VRdose-COSSAN Coupling for Uncertainty Management of Radiological Simulations

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Abstract. A code couple of VRdose, a radiation simulation and work planning tool, and COSSAN, an uncertainty management tool, is presented as a method for evaluating the impact of scenario uncertainty on the outcome of radiological simulations. A test case is run using informed and uniformed input uncertainties which are propagated through VRdose using COSSAN as an interface. The resulting outcome probabilities are analysed to determine the upper dose limit according to user specified confidence intervals, hence increasing the plan efficiency and environment knowledge whilst still being confident of workers safety within the decided level of confidence. For a test case including uniformed uncertainties the dose exposure estimate with 90% confidence is shown to be significantly less than that found by a conservative estimation by VRdose alone (0.584mSv and 0.8132mSv comparatively). When further information is added to the system in the form of gaussian probabilities instead of uniform, the outcome distribution peaks further and the expected dose exposure within 90% confidence is reduced further to 0.329mSv. An additional feature of sensitivity analysis highlights the ability of the coupled software to increase the transparency of the modelled system in an automated way and inform the user of the most pertinent factors to consider.

KEYWORDS: Radiological Protection, Risk, Uncertainty, COSSAN

1 INTRODUCTION

Dose exposure estimation prior to exposure is the standard protocol for workers in the nuclear industry today: this is both due to the capability for risk management and maximizing efficiency through planning. If done by using simulation software, this calculation will be performed by either a Monte Carlo or deterministic method, the choice of which is normally decided by whether the accuracy or the efficiency is priority in the scenario. One such deterministic code which aims to simulate workers' dose estimates in real time is VRdose, developed by the Institute for Energy Technology (IFE), Norway [1]. This software focuses on maximizing workers' safety and efficiency and stands apart from the market as it allows for simulation of dynamically changing environments without laborious iterations.

However as with most deterministic codes, where VRdose excels in computational efficiency, in certain situations it is compromised by the conservative nature of the results. This conservatism arises both from the actual algorithmic process used and the acute need for the user to err on the side of caution where a workers' health and safety is at risk. With input from the developers at IFE this project will show the coupling of VRdose with the uncertainty analysis software, Cossan. This add-on will provide numerous benefits: it will allow for a bounded range of values in scenarios where parameters are uncertain, a fast graphical representation of the effect of changing parameters to choose those optimal for minimization of worker dose exposure, and sensitivity analysis to inform the user of the most pertinent parameters affecting the dose exposure in that scenario. Following is a brief overview of the VRdose and COSSAN software for clarity regarding the coupling methodology.

2 BACKGROUND

2.1 VRdose

VRdose allows the user to build an environment to which gamma sources and workers can be added, all of which can be moved to create a dynamically changing environment: real time dose rates are then calculated. VRdose is currently entirely GUI based allowing for 3D presentation of the scenario along with graphical outputs of the dose rate throughout the workers route. VRdose implements the deterministic point kernel methodology [2] to calculate the workers dose exposure throughout the modelled plan. This technique uses the source characterization, linear attenuation, buildup and conversion factors to calculate the dose exposure (in various possible formats [3]) from the source to the worker at small increments along the worker's path [1]. Hence from the dose rate – time graph the estimated accumulated dose can be found for any modelled plan.

2.2 COSSAN

Currently being developed at the University of Liverpool's Institute for Risk and Uncertainty, COSSAN is a multipurpose uncertainty quantification software package designed for a wide range of applications such as reliability analysis, robustness, optimisation, sensitivity and uncertainty quantification [4] – which this study will mainly focus on. Despite the significant development of deterministic codes in recent years, including VRdose, many neglect the inherent uncertainties of the simulation and do not provide a platform for propagating this 'lack of knowledge' through to the result. By coupling with COSSAN, which can act as a Monte Carlo shell and parser, the link between stochastic and deterministic methodology can facilitate a more informed result whilst also remaining computationally efficient. Rather than producing a discrete output, as most stand-alone deterministic codes do, the VRdose-COSSAN couple can render an output distribution in which the upper and lower bounds and most probable result can now be viewed, without any manual iterations of the radiological simulation tool in question.

3 COUPLING METHODOLOGY

COSSAN includes an inbuilt feature for integration with 3rd party deterministic software. The approach this uses is to alter and store input and output files from the 3rd party software, the variable input quantities are tagged, altered using samples from a defined distribution and then remotely executed with the 3rd party software, where it will act as a black box. The output quantity of interest has also been tagged so that it can be recognized in the output files and plotted in COSSAN.

