RISK PERCEPTION OF A PROBABILISTIC RISK ASSESSMENT: A CASE STUDY

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ABSTRACT

Deterministic risk assessment, where parameters and variables that sometimes have a very high uncertainty are assigned one fixed value, have not been received well by Nevada stakeholders. Probabilistic risk assessment, a more modern approach that deals with uncertainty, has gained acceptance in much of the technical community. This paper describes an effort by the authors to determine whether the general public could understand and accept probabilistic risk assessment as an improvement over deterministic risk assessment. In this effort, a primer was written and a stakeholder workshop was held for instruction and to illicit stakeholder opinion. The primer, which was used as a text for the workshop, included definitions of terms and approaches in layman's language, and examples from everyday life of the deterministic and probabilistic approaches were given. The main example treated transport of tritium contaminated water from the Nevada Test Site to an off-site location. The results indicate that the primer and workshop accomplished their intended tasks. Stakeholders agreed generally that the probabilistic approach 1) uses the maximum amount of information, 2) can be understood by, and communicated to, non-professionals, and 3) provides a realistic tool for making management decisions. All agreed that the probabilistic approach is superior to the deterministic, worst-case approach with the caveat that one must be careful in assigning distributions, i.e., that poorly understood distributions may not be superior to poorly understood single values.

Introduction

Man-made environmental hazards can put citizens at increased risk of detrimental health consequences. Risk assessors estimate this risk, risk communicators explain it to (potentially) affected individuals, and risk managers interpret and make decisions based on the results. But, there are different approaches to calculating risk. The classical approach is called deterministic because it uses fixed single point estimates to calculate risk. On the other hand, a newer approach, probabilistic, uses an entire range of values for variables in its calculation. Interpretation and explanation of the results of classical (deterministic) risk assessment often are unsatisfactory to all parties because of the difficulty of justifying the discrete values used in the calculations. Partly for these reasons, risk managers and communicators have leaned towards application of non-traditional methods of estimating risk, i.e., the probabilistic approach.

Risk is usually estimated by using computer models whose calculations are based on populations of citizens, a hazard to which they are exposed, and the appropriate pathways for the hazard to reach the citizens. Deterministic models require the user to assign a single value for each of its variables such as the strength of the hazard and the ages of the affected members of the population. Thus, users must estimate a single value for each variable, which is usually a "conservative" (worst case) estimate in order to avoid underestimating risk. The authors of this paper are convinced that the use of discrete values for parameters in the calculation of risk is a hindrance to acceptance by the public and the making of efficient risk management decisions. Furthermore, we believe that it is flawed because it is not realistic to represent those parameters by a single number.

To illustrate a serious problem with the deterministic approach, consider a population of the general public of all ages that visits a local park where a wide range of plutonium concentration has been measured. A risk assessment is ordered to determine the danger to the public and to serve as the basis for a risk-management decision to clean it up, to fence off the dangerous areas, or to do nothing. Since plutonium attached to dust particles is inhaled and remains in the body for extended periods of time, the risk is greater for younger persons. A "conservative" deterministic estimate of risk would use the highest concentration and the youngest (most affected age) age when calculating risk. The result could be a greatly exaggerated risk that could lead to drastic clean-up action and wasted resources. On the other hand, using average values for contamination and age could lead to no action when some very high concentration (but physically small) areas could lead to dire consequences in children.

The use of discrete values, therefore, precludes the use of valuable information, and the use of "conservative" estimates can result in risk that is absurdly high and which has no real meaning other than to assign a maximum possible risk. Management decisions based on discrete values of risk cannot adequately account for the uncertainty in the problem, and management decisions based on conservative estimates are not only unreal, but can be extremely costly in terms of resources. These methods do not adequately represent real risks. A more realistic and technically appropriate approach to modeling is to assign a distribution of values for each variable and to include them all in the analysis by using a Monte Carlo approach. This type of modeling produces a distribution of risk values (in the form of a histogram) which represents the probability of occurrence of risk values. It is known as a probabilistic approach and has gained acceptance in the technical community as a more realistic method of calculating and, subsequently, of managing risk. A problem, however, lies in the ability of the public and risk managers to understand and interpret the results of the probabilistic approach.

The work reported here explored the effectiveness of presenting a probabilistic risk assessment of a groundwater contamination problem, rather than the traditional deterministic approach, to a workshop of interested citizens.

The Workshop

The Goal: The goal of the workshop was to determine whether stakeholders would find probabilistic risk assessment more understandable, realistic, satisfying, and believable than deterministic risk assessment.

The Problem: The problem faced by this study was to elicit stakeholder preference for a method of estimating risk when most of them were non-technical citizens who understood neither the classical nor the probabilistic methods. The task, therefore, included instructing interested stakeholders in new concepts in a manner which they could understand. The concepts are (1) risk assessment, (2) modeling, (3) deterministic model, (4) probabilistic model, (5) frequency distribution, (6) uncertainty versus variability, (7) Monte Carlo method, (8) interpretation of probabilistic results, and (9) the advantages and disadvantages of each method.

