Advantages of combining gamma scanning techniques and 3D dose simulation in dose optimisation problems.

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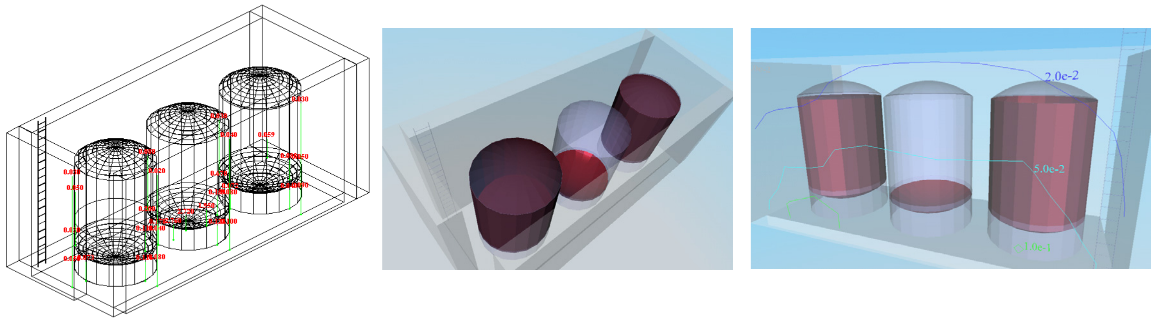
Abstract
In this paper we present a method of combining results from gamma scanning equipment with a 3D dose simulation tool with the aim to achieve a reliable dose characterisation of the work site in order to perform dose assessment and optimisation for work planned in the area.
A first step in any ALARA pre-job study is the radiological characterisation of the work site. Traditionally this is done based on 4π dose measurement and spectral analysis of sweeps or samples taken from the site. This method can be very tedious and dose intensive especially in complex geometries. In recent years equipment such as gamma cameras and gamma scanners started to appear on the market enabling a remote localisation of source positions and geometry. We will show how the data of the gamma scanning can be analysed with a 3D dose assessment tool in order to achieve a reliable source model for the work environment and how the source and geometry modelling information can be used in the dose optimisation problems.

1. Introduction

Planning activities in an irradiating environment involves the technical analysis of the work but also the assessment and optimisation of the occupational dose in order to comply with the ALARA requirements.
This is a complex task requiring the treatment of data going from source strengths, shielding, site geometry, work duration to even the distribution of the work force. Optimizing the dose also means that different work scenarios should be compared to select the one being a good compromise between effort (financial, technical...) and dose reduction. Therefore, a need exists for a tool to simulate the different planned activities in order to evaluate the dose prior to the operation. In order to do so SCK•CEN developed the VISIPLAN 3D ALARA planning tool to assist the ALARA analyst in the field of dose assessment and optimization [1]. The tool allows making a dose assessment in a 3D environment based on a point-kernel calculation corrected with an infinite media build-up factor. VISIPLAN has in the past years proven to be a valuable tool for the ALARA analyst [2-6].
The aim in the pre-job study is to establish an adequate radio-geometrical model of the site enabling a good dose calculation for the work. With adequate we mean a model with a level of detail suited for both calculation speed and required accuracy for the dose assessment in the field of radiation protection.
However before any calculations can start we need to gather information on the geometry, materials and sources present on the site. A major part of the geometry and material information can be found in the technical descriptions and plans of a site. In some cases there exists the need to re-measure the positions and dimension of some infrastructures because they where not build according to plan or they were adapted during the lifetime of the site. In those cases we can resort to techniques like laser scanning to establish relatively quickly an as build plan in a 3D CAD format.
The radiological characterisation of a site is more difficult to achieve. Traditionally this is done using a set of 4π dose measurement at different positions of the site together with spectroscopic analysis of sweeps or samples taken from the sources. This method can be very tedious and dose consuming for complex industrial environments, especially if little information is available on the geometric extend and exact position of the sources. The dose rate map established by direct measurement can be used to assess the dose, under the condition that the radiation field does not change during the operation as a consequence of geometry changes or source removals. When we want to predict doses in changing work environments we need to establish the information on source location, source strength and source composition. Sometimes it is possible to derive the source position, composition and geometry from the analysis of the technical data of the plant. Source strengths can then be derived by fitting the calculated dose rates to the measured dose rates; a technique applied in the source fitting routine available in VISIPLAN (Fig. 1.). This is a practical method but can in some cases lead to missing the contribution of some hot spots that where difficult to measure due to geometric restrictions (difficult to access with the dose measurement device).



