers the possibility to refine the radiological model to improve the accuracy of estimates and configure the dosimetric output provided. The software can also be used as an aid to producing post-work review reports, with real measurements included. Furthermore, the software provides support for presenting information to different types of users for briefing and decision-making, thus serving as an aid to communication between stakeholders in an intervention.

1.2 Intended readership

The audience for this document is potential end-users of the VRdose Planner software.

1.3 Applicability statement

This document applies to Version 2.3 of the HVRC VRdose software and contains information extracted from the HVRC VRdose Software User Manual Issue 2 Revision 2.

1.4 Purpose

This document provides an overview of the HVRC VRdose system. It introduces the software and its intended usage.

1.5 How to use this document

This document introduces the reader to the VRdose software system.

It is intended to provide a general understanding of the capabilities of HVRC VRdose and how these capabilities can be accessed.

The concept section describes the radiological protection concepts that underlie the system.

The overview section describes the processes and principles supported by the software and how it intended to be used.

A glossary is provided in the appendices.

1.6 Related documents

ICRP 60	1990 Recommendations of the International Commission on Radiological Protection. ICRP. Publication 60. Ann. ICRP 21 (1–3), 1991.
ICRP 101	Assessing dose of the representative person for the purpose of radiation protection of the public and the optimisation of radiological protection: Broadening the process (ICRP Publication 101). Ann. ICRP 36 (3), 2006.
ICRP 103	The 2007 Recommendations of the International Commission on Radiological Protection (ICRP Publication 103). Ann. ICRP 37 (2-4), 2008.
HWR-896	Comparative Study of Radiation Visualisation Techniques for Interactive 3D Software Applications (HWR-896), OECD Halden Reactor Project, Louka, M. N., et al., 2011.
HWR-982	A Study of Outage Planning under Complex Radiological Conditions using VRdose Planner (HWR-982), OECD Halden Reactor Project, Vabø, R., et al. 2011.
HWR-979	Comparative Study of Radiation Visualisation Techniques for Interactive 3D Software Applications (follow-up study) (HWR-979), OECD Halden Reactor Project, Louka, M. N., et al., 2011.
HWR-999	Characterization Implemented in a Virtual Environment (HWR-999), OECD Halden Reactor Project, Vabø, R., et al. 2011.
HWR-1030	New Computational Model for Areal and Personal Monitoring in Nuclear Environments (HWR-1030), OECD Halden Reactor Project, Szőke, I., 2012.
HP-Benchmark	Benchmark test results for validation ^[1] of the Basic Point Kernel and the Extended Point Kernel dosimetric code units of the Halden Planner, OECD Halden Reactor Project, Szőke, I. et al., 2012.
ISO/IEC 14772-1	Virtual Reality Modelling Language Specification, 1997. Available online on the Web3D Consortium website at http://www.web3d.org/ .

2. Concept

A significant motivation behind the VRdose has been to make advanced, radiation exposure situation analysis technology accessible to a broader range of users, who can benefit from an interactive 3D visual representation of radiation risks to support ALARA optimisation. By integrating radiological information with 3D models of nuclear facilities and environments, to facilitate risk-informed planning and work execution, we aim to support the optimisation of radiological protection for activities in nuclear environments and enhance safety culture, by increasing stakeholders' comprehension of radiation risks, thus contributing to improving safety in nuclear facilities.

2.1 Introduction

The purpose of this chapter is to provide a brief introduction to the recommendations for radiological protection, as published by the International Commission on Radiological Protection (ICRP) in "ICRP 103". The principles and recommendations of the ICRP are important because they serve as the basis for national regulations related to activities in exposure situations, and represent current best practice for radiological protection planning. They are therefore reflected in the design, terminology, and evolution of the VRdose Planner software, and are thus important to understanding the VRdose Planner.

The key concept in the field of radiological protection, which has been refined over many years, is that of ALARA ("As Low As Reasonably Achievable"). The goal of radiological protection planning is to optimise the level of risk, by minimising the dose, to achieve a level that is acceptable to the stakeholders involved. The word "reasonable" is the key here, as the goal is *not* to aim for the lowest dose for each individual involved in an exposure situation regardless of social or economic aspects. To explain what this means in practice, the ICRP has developed three key principles, which are described below, and makes recommendations within the framework of these principles on how they should be applied.

2.2 Radiological Protection Principles

ICRP 60 (published in 1991) introduced three fundamental principles for radiological protection:

- Principle of Justification
- Principle of Optimisation of Protection
- Principle of Application of Dose Limits

While these principles are retained in ICRP 103, the latter publication provides revised recommendations on how these principles should be applied. Before explaining each of the principles, and outlining some of the recommendations of ICRP 103, it is necessary to note that all three principles apply only for *planned exposure* situations. For *emergency exposure* and *existing exposure* situations, only the first two principles apply. Except for during (or after) an accident situation, radiological protection activities related to a nuclear power plant, for example, fall into the category of *planned exposure* and it is for ALARA planning of planned, occupational, exposure that the VRdose Planner is primarily targeted, although it would also be a useful tool to support decision-making in *emergency* or planning activities in *existing exposure* situations too.

To clarify, ICRP 103 defines three exposure situations that are intended to cover all types of exposure situations that can arise.

- *Planned exposure* situations are those involving the “planned introduction and operation of sources”.
- *Emergency exposure* situations are “unexpected situations such as those that may occur during the operation of a planned situation, or from a malicious act, requiring urgent attention”.
- *Existing exposure* situations are “exposure situations that already exist when a decision on control has to be taken”. This typically means situations with significant natural background radiation, but also includes situations resulting from past accidents or other activities such as weapons testing.