The Methodology to elicit Stakeholder Opinion: There were two main components to the method used by the authors to address the above nine questions and to elicit opinions from stakeholders. One component was the creation of a primer with all steps (in both deterministic and probabilistic approaches), definitions, examples of concepts, and a detailed simplified case study of a current groundwater problem to illustrate the competing approaches. The other component was formation of a workshop of interested citizens, designed to inform them about the groundwater problem, to present two alternative approaches to investigating the problem, and to elicit their opinions about which approach was more understandable and reasonable. The contamination problem addressed the predicted magnitude of tritium contamination that may reach water wells in use by residents of an area close to the NTS. The tritium source was a nuclear device detonated below the water table, and although the groundwater contamination is important, it was used primarily as a vehicle for exploring the public's ability to grasp the probabilistic approach. In order to keep the focus on the probabilistic approach rather than on technical details, a greatly-simplified groundwater transport model was used to explain the science.

The Primer

The draft primer began with an explanation of the goals and components of the project, which included the primer itself and the workshop. The project outline was stated, followed by definitions of all terms that a lay person would need to know. The draft primer was laid out to address the nine issues stated above, then the deterministic and probabilistic approaches were explained and full examples were given for a case taken from everyday life. A final primer would be created after stakeholder input and comments were integrated into the draft edition. The following are examples of the level of explanation given in the primer.

<u>1. Risk assessment:</u> Risk assessment is an estimate of the number of persons in a given population whose deaths would be caused by a given hazard. The population must be exposed to the hazard by a transport mechanism, for example, by radioactive particles carried through the air from the hazard to the population. The amount of radiation one receives, called the dose, depends on the strength of the hazard, the time the population is exposed, the transport mechanism, and many other factors. The risk caused by a certain dose, usually given in incremental deaths (caused by the hazard) per million people, depends in turn on several other factors. Many of the factors necessary to calculate this estimate are unknown or at least not accurately known. The level of ignorance of these factors is called their uncertainty in today's language.

<u>2. Model:</u> A risk assessment model is a set of mathematical calculations usually performed by a computer. Since risk assessment is strongly model dependent, the primer explained the concepts of modeling in everyday language, stressing the fact that modeling is something everyone does informally. For example, when a teacher assigns grades based on "the curve", or when one calculates her car's average gas mileage, she is depending on a model. The equation *gasoline mileage* = *distance traveled* divided by the *number of gallons consumed* (mpg = mile ÷ gallons) can be thought of as a model for calculating our car's gas mileage.

3. Deterministic model: A deterministic model is one in which one single value is used for each variable, for example, we may want to calculate the gas mileage for our new VW bug. We filled the tank with 9 gallons of gasoline, and according to the odometer, we had driven 305 miles, so we use the above deterministic model, i.e., gas mileage = 305miles/9 gallons = 33.9 mpg. We put in one value for distance traveled and one for number of gallons and we got one value of gas mileage.

4. Probabilistic model: In the gas mileage example, we admit that we don't know if the tank was completely full before our trip or when we filled up after our trip, so there is uncertainty about the number of gallons actually consumed. In the past, we have squeezed in as much as another half gallon (0.5 gal) after the pump clicks off and sometimes as little as a tenth of a gallon (0.1 gal). Therefore, since we didn't squeeze at either fill up for this trip, we reason that there could be as much as 0.4 gallon (0.5 - 0.1) difference (either more or less!). Being budding scientists, we check the car's manual and see that the odometer only is accurate to plus or minus one percent (plus or minus 3 miles). Therefore, we know that the number of gallons can lie between 8.6 and 9.4 with 9 being the most likely (accounting for variations in pumps and other factors that we haven't yet experienced, the pump could click off even sooner or later) and the number of miles lies between 302 and 308 with equal probability. A probabilistic model uses all of this information. You don't yet know how, but you soon will.

5. Frequency distribution: A good way to understand distributions is to create one using a pair of dice. The possible outcomes of each roll of two dice are the numbers 2 (snake eyes) to 12. Roll the dice three hundred times (i.e., 300 trials) and write down the outcome for each roll, then count the number of times (the frequency) that each outcome occurs. Next, construct a graph with numbers from 2 to 12 on the horizontal axis and numbers from zero to the maximum frequency on the vertical axis such as in Figure 1. Draw in a vertical bar (for each number) whose length corresponds to its frequency and you have just created a histogram. If you divide each frequency by the total number of rolls (300) and enter those numbers on the vertical scale, you have created a *probability* distribution! Figure 1 shows the final result where the numbers above the vertical bars represent the frequency of the outcomes. That's all there is to it.

