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METHODOLOGY FOR ESTIMATING ACCIDENTAL RADIOACTIVE RELEASES IN
NUCLEAR WASTE MANAGEMENT

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The estimation of the risks attendant to accidental radioactive releases is a necessary step in the assessment of the safety of any nuclear waste management system or subsystem. The amount of a radioactive nuclide and the manner in which it is released under a given set of conditions serve as part of the input data to the subsequent transport, demographic, and dosage models. The result of these model calculations gives a measure of the consequence of the release. This measure may be some dosage rate, or the number of expected fatalities, or some other measurable impact on the biosphere. In this context risk is often defined as the expectation value of the consequence. In equation form

$$\text{Risk} = E\{q\} = \sum_i q_i \cdot p_i = \int_{\text{all } q} q \cdot p(q) dq$$

where q is the consequence, and p_i is the probability that q_i occurs in the discrete case, and $p(q)$ is the probability density function of q in the continuous case.

Another frequent manner of considering the measure of risk associated with a system is by construction of a risk curve (1-3). The probabilities of all incidents leading to

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consequences that equal or exceed a certain value are summed or integrated and this overall probability is plotted against that value of the consequence. In mathematical terms $P(Q \geq q)$ is plotted against q ; where q is a chosen value of the consequence, and $P(Q \geq q)$ is the overall probability for the system that the consequence equals or exceeds q . Sometimes frequencies instead of probabilities are plotted against the value of the consequence.* In order to evaluate radiological risk, therefore, it is necessary to have estimates both of the radioactive release and the probability or frequency of its occurrence.

Radioactive releases may be classified according to the mechanism of release into three different types: 1) dissolution 2) vaporization, and 3) dispersion into the air as fine particles. It is fairly obvious that the release of the same amount of radioactivity of different nuclides could result in different dosages since either the nature of their radiations, their half-lives, or their chemistries are likely to be different. It should also be fairly obvious that a unit of radioactivity of the same nuclide released by each of the above three mechanisms would probably result in three different dosages because of the different pathways followed to and through the biosphere. Each type of release would have a different factor relating amount released to dosage for a unit release of the same nuclide. Therefore, in considering an accidental release of radioactivity one must not only consider the amount of each nuclide released but also the relative amounts of each nuclide that may be released by the different mechanisms.

For a small enough subsystem one can consider the release function model independently of the transport, demographic, and dosage models. We can develop consequence curves for probability or frequency as a function of the amount of radionuclide releases. These results can then serve as input to the succeeding models calculating ultimate impact on the biosphere.

In order to elucidate the methodology we will consider a simple model consisting of a radioactive waste form enclosed in a barrier system. This system is subjected to a certain type of accident that may result in a radioactive release. For simplicity we will consider just the release of a single nuclide by one mechanism. Let x represent a vector variable, the elements of which are values of parameters for the conditions of the accident that affect the release. The frequency density function for this type of accident is given by $f(x)$. In actuality, statistics on

*That is all right as long as it is kept in mind which one is being used when making comparisons or estimating expected values.

frequencies of accidents can rarely be found where x represents more than one, or at most two joint parameters. Therefore, again for simplicity, we will choose x to be some single parameter that serves as a measure of the "severity" of the accident. We will also work here with fractional releases, as the total source term will vary in practice.

The waste form serves as a source term. Let s represent the fraction of the nuclide that would be released from the source if there was no barrier system. For a given value of x there will, in general, be a distribution of values for s . The conditional probability density function for the fractional release from the source, s , for a given x can be expressed as $p(s|x)$. (The less complete the description of the conditions of the accident provided by x , the broader the distributions of s are likely to be.)

For each value of x , there will be some fraction of times that the barrier system is breached, $b(x)$. In other words, $b(x)$ is the probability of breaching the barrier for a given x . There will likely be some threshold value of x for $b(x)$. The function $b(x)$ will then increase monotonically as x increases until it reaches a value of one or approaches one asymptotically.

If the barrier system is breached, some fraction of that radioactivity that was released from the waste form will pass through the barrier. If this fraction is designated as r , then for each value of x there will be a distribution of values of r . The conditional probability density function of r will be given by $P(r|x)$. We will assume that r and s are independent.

