UNCERTAINTY / SENSITIVITY METHODOLOGIES FOR SAFETY ASSESSMENTS OF LOW-LEVEL WASTE DISPOSAL FACILITIES

F. Luiz de Lemos [1]

T.M. Sullivan [2]

J.H. Rowat [3]

G.M. Dolinar [3]

ABSTRACT

Safety assessment for low-level waste facilities requires the interaction of a large number of disciplines in order to model environmental phenomena necessary to evaluate safety of disposal. The physical systems involved can often be very complex. The initial purpose of the safety analysis is to better understand the system under study. Eventually, as the system behavior becomes understood more fully, the assessment is used to support regulatory decisions. Corresponding to the specific goals of the project the objectives for uncertainty and sensitivity analysis will also vary, depending on the stage of the analysis.

Typically, the safety analyst has to simplify the physical system into a conceptual model that can be modeled mathematically. The first step in this process involves defining an exposure scenario and this is often a significant source of uncertainty (future climate assumptions or individual habits). Simplification of the physical system to a mathematical model is another source of uncertainty, commonly called model uncertainty. Other sources of uncertainties include parameter estimation and random variability in parameter~~s~~ measurements.

In assessments the analyst may need to rely on expert judgment due to lack of data, lack of knowledge concerning future conditions and parameter values (and distributions), or any aspects of the system under study that are not well understood by current science. This generates another kind of uncertainty, “subjective uncertainty”.

This paper is part of the work being developed by the IAEA sponsored project: Improvement of Long Term Safety Assessment methodologies for Near Surface radioactive Waste Disposal Facilities (ISAM Project). As part of the ISAM Project a safety assessment process has been proposed and it is the purpose of this paper to examine the application of uncertainty and sensitivity analysis within the proposed safety assessment process.

INTRODUCTION

Difficulties in decision making arise due to the uncertainties that are inherently related to environmental phenomena modeling. The ability to identify and correctly quantify the uncertainties as well as the most important parameters in the LLW Safety Assessment is of vital importance for a good decision making. It is

(1) Centro de Desenvolvimento da Tecnologia Nuclear/CNEN, Brazil
(2) Brookhaven National Laboratory, USA
(3) Atomic Energy of Canada Limited, Canada

impossible to guarantee with absolute certainty that one has made the correct decision, but we can improve the possibility of choosing the right decision by improving the means of quantification and identification of the uncertainties in the calculations.

Substantial efforts have been expended to define the role and use of uncertainty analysis in the context of safety assessment (1through 22). This paper will present a review of what has been done in this field.

The ISAM Project has proposed a safety assessment process as shown in Figure 1.(1) The process is iterative, and as refinements in data , scenario descriptions or other factors are obtained the assessment can be improved with a corresponding decrease in uncertainty. Initially, an estimate of the sensitivity of specific parameters can be used to focus attention where the greatest benefit can be derived - this can be considered to be internal to the assessment . Eventually, the assessment focus will be turned outward, as the goal becomes to convince regulators and the public of the safety of the system under consideration.

Within the ISAM project a summary document on uncertainty and sensitivity analysis will be produced that examines in some detail the issues of uncertainty with respect to successive iterations of the assessment process. In this paper some of the background material will be presented.

SOURCES OF UNCERTAINTY IN DECISION MAKING

The following sections discuss the sources of uncertainty and how they impact on safety assessment.

Parameters

Parameters are variables used to represent physical processes in the models used to assess the performance of a site. A complete safety assessment requires the collection of a large amount of data. (2) A partial list of data which are used to define the parameters follows.

-Waste characteristics-	radionuclides composition as a function of time; total inventory; physical and chemical form; etc..
-Containers characteristics-	mechanical and chemical performance; waste form composition ~~for~~ in each container.
-Repository characteristics-	dimensions; backfill material; concrete characteristics.
-Site characteristics-	hydrogeology; geochemical properties.
-Biosphere characteristics-	weather conditions; land use; population distributions.

Frequently there are large temporal and spatial variations in some of these parameters.. For example the parameter known as dispersivity, which is a measure of how much spreading occurs in the contaminant plume during transport from the disposal site to the receptor, is uncertain. In this case, the impossibility of having complete understanding of parameter variability is a result of lack of knowledge. Professional judgment is then necessary to find the best values for parameters in the case of deterministic calculation and the probability distribution function (pdf's) in case of probabilistic approach.