Figure 1 also includes the cumulative probability curve. It shares the same horizontal axis, but each point represents the sum of the corresponding bar on the frequency distribution (expressed as a percent of the total trials) and all bars on its left-hand side (hence the name *cumulative* probability.) The final bar on the right sums to 100% of the frequencies (or probabilities) since it sums all of the bars.

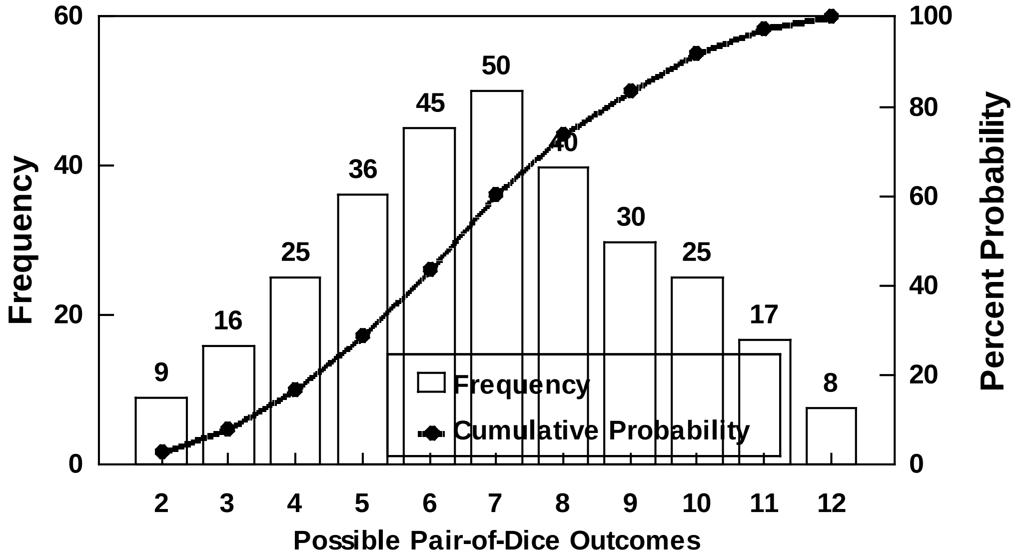

Figure 1. Experimental outcomes from rolling a pair of dice 300 times.

To extend this explanation to our gas mileage example above, we use distributions to describe the information in step 4. The number of gallons of gasoline consumed can be expressed by a distribution which approximates the famous bell curve (Figure 2a). It shows that there is almost no likelihood below 7.75 gal and above 10.25 gal, but a high likelihood (67%) between 8.6 and 9.4 with a maximum at 9.0. Furthermore, the probability of the fill up being between 8.2 and 9.8 is 97% because we allow for the possibility that the variability where the pump shuts off is more than we experienced previously.

The distribution for the miles traveled is given by the "uniform" distribution (figure 2b), which says that we know that the correct odometer reading is between 302 and 308 miles, but we haven't a clue as to which is more likely, therefore, we use a distribution that makes all values in the range equal, therefore, all bars in this distribution are the same height, reflecting their equal probabilities. Step seven tells us what to do with the distributions.

6. Uncertainty versus variability: The difference between uncertainty and variability is often misunderstood and can cause confusion in analyzing complex problems. Uncertainty is simply the lack of knowledge of the single value of a quantity, whereas variability describes the fact that the variable takes on many values in space or time. The following are examples:

Uncertainty: Assume that a contaminant (e.g., tritium) is injected (by a bomb explosion at the Tybo event) within the aquifer. We have x-ray vision (ordinarily reserved for superpeople) that allows us to observe the movement of the contaminant (an elongated volume of contaminated water, which is called a groundwater plume.) We note the exact time when it was created and begins to move with the groundwater, then we watch it until its center arrives at a water well in Oasis Valley and we note the exact time when the plume arrives. We measure exactly the distance between injection point and the water well and divide it by the time required to get there. We now have the exact average speed ($v_{average}$) of the flow. In reality, however, we would never be able to measure $v_{average}$, so we estimate it from prior models, expert opinion, other studies, or we simply take a wild guess. We would never know if any of these methods gives us the correct value for $v_{average}$. In other words, there is uncertainty attached to our estimate of $v_{average}$, but it has <u>one unique exact value</u>, as witnessed by Superperson. In other words, there is no variability to $v_{average}$ for the one bomb and the path it traversed, but there is a large uncertainty because we are estimating it from lousy information.