In addition to *occupational* exposure to workers, ICRP 103 recognises *public exposure* and *medical exposure* as distinct exposure types. The term *potential exposure* is used to describe exposure that is anticipated but not intended in a planned exposure situation. *Potential exposure*, therefore, describes the exposure that would be received if a planned job goes wrong. The risk of potential exposure should be minimised when producing a plan for acceptable exposure to execute a planned activity. Of course, organisations should strive to understand the causes of potential exposure actually received when a job is done, and communicate lessons learnt that could contribute to reducing the risk of potential exposure when executing similar activities in future.

2.2.1 Principle of Justification

“Any decision that alters the radiation exposure situation should do more good than harm” (ICRP 60).

This principle implies that the decision-making process should include an evaluation of whether the net benefit of a change to an exposure situation is positive. The benefits that should outweigh the detriment may be individual or societal. The detrimental risk of radiation exposure may be a small part of the overall equation to determine if the new situation is positive.

2.2.2 Principle of Optimisation of Protection

“The likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors” (ICRP 60).

Given that a situation is justified, we should aim to minimise individual doses, but in such a way that we also minimise the number of individuals exposed, following the principle of ALARA. So within dose limit restrictions applied to individuals, we should aim to discover the best, reasonable, level of protection for the individuals that will be exposed. The VRdose Planner is intended to provide support in the process of identifying the optimal solution for protection for planned exposure, and to identify risks of potential exposure that the stakeholders need to be made aware of to reduce the risk of actually receiving higher doses than planned.

2.2.3 Principle of Application of Dose Limits

“The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission” (ICRP 60).

National laws and regulations on the application of dose limits are generally based on ICRP recommendations. The limits specified by ICRP 103 are primarily intended to guide the application of the optimisation of protection principle

2.3 Recommendations on Applying Radiological Protection Principles

2.3.1 Recommendations on Justification

Within the scope of the VRdose Planner, radiation protection staff in collaboration with other stakeholders would normally be responsible for justifying a job involving operational exposure, however this is formally within the scope of a high level justification for the operation and maintenance of the facility in which the work will take place, so may not need to be explicitly stated in the preparation of a work permit request, for example. When justifying the introduction of an entirely new facility, the responsibility for justification generally lies with governments and national authorities. As this principle extends beyond the responsibility of radiation protection authorities, the ICRP provides only limited guidance on application of the principle beyond acknowledging that different approaches can be taken for occupational and public exposure depending on whether planned actions can be taken on the source or whether it is only possible to modify pathways of exposure, typically in an emergency or existing exposure situation.

2.3.2 Recommendations on Optimisation of Protection

ICRP 103 provides a general overview of recommendations on optimisation of radiological protection, noting that earlier recommendations continue to apply. The latest detailed guidance from the ICRP can be found in ICRP 101, published in 2005, which focuses on dose assessment issue and the optimisation process. As for ICRP 103, ICRP 101 builds on ICRP 60.

In order to minimise dose, we need to optimise time, distance and shielding, while taking into account other constraints used to determine the scope within which the dose can be justified as reasonably low, such as acceptable risk of potential exposure, and other risks and costs. In addition to restricting the individual dose or risk to a worker, the size of the collective dose to all workers involved in a job is also an important parameter that is taken into account in selecting the best of multiple options.

The optimisation process itself is generally iterative and is focussed on planning ahead. While we are, of course, interested in evaluating performance, to learn from it after a job has been done, optimisation is focussed on minimising risk for planned activities. Effective optimisation in practice requires that stakeholders have a common understanding of the basic principles of radiological protection and that an active safety culture, and learning from past experience, is encouraged.

The steps of the iterative optimisation process given in ICRP 103 are illustrated in the figure below:

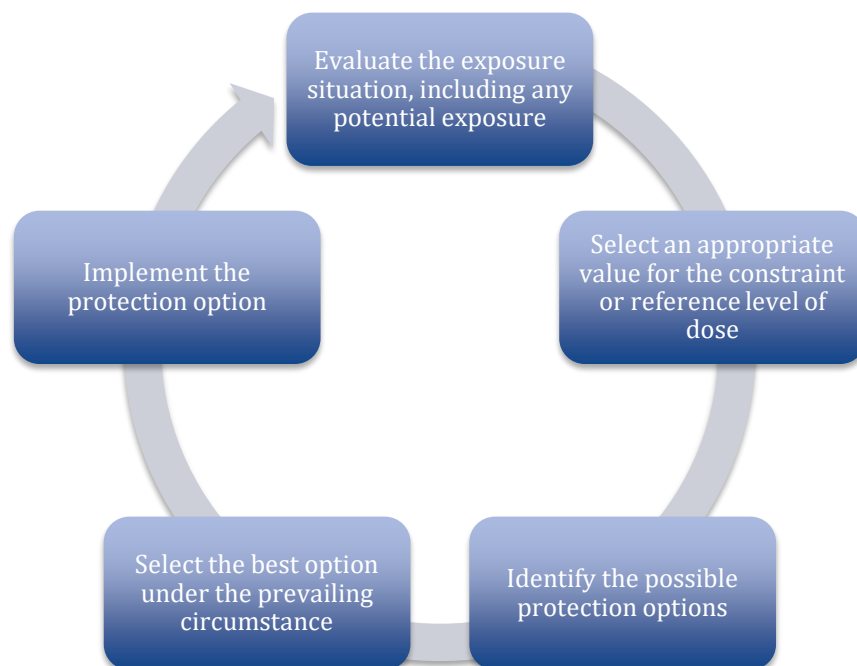


Figure 2.1 ICRP 103 Iterative optimisation process

Considerations to minimise dose in order to identify possible protection options include:

- Less Time → Less Dose
- More distance → Less Dose
- More shielding → Less Dose
- More shielding → More Time → More Dose...