Two examples showing the sensitivity of a specific parameter value on a dose estimate are given in Figures 2 and 3. Figure 2 shows the effect on total dose from a set of 500 simulations where the kd was randomly selected from a predetermined "realistic" range. From this figure it can be seen that the plutonium dose exhibited the greatest sensitivity based on the 500 trial simulation and on the realistic range.

Figure 3 shows the effect of varying the kd in the aquifer and source backfill for a specific contaminant. In this case the data is plotted as pairs (one pair for each kd value of backfill and aquifer) as this representation clearly indicates it is the kd in the backfill source area which has the more significant impact.

Sensitivity analysis of this type can be used to help guide the assessment team in focusing effort on parameters which have the greatest impact on the results. It should be kept in mind that different models may have sensitivity to different parameters.

Data Uncertainty and Variability

Uncertainty and variability in data can be viewed as two separate phenomena.(3). Both lead to uncertainty in decision making. Variability is the representation of the heterogeneity in sample population and uncertainty is the representation of the lack of perfect knowledge.

Models/conceptual

The most appropriate method to representing the physical and chemical processes in the mathematical models is not always clear. Model intercomparison studies provide some insight into the effect of choosing different conceptual models or different mathematical representations of a conceptual model. An example of an intercomparison of this nature was published by the IAEA (4), and it demonstrates the different results obtained when different models (and modellers) were applied on a relatively simple test case. Also for reasons of control and economy, the experiments on which models are calibrated are often carried out on a small scale in laboratories, rather than over longer repositories sites scales. Uncertainties arise because it is not clear that if a model that describes transport on a small scales, it will be appropriate for transport predictions over larger length-scales.(5).

Other causes of model uncertainties are ignorance of the actual relationships between processes that occur, and simplifications on very complex processes.

Scenario

This is related to the long term future of the disposal facility. It includes human use of the land, geophysical processes, intrusion, and other long-term processes.

There is no way to make an exact description of the future, however, one can represent what would be the most probable evolution of the system over the years to come based on past experiences and data. Expert judgment is very important in this approach. Another widely used approach to approximating future conditions is to select them based on current conditions (e.g., set climate conditions based on current conditions). In this case, these reference conditions may serve as a baseline for comparison between different scenarios and parameter sets. An important part of this approach is to choose conditions which permit a defensible, scientifically robust decision to be made.

TYPES OF UNCERTAINTY

According to the cause of uncertainty it can be divided into subjective, stochastic or ambiguous (lack of knowledge). IAEA Safety Series 100 (6), classifies two types of uncertainties, type A and type B.

Type A uncertainty is due to random variability. For example, if the distribution coefficient, Kd is measured by laboratory experiments for the same type of soil with the same properties, one can find several different values. If the number of measurements tends to infinity, the mean value for Kd will be a constant number.

Type B uncertainty is due to lack of knowledge and includes conceptual model uncertainty and parameter uncertainty due to non-stochastic effects. An example for this type of uncertainty could be the actual Kd values under field conditions. Heterogeneity's in soil compositions can result in Kds and other soil hydraulic parameters which vary by an order of magnitude or more (7) from one place to another within a small distance. Therefore this variability could not be treated as chance or measurement variability.

These two types of uncertainties require different approaches to deal with them in order to improve the quality of the safety assessment.

We can find both kinds of uncertainties A and B in safety assessment. During the entire process the analyst constantly has to make decisions as to the best set of parameter values or probability distribution of values to represent a system, and the best conceptual models of the system, e. g., the most likely scenario for future conditions. Those decisions are based on the analyst expertise and not on sample evidence, i.e., the decisions are subjective. So, type B uncertainty has a major role in safety assessment .(8)

An example of combined Type A and B uncertainty in safety assessment is the determination of maximum annual committed dose equivalent per individual of the most exposed population group due to a release of radioactivity to groundwater (6). In this case, the dose per individual is treated as a random variable, type A, since it is impractical to model each individual. However, additional type B uncertainty is introduced due to the lack of knowledge about the appropriate mathematical models and parameters values to use for hydrologic dispersion in groundwater as well as many other parameters to represent all processes involved in reaching the final result (6).