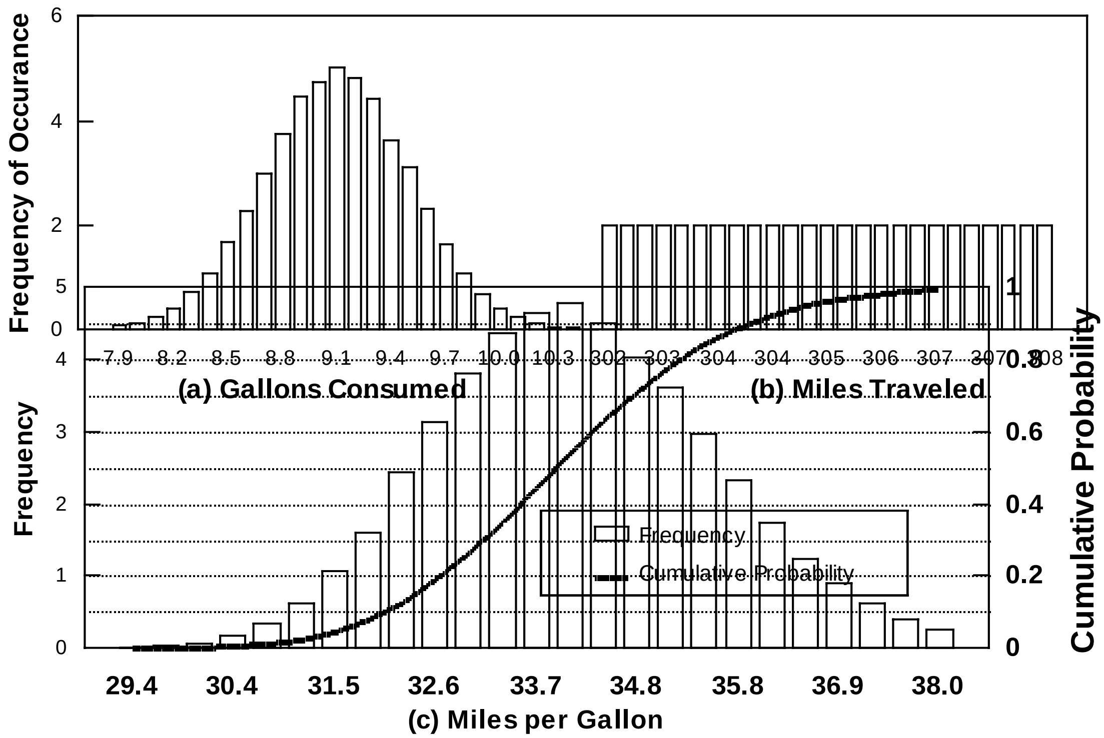

Figure 2. Probability distributions for gallons consumed (bell-shaped curve) and for total miles traveled (uniform distribution) are given in Figures 2a and 2b, respectively. Figure 2c shows the results of the Monte Carlo simulation in the form of trial frequency and cumulative probability distributions.

<u>Variability</u>: Hydraulic head (*h*) is a scalar quantity, which is a measure of the potential energy that groundwater has at a specific location in an aquifer. For an aquifer, at any point in time, the value of *h* varies in all three directions, that is, it is a variable which takes on different values at different locations and can also take on different values at each location at different times in a given aquifer. When we perform a numerical model of the aquifer, one must assign values to many locations. There is usually uncertainty in each of these values because of measurement error or because they are estimated, but that is different than variability. The variability describes the

different values of the variable at the different times and locations, not the lack of knowledge of those values.

Note the difference between uncertainty and variability. Uncertainty describes what we don't know about the value of something, whereas variability means that it changes in time and space.

7. Monte Carlo Simulation: The Monte Carlo method is a trivial, but very powerful, embellishment to the deterministic model. In steps two and three above, the deterministic model for gasoline mileage (MPG = distance traveled ÷ gallons consumed) produced one output corresponding to the single values of distance traveled and gallons consumed. The Monte Carlo Simulation simply repeats that calculation (each repetition is called a trial) as many times as we tell it to (we used 20,000 trials), with the additional feature that each time it recalculates MPG, it chooses different values from the distributions for distance traveled and gallons consumed. The distributions influence what values it chooses, for example, the Monte Carlo routine more often will select values of gallons consumed close to 9 (the maximum) than values near 8 or 10. That's why we create the distribution, to instruct the Monte Carlo routine how to pick the values. On the other hand, it will pick values of distance traveled randomly between 302 and 308 miles because there are no preferential values. The Monte Carlo routine (Crystal Ball, 1996) stores the value of MPG for each trial, then produces a frequency histogram of the results (as we did for the dice outcomes) as shown above in Figure 2c.

8. How does one interpret probabilistic results? Probabilistically, of course! We present the output results in two ways in Figure 2c. One is the output frequency distribution the other is a *cumulative* frequency distribution, which is the same information packaged differently. The interpretation depends on the question that is asked, and several can be asked. For example, if we want to brag about our gas mileage, but we want to be 95% sure that we are bragging safely (i.e., a very conservative estimate), we could pick the value of mileage (31.16 mpg) from the histogram below which 5% of the frequencies lie. That means there is only a 5% chance that we have overestimated the mileage, and a 95% chance that we are underestimating because 95% of the mileages are above 31.16 mpg. That would be a very safe (conservative), modest claim. On the other hand, an immodest claim would be that there is a 5% chance that the mileage was *above* 36.2 mph, and if we were satisfied to only be 50% safe, we could claim between 33.32 and 34.04 mpg.