Effective planning can reduce the time taken to carry out an activity, thus reducing dose. Distance to sources can also be improved through effective briefing of workers and encouragement of a radiation safety mind-set to ensure that workers take breaks in lower dose areas of the work area and move away from sources when carrying out activities that do not require them to be close to a source.

Use of temporary shielding must be justified – is it necessary to comply with the Principle of Application of Dose Limits? If it is not necessary to prevent violation of dose limits, will it contribute to reducing the collective dose of the stakeholder workers, including radiation protection (RP) workers, for the entire planned activity? We should also bear in mind that installation, movement or removal of temporary shielding itself requires spending time in areas of elevated radiation, is normally only allowed to be done with authorisation from responsible RP staff, and planned changes to the exposure situation will often trigger a requirement for control measurements of dose-rate levels, which may significantly increase the time taken to complete a job. Tools such as the VRdose Planner should be useful for modelling alternative scenarios in order to determine which would give the best result, and also be helpful when briefing workers and documenting why the selected solution is considered optimal.

The best option is not always the one that will give the lowest dose. For example, the option that gives lowest planned dose exposure may involve significantly higher risk for potential exposure, fire, flooding, or some other detrimental result. The lowest dose option might also

involve a greater risk of the operation taking significantly longer than planned, again giving increased risk for additional exposure; taking into account the likelihood of receiving greater dose than planned, and the amount of additional dose in that case, what might first appear to be the best option may not be.

2.3.3 Recommendations on Application of Dose Limits

Dose limits are essential to managing the individual health risk to individual workers and are to be treated as absolute constraints on the dose received for planned exposure situations. While many factors can contribute to determining what is *reasonable* in ALARA, when selecting between alternative optimisation plans, the dose limits provide a ceiling for what is an acceptable dose over time. Intentionally breaching the limits is unacceptable and any breach would normally need to be reported to national regulators, and depending on the severity of the breach may have disciplinary consequences for those responsible within the frame of national health and safety laws. Occupational dose limits are significantly lower for pregnant women than other workers, and occupational exposure in aviation and space are also treated as special cases by the ICRP.

Looking at exposure limits only (i.e. not including organ limits) for workers. The ICRP 103 recommended limits for occupational dose are:

- 20 mSv/year averaged over 5 years
- 50 mSv/year in any year
- 100 mSv total in 5 years

Related to the *dose limits* is the *dose constraint*, which is used to guide the optimisation of occupational exposure situations (and public exposure) within the scope of a single planned operation. In an emergency or existing exposure situation the so-called *reference level* is used as the upper limit of dose or risk that an individual could be allowed to receive as part of a planned action. The value to use depends on the exposure circumstances. For planned activities in exposure situations with levels close to the reference value, protective measures would be required. The *residual dose* is the dose expected after protective measures have been implemented, which would contribute to an individual worker's occupational dose.

Note that emergency preparedness should include planning for emergency response, where reference levels are used. Emergency exposure may be permitted (assuming that it is not unavoidable) to exceed the maximum reference level value (100mSv) on a voluntary basis in extreme circumstances only, to save a human life or prevent a disaster – no other circumstance are considered justifiable.

2.4 National Regulations

National regulations on dose limits and radiological protection principle are generally aligned with ICRP recommendations, however national guidelines on the practical application of the principles vary, and individual utilities may also have stricter reporting and documentation requirements than regulators require, hence a software tool to support ALARA planning internationally should ideally aim to be flexible enough to be easily adapted to support established practices, systems and procedures.

An easily accessible example of national regulations and guidelines can be found in the combination of the US NRC 10 CFR Part 20 (and Part 50) and the US Department of Energy Radiological Control Manual. The OECD NEA has published two interesting reports that provide an overview of current challenges and practices, including surveys of national

regulations and practices. The first of these is focussed on radiation protection optimisation, and was produced as input to the ICRP during the development of the ICRP 103 report, while the second focuses on work management aspects.

See for example:

- OECD NEA (2005) *Optimisation in Operational Radiological Protection* (NEA Report 5411), ISBN 92-64-01050-5. Report by the Working Group on Operational Radiological Protection of the Information System on Occupational Exposure. Online, URL <http://www.oecd-nea.org/html/rp/reports/2005/nea5411-optimisation.pdf> (checked 2017.03.06).
- OECD NEA (2009) *Work Management to Optimise Occupational Radiological Protection at Nuclear Power Plants* (NEA Report 6399), ISBN 978-92-64-99089-0. Online, URL <http://www.oecd-nea.org/html/rp/reports/2009/nea6399-WorkManagement.pdf> (checked 2017.03.06).
- US DOE (1994) *Department of Energy Radiological Control Manual*, DOE/EH-0256T. Online, URL <https://www.osti.gov/scitech/biblio/10143998-X3KRUj/native/> (checked 2017.03.06).
- US NRC (1991, 2007) *Standards for Protection Against Ionizing Radiation*, NUREG 10 CFR Part 20, Revision 72 FR 55921, 2007. Online, URL <http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/full-text.html> (checked 2017.03.06).

3. Overview

3.1 System Overview

HVRC VRdose is a tool for modelling radiological conditions, planning a sequence of activities in the modelled environment, and producing job plan reports with dose estimates. The software can also be used as an aid to producing post-work review reports, with the possibility to refine the radiological model to improve the accuracy of estimates. Furthermore, the software provides support for presenting information to different types of users for briefing and decision-making, thus serving as an aid to communication between stakeholders in an intervention.