APPROACHES FOR UNCERTAINTY ANALYSIS

Deterministic

In this approach the model and the representative sets of input parameters are selected and the analysis is performed providing a single outcome. To address uncertainties a single parameter sensitivity analysis is performed. In this approach a single parameter is altered and the effect on the projected outcome is measured. The procedure is repeated for all parameters that are expected to have a major impact on the outcome.

This approach does not permit a rigorous mathematical estimate of uncertainties. To overcome this difficulty, parameters are often chosen which will over predict the dose. Thus, the confidence needed to make the decision on the safety assessment of the disposal depends on the confidence with which the selected parameters lead to conservative outcomes.

Probabilistic

This approach is based on the assumption that the data are random and independent, i. e., type A uncertainty. Monte Carlo is one very commonly used method of uncertainty propagation analysis. Monte Carlo can be performed using one of two random sampling processes: (9)
Simple Random Sampling (SRS) or
Latin Hypercube Sampling (LHS).

In both approaches uncertain variables are assumed to be described by statistical parameters which define the probability of the variable having a given value.

In SRS, a random value is taken from the probability distribution specified for each uncertain model parameter, and a single estimate of the desired endpoint is calculated. This process is repeated for a specific number of samples or interactions. The result is an empirical approximation to the probability distribution of the model output or assessment endpoint.

In Latin Hypercube sampling, the range of each variable is divided into *n* intervals of equal probability. A single variable value is randomly selected from each interval. The *n* values for x_1 are randomly paired without replacement with the *n* values for x_2 to produce *n* pairs of variable values. These pairs are randomly combined without replacement with the *n* values for

x_3 to produce *n* triples of variable values. This process is then continued until all *n* variables have been incorporated into the sample.

In probabilistic analyses parameter variability, type A uncertainty, is addressed through a rigorous mathematical procedure. Combinations of parameters leading to the highest projected outcome are calculated through the sampling procedure.

Subjective probability

It is recognized that in the safety assessment there are many subjective uncertainties, type B. To address these, some authors recommend the use of subjective probability. This approach uses the probability approach discussed above, however experts judgment is used to generate the probability distribution functions(PDF) representing the resulting state of knowledge for the assessment endpoint.(10). The most common probability framework for informational uncertainties is Bayesian probability theory in which the assessments are seen to be quantification of degrees of belief.

Possibilistic - Fuzzy Sets

An alternative approach for treating subjective uncertainties is the use of fuzzy sets theory. This approach provides a conceptual framework for the solution of imprecisely formulated problems. This is one of the reasons why it has been applied in a wide variety of fields of science, from medicine to industrial process control and credibility analysis (10).

The theory of fuzzy sets was developed to treat uncertainties that are non-stochastic in nature (11), i.e., subjective variations. This kind of uncertainty appears due to the extreme complexity of a problem. Also in problems where subjective opinions are part of the decision-making criteria, this subjective component can be represented as a fuzzy number. For example, social concerns will be part of the decision making for a waste disposal site.

In the possibilistic approach a degree of membership is assigned for each input parameter which is a member of a fuzzy set. This allows the data to have ambiguous characteristics belonging to two or more different sets in different degrees.

For example : If we have two sets A-plums and B- peaches, what will be the classification of the nectarine, which is a hybrid of peaches and plums, within these groups? In a traditional approach, crisp sets classification, we should assign degree one or zero for the nectarine in one or another group, i. e., it is either a plum or a peach. In the fuzzy sets approach however, one can assign degree of membership 0.3 to the peach set and 0.6 to the plum set. This means that fuzzy sets theory is much more flexible allowing quantifying ambiguity in information like in human speech.(12)

Fuzzy sets could be used in safety assessment in many different ways. For example, due to the variability in soil properties Kd is expected to vary over the transport path. Expert judgment could be used to classify the values as members of the fuzzy sets High, Medium and Low Kd’s. By this procedure the Kd values are transformed into fuzzy numbers. The fuzzy set Low could correspond to $10 <= Kd <= 30$; Medium for $25 <= Kd <= 80$ and High for $70 <= Kd <= 100$.