As it currently stands VRdose is entirely GUI based and does not read input files or produce output files automatically. As a solution to this, IFE have provided the Java classes and libraries which make up the point kernel calculator used by the software. These will be linked by a custom-made main class which creates the scenario by linking the calculator classes and facilitates input and output files for interaction with COSSAN. A modified version of VRdose has been successfully compiled which reads a custom-made input file compatible with COSSAN and capable of including an unlimited number of scenario objects and worker path movements. This version, used from hereon in, has been thoroughly validated to verify it produces the same outputs as the commercially available GUI version.

Upon execution of a MATLAB script, which utilizes the COSSAN toolbox and acts as the interface between the two codes, the input file is iteratively altered depending on the user's uncertainty specifications. This procedure essentially propagates uncertainties through the model and produces parameterized dose plots which can be analyzed by the user and subsequently used for work planning optimisation, shielding design optimization and more generally as an information gathering tool.

4 TEST CASE

A test case is used to present the results from the couple in comparison to that of a simulation run by VRdose alone using a standard conservative input, erring on the side of the worst case scenario. The test case represents that of a worker entering a waste storage facility where a spillage has occurred. The worker enters, walks past some storage barrels to the scene of the incident, pauses there for 2 minutes whilst carrying out some work and then returns to the exit. In this scenario we suppose that we are uncertain of the source characterisation of the spillage as is common in old facilities. The specific uncertainties are the position of the source (x and y axis) and the activity of the source.

4.1 Input Probability Distributions

In order to fully highlight the influence of uncertainty distributions and knowledge propagation two slight variations on the test case are used. Case 1 uses uninformed probability distributions, the lack of knowledge of the system is reflected by using uniform distributions, i.e. the bounds are known but there is an equal probability of each sample in the range, see fig. 1. Case 2 uses informed uncertainties, here we know that source is much more likely to be found in the centre of the range and as such we use a peaked (gaussian) distribution, see fig. 2.

Figure 1: Example normal probability distribution for case 1, here the distribution of the possible x position of the source is shown.

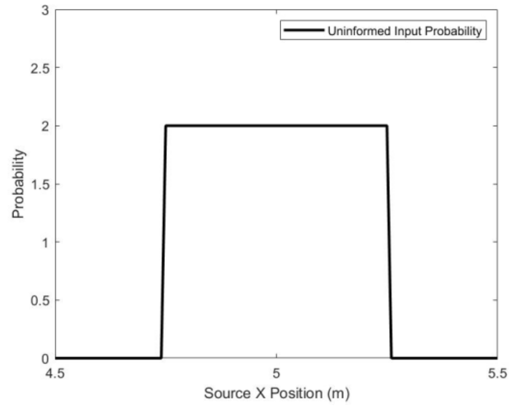
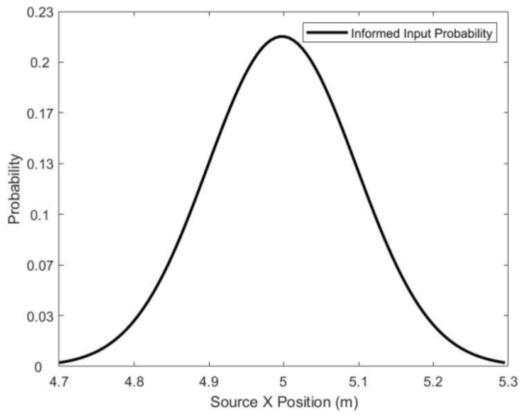


Figure 2: Example gaussian probability distribution for case 2, here the distributions of the possible x position is shown again.



5 RESULTS

The accumulated dose distribution resulting from the set of uniform uncertainty distributions propagated through VRdose using COSSAN is displayed in fig. 3. In fig. 4 the results from case 2 are presented, this is the same case but using a set of gaussian uncertainty distributions as discussed in section 4.1. Table 1 displays the results from both cases against the result from the conservative VRdose estimation alone. The discrete values in table 1 from the couple results are taken from a 90% confidence level (also labelled in fig.3 and fig. 4), this indicates that 90% of the results fall below this result and hence we can infer in the real scenario there is a 90% probability that the accumulated dose will fall below this level. The determination of confidence intervals, or use at all, can be judged as appropriate or not by the user depending on the level of risk and the severity of the worst case scenario. In this case a 90% level is deemed an appropriate balance between risk, probability, and efficiency.

Fig.5. shows a secondary feature of COSSAN, the ability to integrate automated sensitivity analysis into the VRdose point kernel model. This highlights the parameters which have the most impact on the output, in this case we see that source activity is the most impactful and as such would be the parameter which we should be most mindful of.