(a) (b) (c)

Fig. 1. Example of a source strength assessment based on the dose measurements distributed over the site (a). The positions of the main sources (in red) are derived from the technical data of the site (b). The source strengths are determined by fitting calculated dose rates to the measured dose rates and can then be used to determine the dose rates at different positions in the work area (c) (dose rates expressed in mSv/h).

In recent years however equipments like gamma camera's and gamma scanners started appearing on the market enabling an easier, remote localization of sources or hot spot on a site. In this paper we show how these devices can help in the characterisation of a site and can help to establish an adequate radio-geometrical model of the work place. This is demonstrated on an application in an industrial environment. Part of the work presented here was performed as part of the VRIMOR European 5th framework program on "Virtual Reality for Inspection, Maintenance, Operation and Repair" where the viability of the integration of different technologies like gamma scanning, geometrical scanning, radio-geometrical modelling and human motion simulation were explored [7-8]. The results presented here concentrate on the radiological modelling aspects of the work, especially on the interpretation of gamma scanning results.
First we will give a short description of the gamma scanning equipment used and introduce the method we developed to analyse the gamma scan with VISIPLAN. Finally we demonstrate the method in the characterisation of an industrial environment at a nuclear power plant.

2. Gamma scanning and gamma scan interpretation

The method to interpret gamma scans is based on the application of the EDR-scanner develop by CIEMAT (Spain) [7-8]. The scanner integrates three sensors, a collimated gamma detector a video camera and a laser distance meter. The gamma detector is a Cs(Tl) crystal coupled to a photodiode with an energy threshold in the 150-200 keV range. The detector is located in a stainless steel housing with a lead shielding as can be seen in figure 2. The effective shielding is about 5 cm lead with a higher shielding value in the area surrounding the collimator opening. The collimator aperture used for the measurement is ±4°. The whole system is mounted on a pan and tilt platform enabling an automatic scan of the area. Spectra are measured in the different detection directions and stored in a 25 energy bin format together with the collimator direction and the distance to the measured object. A special interface was developed to transfer and display the measured results in VISIPLAN.
The interpretation of the gamma scans involves two parts. A first part concentrates on the visual interpretation of the scans, overlay images are used in order to determine the position of hotspots or the geometry of the sources. It is recommended that a series of scans are taken from different positions on the site. This enables to determine source positions using triangulation and reduces the risk of associating a source to the wrong object. This analysis leads to a first suggestion for the source distribution of the site. The model is then confronted with the available technical data of the site in order to qualitatively check that the proposed source distribution is a good candidate.
The spectroscopic capabilities of the scanner are used to determine the isotope vector important for the dose assessment. The isotope vector data can be further enriched by introducing data obtained through spectroscopy on samples taken from the content of certain volumes.

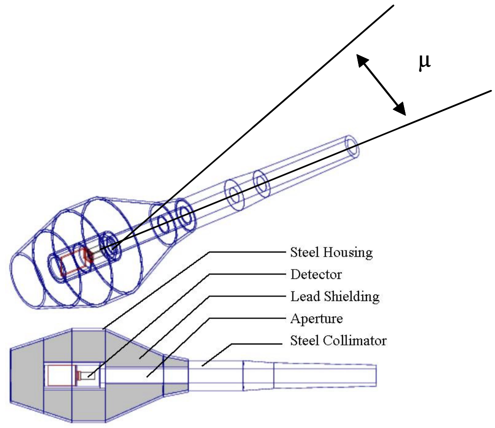


Fig. 2. Layout of the EDR gamma scanner (CIEMAT). μ indicates the angle enclosed by the collimator direction and a point source direction.