The point here is that this analysis of gas mileage takes into account the uncertainty in our knowledge of the distance traveled and the amount of gasoline consumed, it displays the results of 20,000 trials in one graph, and it allows one to make realistic claims about the car's performance because we have considered all of the information at our disposal.

9. What are the limitations of the probabilistic method? The major limitation to using the probabilistic method is the ability to properly define the distributions for the variables or parameters in the problem. Our example above is simple, but nevertheless, one could argue that our choice of a near-bell-curve distribution for the gasoline consumption could not be justified. One could, perhaps, just as well have chosen another shape of distribution, and so it goes. When very little is known about a problem (i.e., very few data exist) assigning a distribution becomes an

educated guess. It will be up to the experts to decide whether an educated guess embodying data and expert opinion is better than a single value. But, that is the major problem.

A second limitation in the use of the probabilistic method occurs in very large models where each calculation is computer intensive, such as is the case in numerical groundwater transport models. Using the Monte Carlo simulation in these cases becomes too time consuming to be practical.

The Case Study

In 1975, a nuclear bomb, named Tybo, of magnitude between 200 and 1,000 kilotons was detonated in the groundwater (below the water table) in Western Pahute Mesa. It is speculated that contaminants (mainly tritium) produced by the bomb travel with the groundwater to a point 30 kilometers away in Oasis Valley and may be intercepted in the future by one of the water wells used there for irrigation and drinking water. The 30 kilometer route shown in Figure 1. Therefore, high levels of tritium (above a concentration of 20,000 pCi/l) pose a health threat to humans in Oasis Valley.

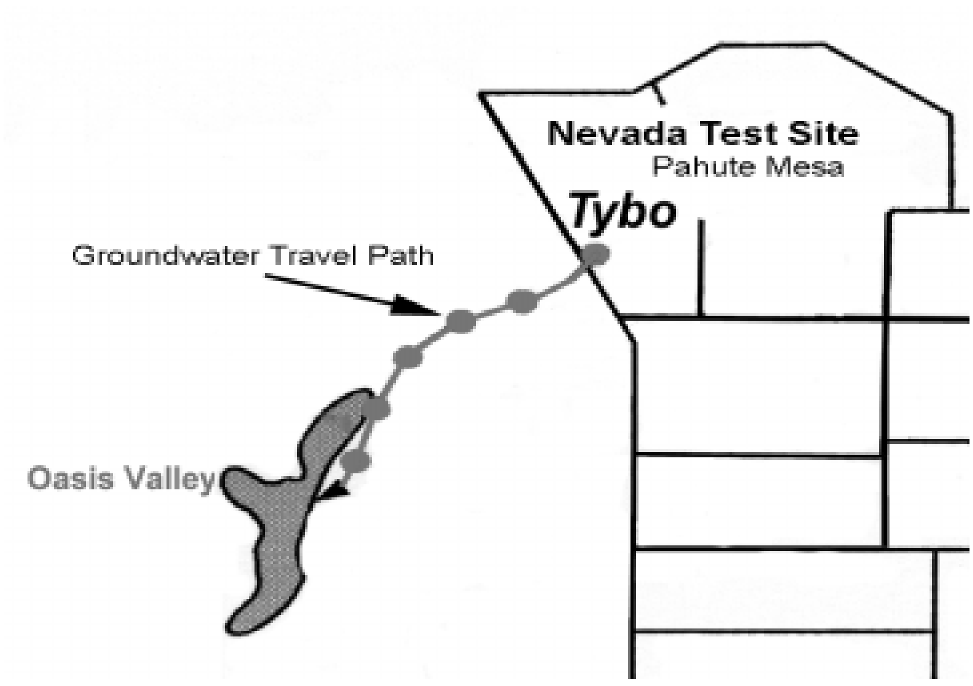

Figure 3. Thirty-kilometer groundwater flow path from Tybo to Oasis Valley used to illustrate the probabilistic approach (Figure taken from U.S. DOE, 1997.)

Goal: Our goal is to estimate the concentration of tritium in a contaminant plume that travels from Tybo to a receptor point in Oasis Valley. The estimate should take into account variability (of hydrological parameters) and uncertainty (of contaminant plume transport speed and spreading) and should incorporate all known information about the problem.

Tritium Transport Description: The contaminant plume is assumed to begin in a spherical cavity (formed by the explosion) that is filled with tritiated water (tritium dissolved in water.) The cavity walls are fractured, so that the spherical plume of tritiated water moves with the groundwater flow towards its destination in Oasis Valley. During its journey, the tritium diminishes by radioactive decay, and dilutes by physical spreading (dispersion) of the plume. The dispersion occurs in three dimensions, but mostly along the direction of travel such that the spherical plume becomes an ellipsoidal plume.