3.2 Applications

HVRC VRdose is primarily intended to support radiological protection planning and optimisation of protection within dose constraints for planned activities.

Specifically, it can be used for

- Preparation for jobs in radiological environments
- Preparation of work permit requests and preparation of radiological work permits
- Briefing of staff, contractors, and other stakeholders
- Post-job analysis and reporting
- Education and training in radiation protection and ALARA mind-set
- Testing and visually assessing the results of new dose calculation models

3.3 Key Features

The HVRC VRdose supports near real-time calculation of shielding effects, doses, and relative contributions to dose by different isotopes, enabling the rapid evaluation of alternative protection optimisation or maintenance procedure scenarios. To support the user in interpreting the results of calculations, the VRdose Planner provides charts, graphs, and 3D radiation visualisation, updated immediately to reflect any changes to the modelled radiological condition, such as changing shielding materials, and human activities over time.

Overview of key features:

- Supports modelling of radiological conditions
- Supports real-time calculation of shielding effects, doses, and relative contributions to dose by different isotopes, enabling the rapid evaluation of alternative job scenarios
- Provides visualisation of potential hazards to support risk-informed decision making
- Supports users in following existing job planning procedures and fulfilling reporting requirements
- Can be interfaced with alternative dosimetry models and calculation codes

Alternative calculation software modules can be used if they can provide appropriate input data and are interfaced using a supplied SDK. This functionality enables the use of calculation methods other than those supplied, and offers a convenient technology for comparing of dose estimates produced using different calculation methods. This enables the software to leverage existing, qualified, calculation methods, and to be used to support the development and testing of new calculation codes.

3.4 System Users

HVRC VRdose is aimed at three main classes of end-user:

<i>Radiation Protection</i>	use the software to model radiological conditions, optimise the placement of shielding to support work in specific areas of a nuclear facility, and evaluate the radiological consequences of the existence of different isotopes in a nuclear facility over time. Also use measured dose-rate values as an aid to modelling radiological conditions as accurately as possible.
<i>Engineering</i>	uses the software to produce pre-job work descriptions for planned work with descriptions of activities and estimated durations. Use the software to optimise routes, work locations, waiting locations. Provide feedback to Radiation protection if necessary. Also use the software to support the production of post-work experience review reports.
<i>Instructors</i>	use the software to communicate radiological conditions or a job description to staff or students. Instructors may have either (or both) a work planning or radiation protection background.

Radiation Protection and Engineering staff would normally collaborate to agree on the area in which work will take place and to optimise the positioning of shielding and other countermeasures related to the radiation exposure situation. More information on the tasks that the VRdose Planner supports within a typical workflow is provided later in this chapter.

3.5 System Overview

The software system comprises of the following main components

- *VRdose Planner*: Main tool with 3D workspace used to add, access, and manipulate data in the database, and produce reports
- *VRdose Briefer*: A dedicated 3D viewer for presenting scenarios prepared using the VRdose Planner in briefing situations
- An integrated database, in which data used by the Planner and Briefer is stored

Data is typically imported into the VRdose Planner from files and/or a database, and include:

- Detailed 3D geometry to visualise a nuclear facility or environment
- 3D geometry representing tools and equipment required to carry out a job
- Isotopic characterisation of sources (historical data, recent surveys, etc.)
- Dose-rate maps (if an external dose modelling system is used to produce dose maps)
- Actual dose-rate measurements

The VRdose Planner can be used to produce:

- Scenarios with job activities and trajectories that can be replayed as animations
- Dose graphs per worker or dosimeter in a scenario
- Pre-job work reports with a description of a scenario and the associated dose predictions
- Post-job experience review report given the entering of measurement data made when a scheduled job described in a scenario was actually carried out.

In order to define radiological layouts and job scenarios, information is imported from files, entered interactively through direct manipulation of 2D UI components or 3D objects using a mouse, or filling in forms with a keyboard. The user is supported in decision-making and evaluation of alternative scenarios through 2D charts and graphs and 3D plots of radiological conditions. Data entered is stored in a database and subsequent planning activities are thus able to use radiological conditions modelled previously, or expected as the result of planned work that is scheduled, as the starting point for planning further activities. Historical data for jobs that have been completed is available for use by instructors to support the training of staff, learning from past experience, while team leaders can brief workers on planned activities. The combination of graphs, 3D visualisation, and animation of planned work sequences make this a powerful communication aid.

Most data provided to model radiological conditions and to simulate job scenarios are entered interactively using an interactive 3D workspace. Objects in a layout and participants in a scenario are introduced to the workspace using a 3D drag and drop user interface, and some objects have parameters that can be manipulated directly or by entering values. In order to convey a sense of the dimensions of the layout and objects modelled, the user can display a grid with user-configurable spacing and also display the dimensions of selected objects, including routes/trajectories for objects or workers that move during a scenario. Free camera navigation is supported to enable the user to position a virtual camera, and target based travel techniques, including pre-defined and custom viewpoints and “go to selection” are supported.

3.6 3D Geometry Data Management

While the VRdose Planner can be used to model simple scenes using an empty floor situation to which source and shielding are added, detailed 3D models are normally added to the system database in a geometry interchange format. In the first version of the VRdose Planner, ISO VRML97 geometry data format was supported for importing models to the *Model Bank*. Most CAD systems are capable of exporting 3D models in ISO VRML97 format, and third party geometry conversion tools and services are available for CAD systems that do not support direct export in this format. In version 2.0, models can also be imported in the newer ISO COLLADA/DAE format.