This could be very helpful for site characterization when making experiments for determination of Kd would be expensive, but at the same time a certain level of accuracy is wanted. In this example, the fuzzy sets for Kd correspond to ranges of values and the assigned degree of membership represent the degree of belief that a particular value belongs to a certain range. For certain portion of the soil Kd could have degree of membership 0.8 to the fuzzy set High, for example. Using a similar approach structure as for Monte Carlo analysis, all of the possibilistic variables are sampled and the result is a range of possible outcomes quantified by the degree of membership. This permits the analyst to judge the most likely outcome as well as the likelihood of other outcomes.

As an example, fuzzy set theory has been applied to waste characterization (13). In this approach, the whole repository is divided into groups of wastes according to certain characteristics like release process, waste form, inventory, package material, origin and others that could be of importance for that particular facility. As it is difficult to say exactly what is inside of each package, or even if it were known, it would be difficult to find a set of parameters that fit the hundreds of packages at the same time, the analyst would than use the appropriate techniques to assign degrees of membership for each packages into a certain group or class of set of parameters. Further these degree of membership are combined using specific techniques to find the more likely waste release from that facility.

It is very important not to confuse probability distribution function and membership function. Probability deals with objective variability that is a result of chance or randomness. For example, problems like picking colored balls out of an urn (11). Fuzzy sets deals with ambiguousness in information due to lack of knowledge, complexity and vagueness.

SENSITIVITY/IMPORTANCE ANALYSIS

Importance analysis is used in order to determine the relative importance or significance of the model parameters. Therefore, specific parameters or assumptions can be identified, for which additional data collection or design modification would likely provide the most benefit in terms of building confidence in the decisions regarding compliance (8).

EXAMPLES OF UNCERTAINTY ANALYSIS BY DIFFERENT GROUPS

Some examples are presented on how uncertainties are treated by groups in different countries.

Canada- The Preliminary Safety Analysis report (PSAR) for the Intrusion Resistant Underground Structure (IRUS) (14) provides a comprehensive analysis of safety issues concerning a Low Level waste Repository.
The sources of uncertainties that are considered are:

1- Future evolution of the IRUS facility established through a Features, Events and Processes (FEPs) analysis and relevant human activities.
2- Model conceptualization where site-specific information and expert opinion were used to build the NSURE model.

3- Numerical and coding errors.
4- Parameters values. The code SYVAC3 was used in the deterministic mode and for each simulation used a parameter value chosen by the assessor. The parameter values were selected according to the following principles:

-radiological and chemical consequences would not be underestimated
-the values were consistent with assumptions made in modeling IRUS
-the values were consistent with the assumptions defining the scenarios being assessed

Sensitivity analysis was used to quantify the effects of changes in single parameter values on the results of interest, in particular the annual dose to a representative member of the receptor group.
Also pseudo-random sampling methods were used to investigate the impact of changing parameter values on the dose estimates.

-**European Commission**- The MUNVAR Project (15), a work sponsored by the European Atomic Energy Community has extensively investigated the types of uncertainties encountered in the modeling the possible future behavior of radioactive waste repositories and techniques for handling them, including fuzzy logic as an alternative to probabilistic calculations. MUNVAR project stands for: Review on Development of Methodologies for Modeling with Uncertainty and Variability.
This project was carried out under a cost-sharing contract with the European Atomic Energy Community in the framework of its fourth R & D program on management and storage of radioactive Waste (1990-94), part A, task 4: Disposal of Radioactive Waste.

The objective of this MUNVAR project was to “review and investigate the types of uncertainties encountered when modeling the possible future behavior of prospective radioactive waste repositories and to consider techniques for handling them”(15).

The participants of this project were:
Intera Information Technologies (UK); University of Bristol (UK); and Iridia, University of Brussels (B).

According to MUNVAR report (15), uncertainty analysis is well developed for Type A parameter uncertainty with the use of probabilistic safety assessment (PSA) techniques. Uncertainties in the future conditions are generally handled by scenario approach or by simulations; however, the assignment of probabilities to scenarios has proved difficult , and expert judgment is the only way to resolve them. The Fuzzy set approach~~es~~ was to combine expert opinions of all types, and it has demonstrated that this approach can also be used for parameter uncertainty (15) .