Figure 3: The outcome probability distribution for the specified input uncertainty distributions of case 1; those with normal (partly uninformed) distributions.

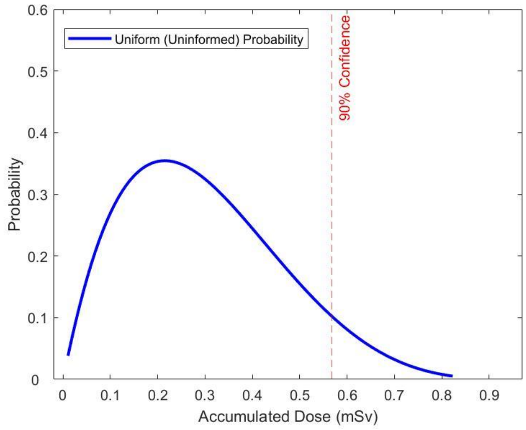


Figure 4: The outcome probability distribution for the specified input uncertainty distributions of case 2; those with gaussian (informed) distributions.

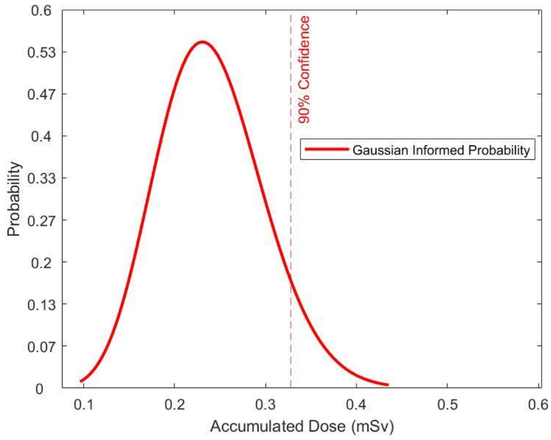
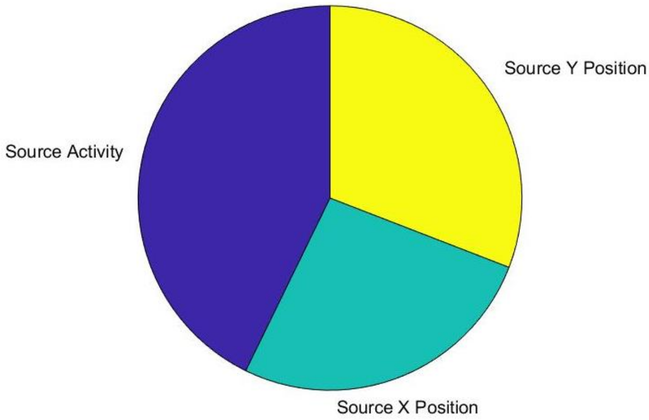


Table 1: Comparative results from the standalone VRdose and the VRdose-COSSAN couple, using gaussian and normal input probability distributions. Couple results given are for a 90% confidence level.

Comparative Dose Exposure Results (mSv)		
VRdose	Couple (Case 1)	Couple (Case 2)
0.8132	0.584	0.329

Figure 5: Global sensitivity analysis run using uncertainty distributions from case 2.



6 CONCLUSION

The results from the 90% confidence interval of the two cases are significantly lower than the conservative estimation which approximately corresponds to the tail end of the distributions. Here we see that even for the case of the uniform uncertainties there is an almost 0% probability of this conservative estimation, hence justifying the use of uncertainty propagation and confidence intervals for the sake of increasing planning efficiency. The transformation from uniform to gaussian uncertainty distributions is reflected in the output distribution by the sharpening on the peak and hence the lowering of the value at the 90% confidence, this highlights the importance of propagating as much knowledge about the system as possible even if that knowledge is regarding the 'lack of knowledge'. The last feature presenting the global sensitivity analysis shows the parameter which has the most impact on the variation of the output, displaying to the user which parameter is most important to be aware of in the planning process and which, if possible, we should attempt to reduce the uncertainty of. Each of these features, and the possibility of others from the COSSAN toolbox, has provided the user with more information regarding the system without any manual iterations. COSSAN coupling has facilitated this efficient and automated process.

This link between deterministic and stochastic techniques has proved to be a useful tool to take into consideration uncertainties: creating a representation of the possible set of outcomes rather than only the most conservative. The study has served as a feasibility study of a practical add-on for users of VRdose to increase functionality, and in the wider context could also serve a useful add-on for many other deterministic codes in the field [5]. Whilst the project presented here is specifically for the optimization of work planning and radiation protection, the underlying computational principles have the potential to be adapted for a wide array of other disciplines.

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