In the Model Bank, we distinguish between *Rooms* (e.g. the nuclear facility itself) and 3D models that can be added to a layout by the user as part of a scenario, such as tools and equipment needed to perform a job. Rooms can be date-tagged in the Model Bank, so the system can determine which of multiple versions of a plant model to use depending on the date associated with a scenario and the date of a model version. In theory, this makes it relatively easy to integrate existing 3D plant databases by importing date-specific plant models as “Rooms” the VRdose Planner.

3.7 Radiation Visualisation

Given a set of sources and a shielding configuration, or a set of pre-calculated dose maps, the system enables the user to toggle a 3D visualisation of the radiological conditions in order to support decision-making about the form of the radiological situation.

Several 2D and 3D visualisation techniques are offered that can be user-configured and combined, with a set of default configuration provided based on the results of usability studies. The visualisations are colour coded and the user can select between user-

configurable sets of colours, which map radiation levels to colours. The software supports switching between visualisation configurations and colour sets on the fly.

Examples of the kinds of 3D visualisation techniques supported by the software are illustrated below. For volumetric rendering techniques such as the "isosurfaces", it is usually helpful to turn on value-dependent transparency, so that the shape of the highest dose levels is more easily visible through the lower levels. A perceptual colour map (based on a blue to yellow heat scale) selected (Figure 3.1, Figure 3.2, Figure 3.4, Figure 3.5, Figure 3.3).



Figure 3.1 Point cloud with Density Proportional to Radioactivity Level.

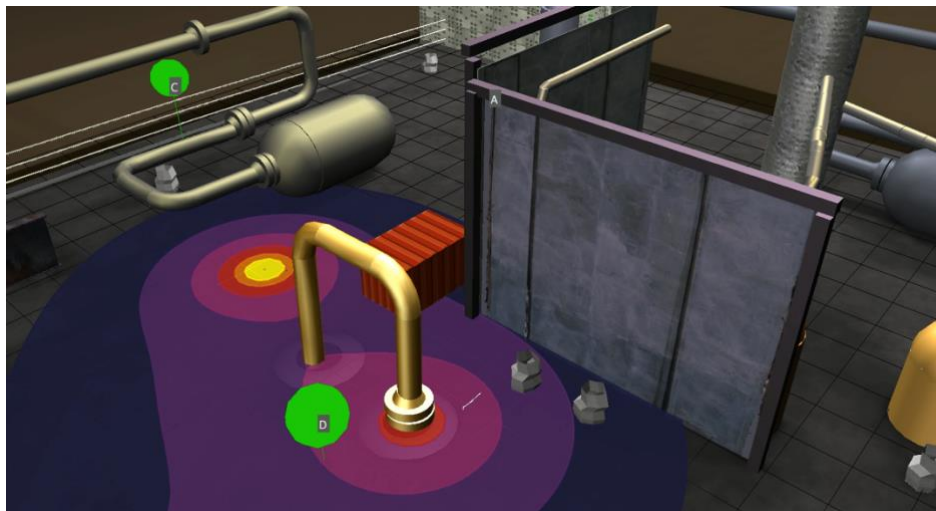


Figure 3.2 2D slice cross-section of 3D data.



Figure 3.4 Scalar field comprising of a grid of boxes.

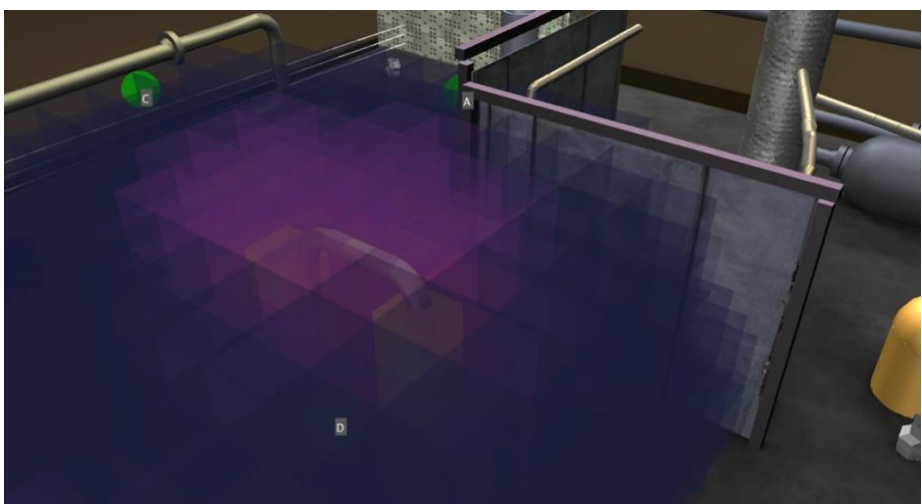


Figure 3.5 Volumetric visualisation technique.