Approach: We created a greatly-simplified, but plausible, contaminant transport model to illustrate the probabilistic procedures. Our transport model is a mathematical equation that calculates the tritium concentration by taking into account the original cavity radius (R) and tritium concentration (C_o), radioactive decay (half-life = 12.5 years), and the three dimensional dispersion (d_x, d_y, and d_z) of the tritium plume. The model is:

$$C(C_o,t,R,d_x,d_y,d_z) = C_o \bullet e^{-.695t/12.5} \bullet [4/3\pi R^3]/[4/3\pi d_x d_y d_x]$$

which is **Final Concentration** (pCi/liter) **=** **Original Cavity Concentration** (pCi/liter)

- **Radioactive Decay Factor** (12.5 year tritium half life)
- **Dispersion Factor** (Cavity Volume/Ellipsoid Volume)

The radioactive decay factor depends on the time duration of plume movement (t), which is determined by the speed of groundwater flow and the size of the plume is increased by the 3-d dispersion which is caused by microscopic irregularities in the aquifer medium. The zone in which 99.7 percent of the contaminant mass occurs is described by an ellipsoid with dimensions measured from the center of mass, of $d_x = (2D_x t)^{1/2}$, $d_y = (2D_y t)^{1/2}$, and $d_z = (2D_z t)^{1/2}$, and given that $D_x = \alpha_x v$, and $d_x = vt$, the distances from the center of mass can also be written $d_x = (2\alpha_x d_t)^{1/2}$, etc., where d_t is the total distance traveled from source to reception (30 km). The volume after distance d_x is $4/3\ \pi d_x d_y d_z$. The α are dispersivity coefficients whose values are assumed to be α_x (direction of travel) = 500 meters, α_y (lateral) = 50 meters, α_z (vertical) = 5 meters. R is assumed to be 100 meters.

Although some of the workshop participants were not comfortable with mathematics, the four contributions to the final concentrations were explained and were sufficiently well understood for the purpose of the demonstration.

First, the equation was treated as a deterministic model by inserting mean values for the parameters and producing a table (Table 1 below) corresponding to a range of groundwater flow speeds (taken from the literature) from 2 to 1,280 meters/year.

Table 1 gives the decay adjusted and the final (adding dispersion) concentrations. We see that the major decrease in concentration is caused by the radioactive decay, but that another three and a half orders of magnitude of dilution occur because of dispersion. Based on this simple analysis, if the average speed were less than 640 meters/year, we could just about forget about danger at Oasis

Valley because the drinking water standard allows a concentration of 20,000 pCi/liter, which is only exceeded if the groundwater speed is greater than 640m/y.

Table 1. Tritium Concentration at Oasis Valley

Average Speed (in meters/year)	**Travel time (years)**	**Decay adjusted (in pCi/liter)**	**Final Concentration (in pCi/liter)**
2	15,000	≈0.0	≈0.0
20	1,500	6×10^{-28}	1.2×10^{-31}
40	750	7×10^{-10}	1.4×10^{-13}
80	375	0.8	1.5×10^{-4}
160	188	25,300	4.8
320	94	4,600,000	871
640	47	62,000,000	11,700
1,280	23	226,000,000	43,000

Adding the dispersion factor produces two different effects. One is dilution and the other is elongation of the plume. The dilution lowers the concentration, but the elongation means that some tritium will arrive sooner than the main part, hence it will not decay as much. The two effects tend to counter each other in the advanced part of the plume and complement each other in the retarded part. Such effects complicate the problem, but we are not concerned about that here.

Probabilistic Model. Now we will use exactly the same equation, but we will use it in a Monte Carlo routine. First, we will simplify the arithmetic by combining terms, writing time (t) as (distance traveled)/(average speed) = d_t / $\bar{\mathbf{v}}$ ($v_{average}$) where d_t = 30,000 m (30 km) to get .

$$C = 2.17 \times 10^{-6} C_o R^3 \, e^{-[1663/\bar{\mathbf{v}}]} \alpha_x^{-3/2}$$

where $\bar{\mathbf{v}}$ is expressed in meters/year and R and α_x are expressed in meters.

We will vary the initial Concentration C_o, flow speed $\bar{\mathbf{v}}$, cavity radius R, and the dispersion constants α_x, α_y, and α_z (which reduce to only α_x because they are related.)