Other countries approaches analyses can be found in reference 15.

CONCLUSIONS

Uncertainty analysis is recognized as a key factor in the decision process for safety assessment. The identification of sources of uncertainties as well as the types of uncertainties are necessary in order for the analyst to find the best way to quantify and consequently improve the degree of confidence he or she can have in the safety analysis.

Understanding uncertainty will also be a major factor in the acceptance of the safety assessment case by the public and the regulatory authorities.

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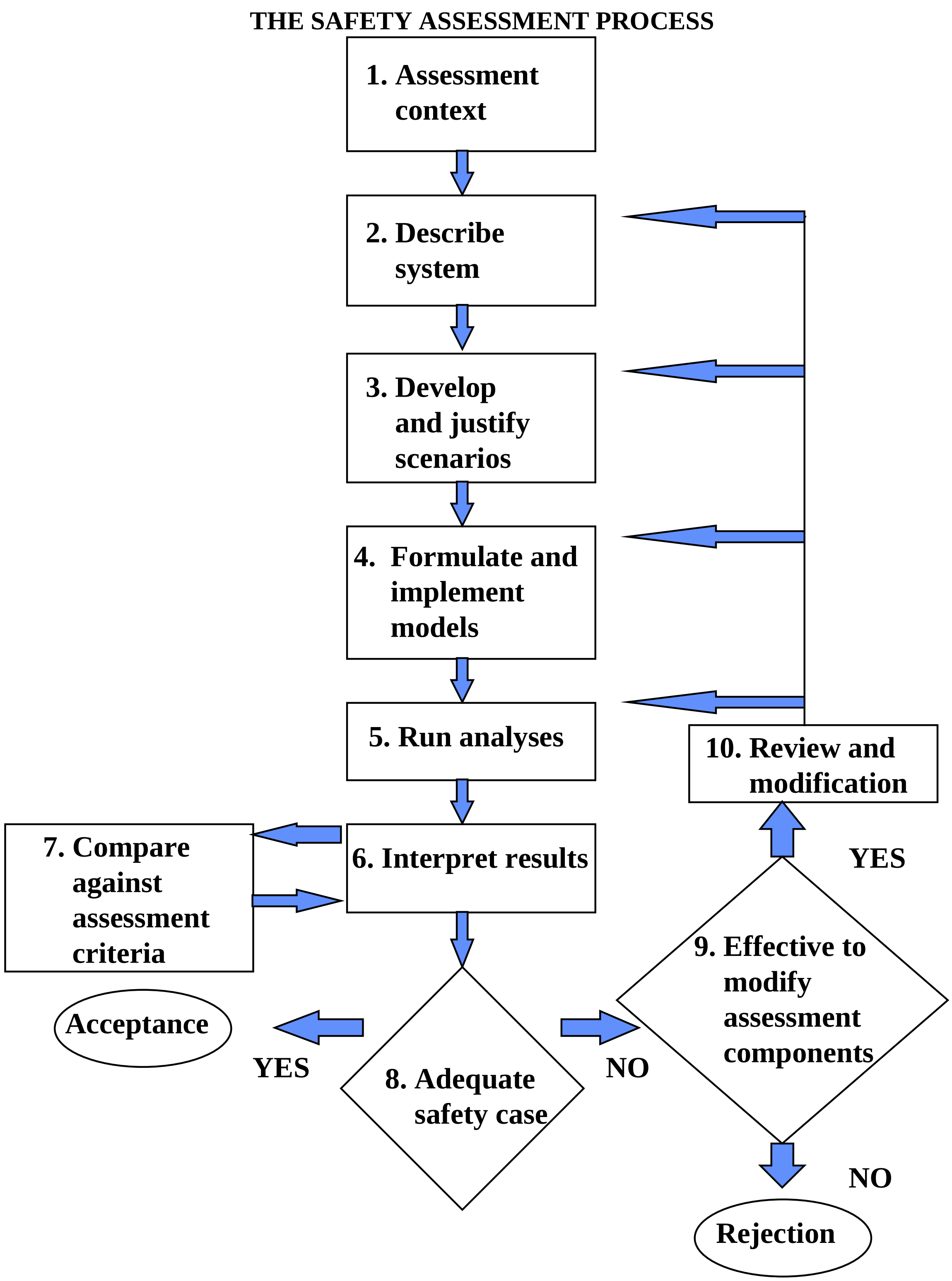

Figure 1: Proposed Safety Assessment Process Flowchart [ISAM].