Once the source geometry is established we can perform a quantitative analysis of the scans. This means that we will try to determine the source strengths on the site by comparing calculated scan results with the measured ones.

In order to do this we need to establish a relationship between the effective dose at the detector position and the response of the detector to this dose. This can be done by determining the response of the scanner for different detector orientations to the radiation field generated by a point source emitting photons at energy En. This will establish a relationship between the Instrument dose rate "IDR" and the effective dose rate at the instruments position for a gamma source emitting at energy En. Taking into account the axial geometry of the scanner we can define the instrument response function depending on then energy En and on the angle μ (Fig. 2.). The relationship between the instrument and the effective dose rate is given as:

$$\varepsilon(En,\mu).E(En) = IDR$$

and

$$IDR = \sum_i h_i.CPS_i$$

with h_i the dose conversion factors for a rotational irradiation geometry and CPS_i the counts per second detected in the energy bin En_i. The directional sensitivity of the detector-collimator couple was measured for a Co-60 and a Cs-137 source at a distance large enough to generate a plan-parallel radiation field at the detector position. The derived dose rate response function is the basis for the source strength evaluation method used in VISIPLAN-VISIGAMMA.

The source strengths are determined by fitting the simulated gamma scan expressed in IDR-values to the measured one. The simulated scan is calculated taking into account the geometry, material and source information in the model and the energy dependent directional dose response function of the EDR scanner.

This methodology was first tested in the laboratory, in a controlled environment consisting of two well known sources. The method performed well and was able to determine the source strengths within 20 and 30%.

3. Demonstration of the method in an industrial environment

A demonstration of the method was performed within the VRIMOR project. The industrial area selected is part of the auxiliary building of Almaraz Nuclear Power Plant (Spain) [8].
A geometric scan of the area was performed by Z+F Ltd using their "Imager 5003" laser scanner. A CAD model was created based on the measurements and then transferred to a VISIPLAN model including material information. The materials data associated to the volumes were gathered on-site by Tecnatom.
The geometric scan was followed by the gamma scanning campaign performed by the CIEMAT team. The distance and orientation data of the EDR-scanner are fitted to data of the geometry scan in order to determine the EDR position in the CAD, respectively the VISIPLAN model.
The results of the geometric scan and the model derived from it in VISIPLAN are given in figure 3.
Two gamma scans were used in the radiological characterisation of the site, their positions are also shown in figure 3. The overlay images of the scans are given in figure 4.