We assume that C_o varies from 0.083 - 830 x 10^8 pCi/liter with equal probability (a uniform distribution.) We do not know the value of $\bar{\mathbf{v}}$ (it has uncertainty, but no variability) but we would estimate its distribution by using geostatistical simulations (not explained here). The hydraulic conductivity (which is usually represented by a log-normal distribution) mainly determines $\bar{\mathbf{v}}$ and our geostatistical simulations of velocity would use such a distribution, but when we construct a distribution for $\bar{\mathbf{v}}$, the *Central Limit Theorem* tells us we will end up with a Gaussian (bell-shaped curve) distribution. We arbitrarily assume that the mean and standard deviation for this distribution are 160 m/year and 100 m/year, respectively. By that assignment, we are saying that the probability is 68.3% (± one standard deviation) that $\bar{\mathbf{v}}$ lies between 60 and 260 m/year, and that the probability is 95.4% (± two standard deviations) that it lies between 2 (we do not consider speeds less than 2 m/y) and 360 m/year.

We arbitrarily assign R a Gaussian distribution with its mean value R_{mean} = 100 m and its standard deviation equal to 10 m. Likewise, we assign α_x a triangular distribution beginning at $\alpha_{x(minimum)}$ = 250 m, the peak $\alpha_{x(peak)}$ = 500 m, and $\alpha_{x(maximum)}$ = 600 m.

We enter our model equation into an Excel spread sheet and perform the Monte Carlo simulation by using 20,000 trials. The results are shown graphically in Figure 4 in the form of relative (grey vertical bars, right-hand scale) and cumulative (heavy black line, left-hand scale) probability distributions for tritium concentration. For exact numerical values, one must refer to tables generated by the Monte Carlo program.

What does it all mean? The Monte Carlo output, i.e., the relative and cumulative probability distributions encapsulate much of the information produced by the probabilistic approach. The relative probability tells us that the most likely concentration to arrive at Oasis Valley is less than 26,000 pCi/l (taken from computer generated tables) which is slightly greater than the drinking water standard. The cumulative distribution tells us that the probability is 50%, 85%, and 95% that the concentration is below about 400, 20,000, and 65,000 pCi/liter, respectively (values also taken from tables).

Sensitivity Analysis: A powerful feature of the probabilistic approach is the sensitivity analysis which gives the percent of the total variance (a measure of uncertainty in this case) that is contributed by each of the distributed variables. Table II illustrates that 97% of the variance is due to the uncertainty in the groundwater speed, and that the other three variables contribute very little. That, of course, is due to the travel time's (distance/speed) influence on radioactive decay, which is easy to see in this simple model.

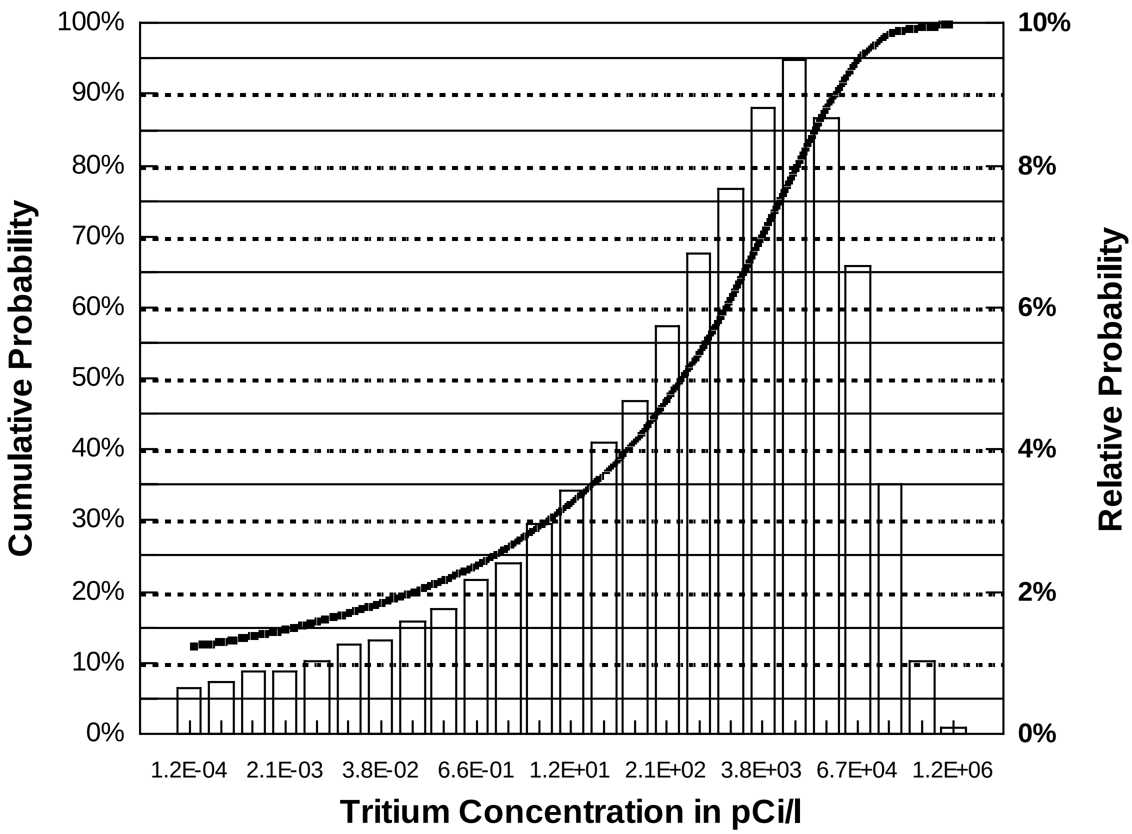

Figure 4. Monte Carlo results of probabilistic approach applied to prediction of transport of tritium-contaminated groundwater from Pahute Mesa on the Nevada Test Site to Oasis Valley (off-site location). Groundwater speed, initial tritium concentration, initial cavity radius, and hydrodynamic dispersion were treated as probabilistic input.