The overall fractional release from the system t , assuming a barrier breach, is equal to the product of r and s , or

$$t = r \cdot s.$$

We need now to generate the function $P(T \geq t)$, the probability that the overall fractional release equals or exceeds the value of t , so that we may plot $P(T \geq t)$ versus t . We may obtain our desired results by using extensions of the following relationships involving probability density functions, remembering that r , s , and t all have limited ranges extending from 0 to 1.

$$p(t)dt = \int_{\text{all } x} p(t,x)dt dx$$

$$p(t,x)dt dx = p(t|x) \cdot p(x)dt dx$$

$$P(T \geq t|x) = \int_t^1 p(t|x) dt$$

$$P(T \geq t) = \int_t^1 p(t) dt = \int_{\text{all } x} P(T \geq t|x) \cdot p(x) dx$$

To obtain $P(T \geq t|x)$ we first consider the probability distribution function of a random variable that is the product of two other random variables:

$$z = u \cdot v$$

Where $p(u)$ and $p(v)$ are continuous from 0 to ∞ , the cumulative probability distribution of z is given by:

$$P(Z \leq z) = \int_0^{\infty} p(u) \left(\int_0^{z/u} p(v) dv \right) du$$

In the case where u , v , and z are all limited to the range from zero to one

$$P(Z \leq z) = \int_0^z p(u) du + \int_z^1 p(u) \left(\int_0^{z/u} p(v) dv \right) du, \quad z/u \leq 1$$

and

$$P(Z \geq z) = 1 - P(Z \leq z) = \int_z^1 p(u) \left(\int_{z/u}^1 p(v) dv \right) du, \quad z/u \leq 1$$

where the integrals with respect to v are evaluated only for values of $z/u \leq 1$. Since t is also a product of two random variables r and s , we can use a similar treatment to obtain $P(T \geq t|x)$. If we remember that r is the fractional release through the barrier assuming a breach, and that $b(x)$ represents the probability that the barrier system will be breached, we may write

$$P(T \geq t|x) = \int_t^1 p(r|x) \left(\int_{t/r}^1 p(s|x) ds \right) dr \cdot b(x), \quad t/r \leq 1$$

and

$$P(T \geq t) = \int_{\text{all } x} \left[\int_t^1 p(r|x) \left(\int_{t/r}^1 p(s|x) ds \right) dr \cdot b(x) \right] \cdot p(x) dx, \quad t/r \leq 1$$

where the inner integral is evaluated only for $t/r \leq 1$, and the expression in the square brackets is integrated over all values of x .

Usually one knows very little about $p(r|x)$ and $p(s|x)$. However, it is generally much easier to estimate expectation values of r and s as a function of x . If we consider the distributions of r and s as being concentrated at the expectation values, then $t(x) = r(x) \cdot s(x)$ and

$$P(T \geq t) = \int_x^\infty b(x) \cdot p(x) dx$$

In essence we have assumed delta-functions for the conditional probability distributions of r and s . This treatment tends to underestimate the probabilities of extreme low and extreme high values of t while still leading to the same overall expectation value for t .

In order to be able to plot frequency rather than probability that a consequence exceeds a certain value the frequency density function of x should be used in the above expressions wherever the probability density function appears.

So far only preliminary work has been done on programming the above equations for the computer and carrying out calculations. The results of two test calculations are shown in Fig. 1. The same frequency density function for x was used in both sample calculations and was based on data given for imparted velocity changes in truck collision accidents in the Sandia report on accidents involving large packages(4). This frequency function was chosen to lend some semblance of realism to the test calculations, but the results at this stage should not be considered representative of such accidents in transporting spent fuel or high level waste. The ordinate in Fig. 1 is the frequency with which the overall fractional release is greater than or equal to the value t , $F(T \geq t)$. The units here are (transport miles)⁻¹ but could just as well be considered arbitrary. The abscissa is t , the

fractional release. Different curves for b as a function of x and peak values of r and s as functions of x were used in the two calculations, and were arbitrarily assumed. In both test calculations three different conditional probability density functions were assumed for r and s . The three were a delta-function, a symmetrical triangular distribution, and an asymmetric triangular distribution. The two triangular distributions were chosen for their ease of calculation and as indicative of the effects produced by different distributions.

The parameters used for the two test calculations were chosen primarily for test run purposes and not necessarily to represent any particular cases. There are some things apparent from the results. As might be expected, for the high-release, low-probability occurrences the delta-function gives the lowest frequencies while the asymmetric distribution gives the highest frequencies. The differences in the results for the three assumed conditional probability functions can vary greatly depending on other parameters. Calculations of this sort can be used in sensitivity and uncertainty studies as well as setting the stage for calculations on baseline systems. We expect to continue and expand these calculations in the near future.

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Figure 1. Results of two test run calculations. The ordinate is the frequency with which the overall fractional release is greater than or equal to some value t . The abscissa is t , the overall fractional release. (Units for the ordinate may be considered arbitrary.)