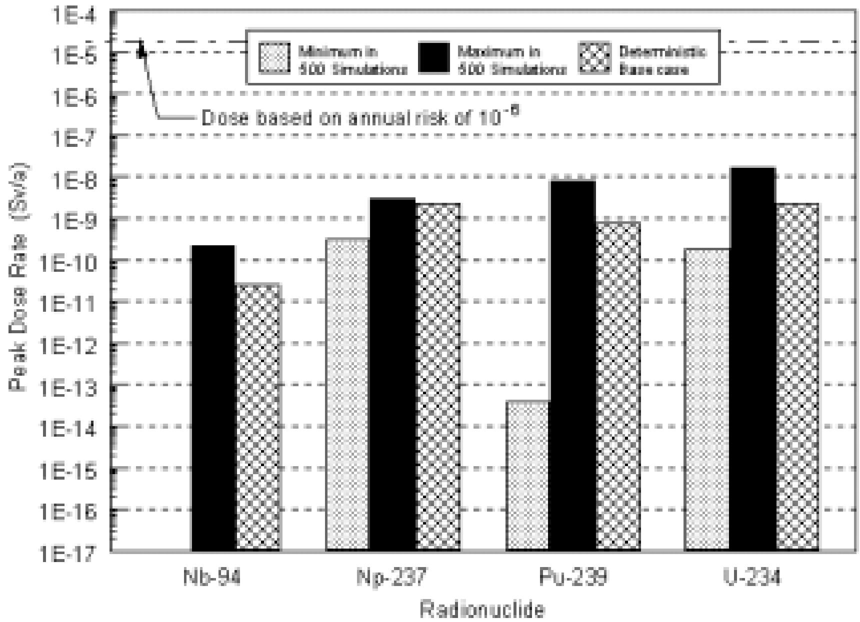

Figure 2: Effect on a total dose from a set of 500 Kd's randomly selected

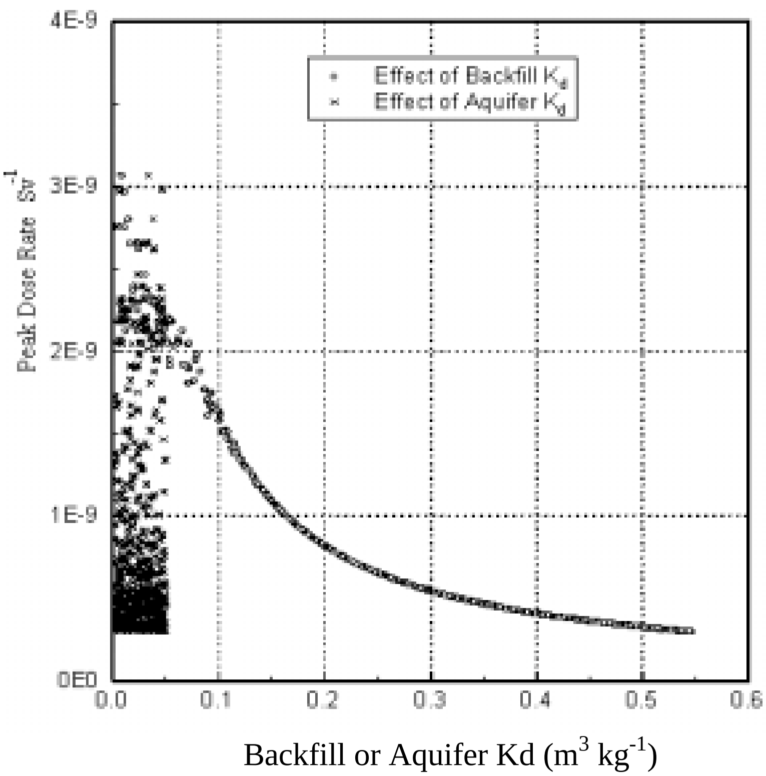

Figure 3: Effect of different Kd values on peak dose.