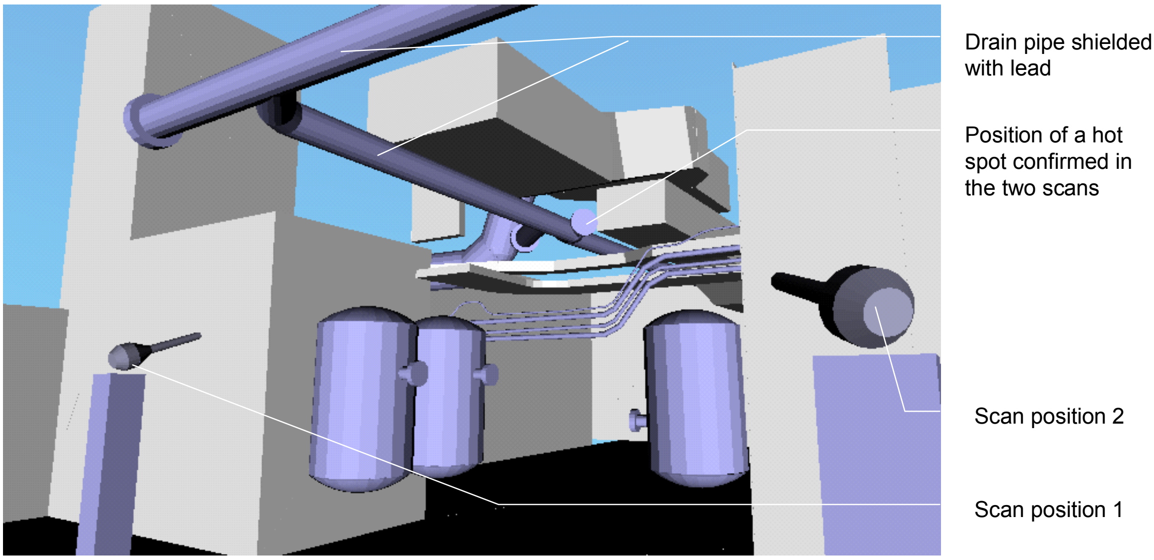


Fig. 3. VISIPLAN model of the site geometry indicating the position of the gamma scanner during the two scans.

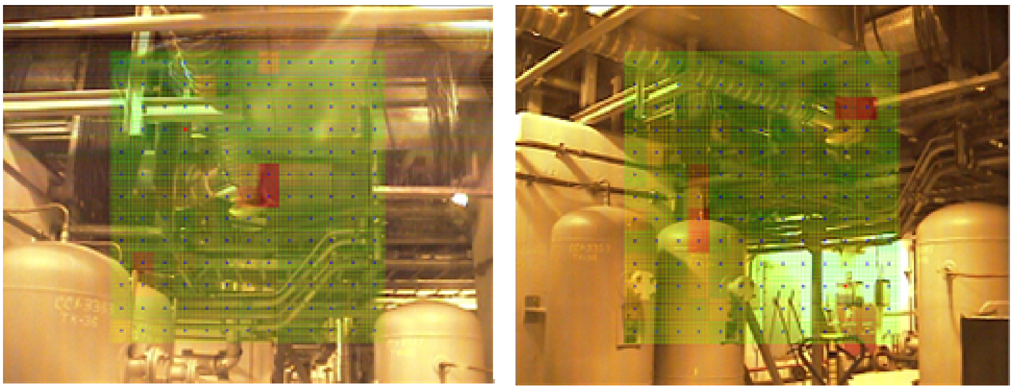


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Fig. 4. Gamma scan intensity overlay image taken from two scanning positions (red indicates higher gamma intensity).

A hot spot can be seen at the tube with the end flange. The position of the hot spot is confirmed in the second scan taken from another position. The spectral analysis of the measurements suggests that Co-60 is the pre-dominant isotope, so it was decided to continue the analysis with Co-60 equivalent sources.
A first attempt to simulate the scans using one source, positioned at the hot spot, failed and leads us to further analyse the technical data of the site. The technical information gathered by Tecnatom suggests simulating the area using the source distribution presented in figure 5. Three cylindrical volumes are used representing the source A, B and C in the tubes. This model proved to be more realistic and could account

for the high background detected in the gamma scanner signal. Based on this model we determined the source strength of the A, B and C sources (fig. 5.). A good agreement was now found between the simulated and the measured gamma scans.
Once the source strengths determined we calculated the dose in the area with the VISIPLAN tool and compared the calculated dose rates with the dose rates measured on site (fig. 6). An agreement was found within 20 to 30 %, a good agreement considering the accuracy of the point-kernel calculation method used in VISIPLAN and the gamma scan calibration method proposed for the gamma scan interpretation.
It is interesting to notice that the direct viewing of the scans would lead us to believe that only one important source (source A) is present in the scene. However the detailed analysis using the 3D model in VISIPLAN showed that the drain pipes B and C are also major contributors to the dose. Source B lays only partly in the field of view of the scans and source C is outside the field of view but they account for the high background detected in the scans. This analysis was only possible because we performed a thorough calibration of the gamma scanner in all directions and could account for the contribution of source B and C to the signal.