It does not, however, mean that the other variables are unimportant, rather only that their contribution to the variance (uncertainty) of the output is small. In fact, one sees from Table II that as one decreases the source-to-receptor distance from 30 km to 0.5 km, the initial concentration of the tritium becomes the most important contribution to variance, which cannot be seen so easily from our model. The lesson is that the dimensions of the problem as well as the amount of uncertainty in the variables strongly affect the relative variance in the final result. There are many other details and subtleties that are not mentioned because of space limitations.

Table II. Sensitivity Study: Percent Contribution of Variance

	Source-to-Receptor Distance (km)						
Variables	**30**	**15**	**10**	**5**	**3**	**2**	**0.5**
Groundwater Speed 97%	90%	83%	63%	41%	31%	6%	
Initial Concentration	2%	8%	14%	30%	46%	53%	73%
Dispersion Coefficient	1%	1%	2%	3%	5%	5%	10%
Initial Cavity Radius	0%	1%	2%	4%	8%	10%	11%

Risk: So far we have calculated the probable concentration of tritium at Oasis Valley. Risk due to drinking the contaminated water at Oasis Valley for one year can be calculated from the equation

Risk = [**C**(pCi/l)]·[**intake** (l/year)]·[**dose conversion factor** (mrem/pCi)]·[**risk coefficient** (risk/mrem)]

To calculate the risk probabilistically, we would assign distributions to the other parameters and let the Monte Carlo routine perform the trials. The result is a distribution of risk which risk managers can use to make decisions. Because of paucity of space and because it provides no new insight into the probabilistic approach, we will not demonstrate the risk results.

Stakeholder Workshop : The workshop (split into two groups) was comprised of 20 participants having a wide range of age, education, and experience. Although they were biased toward technical proficiency (50% have technical degrees), it was felt that they were representative of the stakeholders who would make the effort to understand risk assessment. The primer was well received by the majority of them with most comments addressing style rather than content. Some felt that some of the examples were silly while less technically proficient participants felt that the "silly" examples helped them understand the concepts. But all felt that the primer was a valuable asset in understanding the groundwater problem and the competing risk assessment approaches. The workshop (three two-hour sessions) was invaluable to the participants for clarifying issues and to the presenters for evaluating their progress and eliciting their opinions.

The more technically proficient participants gained a deep understanding of the problem, and agreed that the probabilistic approach lends itself to a greater level of understanding and provides a more realistic management tool. There was no disagreement from others, although their understanding was not as deep. The only disagreement was over the use of the probabilistic method as a screening tool. Some felt that the deterministic approach was a faster method and gave adequate results for screening, while others felt that for most models, the probabilistic approach was so easily implementable by using modern computers and software, that there is no need to bother with the deterministic method. All agreed that the probabilistic method is more realistic, mostly because it allows the inclusion of a more complete set of information. Likewise, all agreed that, when the probabilistic method is fully understood and when the variables in the model can be described without resorting to wild guesses, the result will be much improved over the single deterministic result, thus providing a more efficient basis for making management decisions.

Summary: The primer and workshop appeared to have accomplished their intended tasks, namely they instructed the participants in the two risk assessment approaches and evoked their opinions of deterministic versus probabilistic methods of evaluating risk. They agreed generally that the probabilistic approach 1) uses the maximum amount of information, 2) can be understood by, and communicated to, non-professionals, and 3) provides a realistic tool for making management decisions. All agreed that the probabilistic approach is superior to the deterministic, worst-case approach with the caveat that one must be careful in assigning distributions, i.e., that poorly understood distributions may not be superior to poorly understood single values.

We feel that we have shown, through the method describe in this paper, that the perception exists among the participants in our workshop that the probabilistic method can effectively communicate risk and the associated uncertainty.

FOOTNOTES

[a] Nevada Risk Assessment/Management Program, University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV. 89031.

[b] The Nevada Risk Assessment/Management Program (NRAMP) is a joint effort of the Harry Reid Center for Environmental Studies (HRC) at the University of Nevada, Las Vegas, and the firm of E. J. Bentz and Associates of Springfield, Virginia, under the auspices of the U. S. DOE's EM Program Office of Science and Risk Policy (Grant # DEFG 01 96 EW 56093).

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