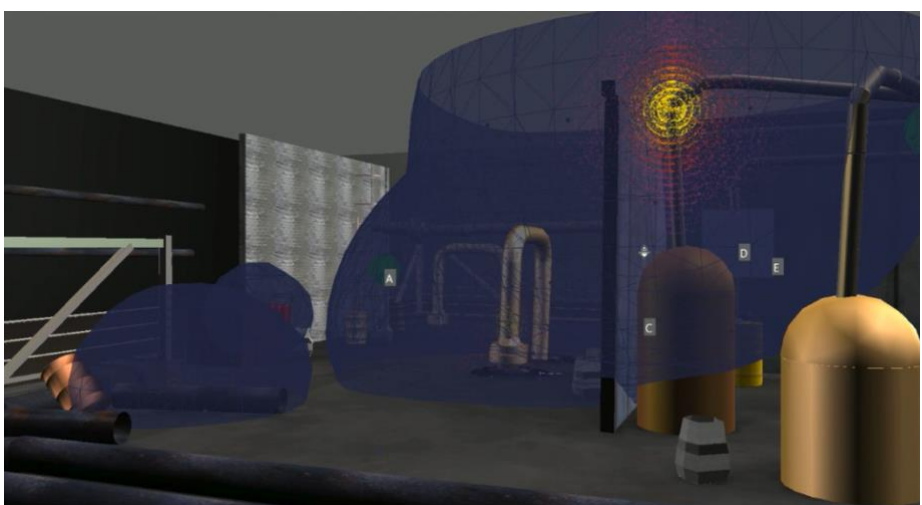


Figure 3.3 View Dependent smooth isosurfaces in combination with a point cloud, showing the boundary between the radiation level at the current location and the next level.

3.8 Workflow

In this section, an overview of the general radiological protection planning, optimisation and monitoring workflow supported by the VRdose Planner is presented. The following sections briefly explain how the VRdose Planner supports each of the activities illustrated.

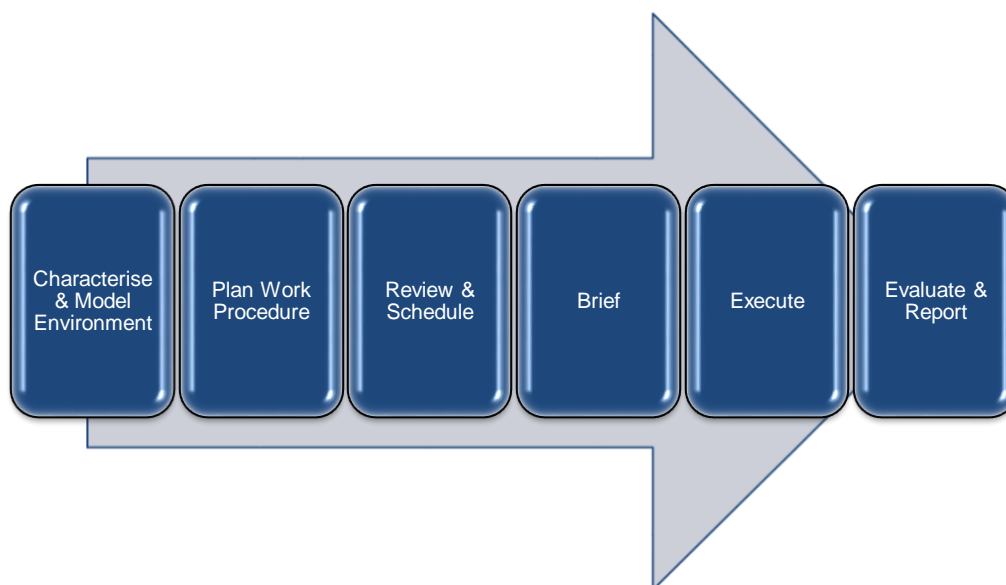


Figure 3.6 Workflow Diagram

When planning a job in a radiological complex situation, we need to be able to transfer information between each planning activity and to explain how that is done we must introduce a handful of concepts that are used to manage the information flow in the workflow (Figure 3.6). The following concepts are referred to frequently in the sections that follow, and in some cases more detailed explanations are provided later:

- **Scenario:** A collection of *participants* that perform actions over time in a *room*. A scenario always has a specified start and end date, and a status (draft, scheduled, completed etc.)
- **Participant:** An object that can be added to a room, thus participating in a scenario
- **Room:** A virtual environment in which a scenario takes place. It is typically represented as a single static 3d model representing a building. While static within the scope of a single scenario, there may be multiple variants of a room model representing the (planned or actual) state of the building at specific dates/times
- **Layout:** A static representation of the virtual radiological environment that represents a snapshot at a specific time that can be used as a reference scene configuration for new scenarios. Typically comprises of room + sources + shielding, but sometime other equipment left as the end state of a related job (e.g. a job is spread over several days represented by separate scenarios)
- **Project** is a collection of related *scenarios* and *layouts*, with additional common project meta-data (expected start date, expected end date, description, references)

These and other definitions can also be found in the appendix.

3.9 Supporting Characterisation and Modelling the Environment

A layout can contain known radionuclide sources, which can have different shapes or forms. In the current version of the VRdose Planner, sources can have the forms of lines, points, quads, or closed volumetric meshes.

The radionuclides supported by the included calculators include ^{60}Co , ^{58}Co , ^{110m}Ag , ^{137}Cs , although two of the calculators include additional radionuclides. Sources have a date associated with the values of the properties that describe its character. This enables the software to consider decay, using a simplistic model based on half-life over time.

Shielding can be introduced into a layout, and be moved as part of a work scenario. At present, shield composition is limited to iron, lead, water, concrete and sand. Rectangular, cylindrical, and volumetric mesh shield geometry are supported with user-configurable dimensions.

3.9.1 Measured Dose-rate Data

Measured dose-rate measurements associated with specific dates and times collected during a radiological survey can be stored in the database, and are useful as an aid to characterisation, planning and review. These measurements can be visualised with colour-coded values at the location of the measurement within a user-configured timeframe relative to the “current scenario time” in a scenario, to see the most recent measurements relative to the planned time of a scenario. If a layout contains sources or a dose map then you can also access a table of showing the estimated value (at scenario time) at each measurement location, the measured value, and the %deviation (+/-).