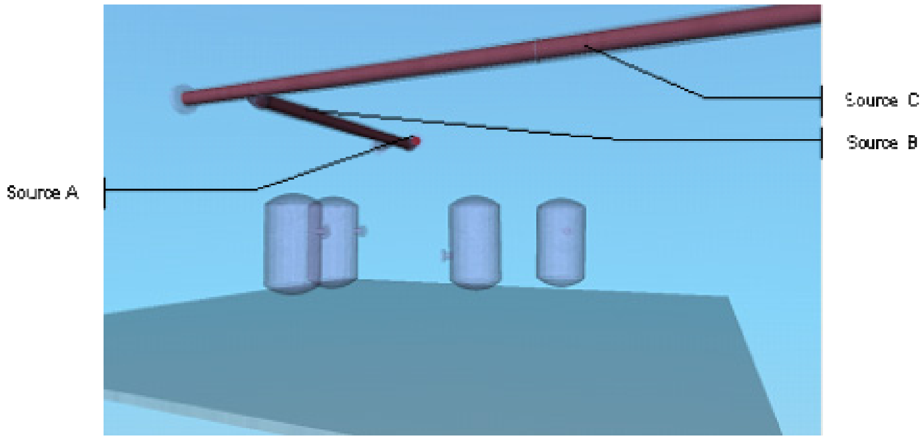

Fig 5. Simplified model of the area including the source distribution derived from the analysis of the scans and the technical data of the site.

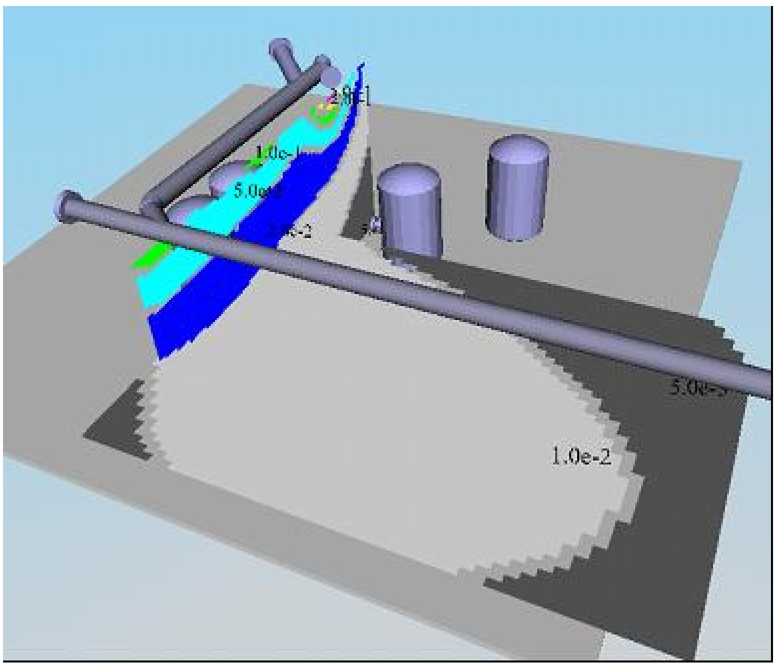

Fig. 6. Dose rate map calculated in two planes of the area using the VISIPLAN tool.

Conclusion

The standard radiological characterisation of a site can now be augmented by using devices such as gamma scanning in order to determine source positions, source geometry and source composition. Hot spots that could be missed by traditional methods can now be picked up through the gamma scanning.
A thorough 4π calibration of the gamma scanner combined with the use of a radio-geometrical model makes it possible to perform a quantitative analysis of the source strengths leading to an adequate radio-geometrical model of the site that can be used in dose assessments and optimisation for work planned in irradiating environments.

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