3.9.2 Radiation and Dose Calculation

The VRdose Planner is supplied with three calculators. Two of these are point-kernel based calculators for estimating the dose, isotopic contribution to dose, and shielding effects, while the third is a pseudo-calculator that does not compute dose maps itself but uses data from imported dose maps to estimate the dose at any location within the dose mapped space.

By default, we expect most users to use the supplied point-kernel calculators for most planning and optimisation purposes, but with the option to import data from other offline calculators for plans that are to be scheduled, typically because the offline calculator has been qualified for use or because more complex methods (such as monte-carlo simulation) are required by company or national regulations.

The supplied point-kernel calculators have the advantage of being reasonably accurate and being able to cope well with dynamically changing situations with close to real-time response. Changes to sources and shielding conditions or properties trigger an immediate update of the radiological situations, and any associated visualisations. The VRdose Planner calculates accumulated dose equivalents for virtual dosimeters using either real-time or pre-calculated dose map data as basis for calculations.

Both point-kernel (pk) calculators are documented in detail in a Halden Work Report (HWR-1030), available to VRdose Planner users on request. A benchmark comparison between results from the supplied calculators and reference calculations is provided in the VRdose Planner system documentation. The two pk-calculators are labelled *basic* and *extended*, where the basic model is relatively simple and very fast, but not applicable to all situations,

while the extended calculator is significantly more accurate in a much broader range of situations, but is also significantly slower. In comparison with monte-carlo based methods, it is unfair to describe either method as *slow*, as the difference between the two pk-calculators is essentially a question of how many re-computations we can achieve per second while multiple sources or shields are moving.

3.10 Supporting Work Procedure Planning

3.10.1 Scenarios

The fundamental building block for the simulation of a work procedure in the VRdose Planner is the scenario. A scenario comprises of a set of participants that perform actions in a sequence in a room

- *Room*: The modelled space in which a job takes place – typically a model of part of a nuclear facility. Although the model may change over time (especially in a decommissioning setting), it is generally static within the scope of a single job.
- *Participants*: manikins or other objects, such as tools, sources, shields, vehicles
- *Actions*: walking, lying down, crouching, waiting, working, etc.

Actions take place on a trajectory or path through the room and represent a participant's position in the scene at a specific time as dictated by a participant's actions. Sets of actions can be grouped as *steps* with a description entered by the user, thus enabling the organisation of sets of actions into a *work plan*. Steps can reference standardised procedures that specify in detail how a specific work task should be done but the details of that are not usually modelled in the VRdose Planner, where the focus is primarily on where a task is done and for how long rather than on producing a detailed animation of the micro-actions of the procedure itself. For example, a work step might be "remove the screws using a screwdriver", where the user is simply "working" (action) for an estimated duration of time at a specified location using the object *screwdriver*.

A visual timeline provides an overview of a scenario, listing participants and showing a schedule of actions and a visual representation of the work plan is also provided to enable the easy grouping of actions into work steps.

3.10.2 Radiological Environment Analysis

The radiation visualisation capabilities of the system are very useful for rapidly identifying optimal wait areas or areas to avoid unless absolutely necessary. For any scenario, the expected total dose per worker, collective dose, and maximum and minimum dose are also readily available to the user, but a number of additional features are also provided to assist in the optimisation of shielding.

For example, you can:

- Display the collective dose history for all virtual dosimeters for the time interval represented by the scenario, or for a single selected virtual dosimeter
- Display shielding effects information per virtual dosimeter for the radiological situation at the current scenario time
- Display the per isotope contribution to dose-rate per virtual dosimeter

The second two examples above are only available if using a calculator that supports the provision of this information (e.g. in the standard package, this data is not available if imported dose maps are used instead of one of the two point-kernel calculators).

3.11 Supporting Review and Scheduling Process

An Annotation Manager function supports adding feedback and comments to a scenario. Annotations are also used to highlight key things in a scenario, such as hazards, access ways, that can be displayed during a briefing session, and are required for pre-job reporting. The annotation manager can also be used to handle checklists.

It is possible to compare the “vital statistics” of scenarios in the database, such as the duration, max/min dose-rate, accumulated dose, etc., which is useful for quickly comparing alternative plans, or comparing a proposed plan with a similar “historic” scenario that has been completed in the past. This information is provided in both tabular and graphic form and can be exported as a report from the system. The table itself can also be exported as raw data for use in spread sheet or statistical software.

3.11.1 Pre-Job Work Plan Reports

Pre-job work plan reports can be exported from the VRdose Planner, including report elements selected by the user to configure what information should be included. It can therefore be used to produce report data required for producing work permit applications, work permits, safety cases, pre-job reports, etc. (see for example the US Department of Energy Radiological Control Manual for examples of information elements that should be included in various report types).

Examples of information elements that can be included in a report from the VRdose Planner are:

- Timeline
- Work steps
- Maps and routes
- Overview of estimates for doses with charts
- Annotations

Other information that should be included in reports can be added (or referenced) and stored in the database, primarily via the annotations system, enabling practically all report elements recommended by the ICRP, national regulators or authorities to be included, if desired.

3.12 Supporting Briefing

VRdose Briefer is a dedicated presentation tool can load scenarios produced using the VRdose Planner. It can be used by instructors to step through animated work procedures and visualise radiological conditions, and can also be used for personal study. It is used to present scenarios “full-screen” with limited functionality in comparison with the VRdose Planner.

Specifically, the VRdose Briefer can be used to:

- Present and explain steps of work procedures
- Highlight potential issues and hazards
- Illustrate radiological conditions

A significant restriction of the VRdose Briefer is that scenarios cannot be modified using it, and it does not provide access to dose charts and other detailed information, however the VRdose Planner can, of course, also be used for briefing where more detailed information, complex alternatives, or “what-if” cases need to be explained.

3.13 Supporting Execution of the Scheduled Plan

The VRdose Planner currently supports execution of a scheduled plan in that it can be used to produce printouts of job plans, estimated values, dose maps, and so forth that can be carried by individual workers. Immediately after a job has been completed, a scenario can be annotated with comments and actual measured values, which can then be used for experience review (see below).

3.14 Supporting Experience Review

The VRdose Planner provides flexible support as part of the preparation of post-work experience review reports and visual support for debriefing. In many ways, this activity is similar to pre-work briefing and reporting, but can include actual values for personal dose equivalents and dose-rates logged at control points during the job. To support organisational learning and debriefing it is useful to be able to annotate completed jobs to note and compare the actual durations of major work steps, expected and measured doses, and to record explanations for significant deviations. If a serious incident took place during the execution of a job then the software may be useful to help stakeholders discover the reason and to produce any additional data or explanations, with illustrations, required to provide genuinely useful information when reporting the incident.

3.15 Supporting Organisational Learning

Once scenarios have been prepared and the planned work has been executed, they can be useful for preparing case studies to teach best practices for educational purposes, and the radiation visualisation capabilities can be excellent for training new employees and contractors. Furthermore, over time, the historical data accumulated in the database can serve as a useful digital archive which, given sufficient amounts of data, may be useful for statistical analysis and other data mining activities to support organisational learning.

3.16 Interfaces for Customisation, Integration, and Extension

The software is designed to support easy extension to support new functionality, and to integrate into existing information architectures. While the standard system uses an embedded SQL database, customisation of the software is possible through custom development in collaboration with IFE, to bridge to alternative data sources, in particular for plant geometry data or historical radiological data. A Java-based plugin interface is provided to enable alternative radiation/dose calculators to be wrapped and integrated. An SDK for producing calculator plug-ins is included with the software installation and can be used without assistance from IFE.

3.17 System Requirements

The minimum recommended requirements for the system are:

- Intel Core i5 x64 processor or similar
- 6GB RAM
- Microsoft Windows 10 64-bit or macOS 11
- 3D Graphics accelerator card with OpenGL 3.3 support
- A three-button mouse (or a two-button mouse with scroll-wheel "button")

The software can sometimes be used on a less powerful hardware however system performance will not be optimal.

The recommended requirements for the system are:

- Intel Core i7 x64 processor or similar
- 16GB RAM
- 64-bit Microsoft Windows 10 or macOS 11
- Discrete AMD or NVIDIA 3D Graphics accelerator with OpenGL 4.2 support
- A three-button mouse (or a two-button mouse with scroll-wheel "button")

Installers for 64-bit Linux can be provided on request.

3.18 Summary

The VRdose system offers end-users advanced radiation dose estimation technology that enables interactive 3D visual representation of radiological conditions to support ALARA optimisation.

4. Appendix

4.1 Glossary

Action	In the context of a scenario, an activity that a participant can perform, such as moving, waiting, working, and so forth.
Administrator	The user that is responsible for the management of the software installation.
COLLADA	See DAE.
DAE	Digital Asset Exchange; an ISO-standard file format for exchange of digital assets, including 3D models between software systems (ISO/PAS 17506:2012).
Developer	A programmer using the software to implement extensions to it
GPU	Graphics Processing Unit. A dedicated processor that is highly efficient and manipulating graphics and images. Usually employ a highly parallel architecture that can also support the execution of general-purpose parallel computing algorithms.
HTML	Hypertext Mark-up Language.
IFE	Institute for Energy Technology (Institutt for energiteknikk). A research foundation in Norway located at Kjeller and Halden.
Instructor	A user that is using the software for teaching or briefing purposes.
JPEG	An image format with lossy compression.
Layout	A static representation of the virtual radiological environment that represents a snapshot at a specific time that can be used as a reference scene configuration for new scenarios.
Manikin	A virtual human. A 3D model of a human used to simulate and evaluate jobs. Usually represents a worker.
Model Bank	a hierarchically organised model database that supports the storage and access to 3D models with meta-data and version control of models
Participant	An object in a scene that can perform actions, thus participating in a scenario.
PNG	An image format that supports efficient lossless compression.
Project	A collection of related scenarios and layouts, with additional common project meta-data (expected start date, expected end date, description, and references.)
Room	The virtual environment in which a scenario takes place. It is typically represented as a single static 3d model representing a building. While static within the scope of a single scenario, there may be multiple variants of a room model representing the (planned or actual) state of the building at specific dates/times.

Scenario	A collection of participants that perform actions over time in a virtual radiological environment. A scenario always has a specified start and end date.
Scene	The view of a layout displayed in a 3D view, comprising of a hierarchy of participants in a room.
SDK	Software development kit. A code framework for extending the functionality of the software system.
SQL	Structured Query Language; A standard language for querying relational databases.
UI	User interface.
User	The end-user of the software system.
XML	Extensible Mark-up Language; A set of rules for encoding arbitrary data and documents in a machine-readable form.
VR	Virtual reality. Interactive 3D visualisation, ideally displayed full-scale.
VRdose Planner	3D job planning tool with radiation visualisation and dose estimation.
VRdose Briefer	Presentation tool for playback of scenarios created using the Planner
VRML	Virtual Reality Modeling Language. VRML 97 is an ISO standard 3D file format (ISO/IEC 14772-1:1997).