RADIOLOGICAL EVALUATIONS IN ROUTE SELECTION FOR HIGH-LEVEL NUCLEAR WASTE TRANSPORTATION

Kyle H. Turner, PhD
Daniel D. Moreno
Dames & Moore

ABSTRACT

Explicit consideration of the radiological doses which could result from potential in high-level waste transportation accidents is important in route selection both as an analytical tool for the decision-maker and as an enhancement for public acceptance. This paper describes a generalized approach which could be implemented at all stages of the route selection process, and presents results of the application of a simple dose/routing model to a hypothetical transportation data set.

INTRODUCTION

Transportation may prove to be one of the most controversial aspects of the high-level nuclear waste (HLW) program because of the large portion of the country through which shipments must pass and because of the large number of people who perceive they may be affected. The single most often-voiced concern relates to transportation accidents and their potential impacts on persons in the vicinity of HLW transportation routes. Accordingly, dose analysis of alternative transportation routes can be an important component of both the technical and institutional aspects of the HLW route selection process.

GENERAL DOSE CALCULATION CONSIDERATIONS

Calculated dose from a given radioactive materials release can be expressed in the general form

$$D = DCF \times DF \times Q \qquad \text{(Eq. 1)}$$

where (units given are examples for illustration only, other units may apply to actual calculations):

D = Dose or dose rate (mrem or mrem/hr),

DCF = Dose conversion factor (mrem/pCi/liter)

DF = Dilution factor applicable the the pathway of transport from source to receptor (1/liter),

and

Q = Quantity released or release rate (pCi or pCi/hr)

It should be noted that each factor on the right side of Eq. (1) is isotope-dependent; thus, the dose from each isotope present must be calculated and summed to obtain a total dose for a given release. In order to simplify discussions in this paper, this summation is not expressed explicitly, and the reader should note that, in any dose equation presented herein, the summation over the isotopic composition of a release is implied.

The dose conversion factor (DCF) relates the dose received by an individual to the radioisotope concentration present at the point of exposure. DCF's are unique to the organ for which dose is being calculated and to each isotope present; they have been derived from experimental study and are available in the literature. Thus, the DCF's do not depend on either site-specific conditions or design parameters applicable to a specific release.

For transportation-related events, the source term (Q) is derived from consideration of cask design, accident parameters, the isotopic inventory in spent fuel or waste, and the potential pathways of exposure (i.e., airborne (particulate and gaseous), liquid, and direct radiation).

Radioactive materials are diluted in transit from the point of release to the point at which exposure occurs; the dilution factor (DF) quantitatively reflects this process. DF's are specific to each transport pathway, and depend on processes such as atmospheric dispersion, plume deposition, hydrologic dilution, geometry, radioactive decay, and chemical reactions. Each of these processes (as well as the transport pathways which may apply) depend on environmental conditions extant at the point of release, or, in the case of HLW transportation, the point along a route at which an accident occurs.

DOSE CHARACTERIZATION OF ALTERNATIVE ROUTES

In order to examine the use of dose calculations as a basis for evaluating alternative HLW transportation routes, is first necessary to examine a single route element (Fig. 1). If it is assumed that environmental conditions governing the dilution process are invariant within route element i, potential transport pathways and receptor points can be identified and a resultant dose, Di, calculated.

It should be noted that this analysis assumes that a release inventory, Q, has been calculated; however, Q does not vary spacially (i.e., Q is the same for each route element), and, for routing purposes, route element i can be equally well characterized by dose from a unit release, or D_i/Q. Remaining discussions in this paper are applicable to either case, and Di may be considered interchangeable with D_i/Q.

Once doses have been calculated for each element in an alternative route, a "composite" dose for the route can be obtained by summing the individual element values:

$$D_{\text{route a}} = \sum_{i=1}^{n} D_i \qquad \text{(Eq. 2)}$$

where n is the number of elements in Route a. By repeating this process for each of the routes under consideration, the composite doses form a basis for comparing and/or ranking the alternatives. Accidents on routes with lower composite doses would be expected to have less severe consequences, on the average, than those occurring on routes with higher composite doses. Thus, the composite dose con be used as one measure of the overall suitability of the route.

Because the exposed population is higher for accidents near populated areas, another appropriate measure for route suitability can be derived by using the population dose as the basis for evaluations. In this case,

$$D^{pop}_{route\ a} = \sum_{i=1}^{n} \sum_{j=1}^{m_i} D_i \times P_j \quad \text{, (Eq. 3)}$$

where m_i is the number of population centers potentially affected by a release occurring at route element i, and P_j is the population residing in population center j.

ENVIRONMENTAL DATA AND THE DILUTION FACTOR

It will be recalled from examination of Eq (1) and the above discussions that changes in calculated dose for one route element versus another occur only because of changes in dilution factors applicable to conditions within them. Thus, the composite dose is a measure of the environment's ability to disperse releases along a route. Functionally, then, the most critical aspect of the analysis described herein is the identification of potential pathways through which accidentally released radioactive materials may travel and the quantification of dilution which occurs in transit to the point of exposure.

Compiling this environmental data is especially difficult for transportation accidents because releases could occur anywhere along thousands of miles of the network. In general, each route element presents a different set of exposure probabilities, pathways, and dilution-in-transit scenarios. A rigorous assessment of potential doses from transportation accidents requires a thorough characterization and cataloging of land and water use, and of demographic, meteorologic, and hydrologic data over literally thousands of miles of the transportation network -- an obviously infeasible task in the early stages of HLW transportation planning and an imposing one even when specific routes have been identified.

Because this route characterization method relies on a direct measure of impact(dose), however, different data sets can be used at different stages of the routing process. For example, national-level, summary meteorological and hydrological data can be used to provide a generalized characterization of the overall reactor-to-repository area of interest. As the routing process narrows the scope of investigations, increasingly detailed and, eventually, site-specific data can be used to update results. Also, a different level of data detail can be used for different route elements, allowing more detailed study of particularly problematic route elements where, for example, micro-meteorological conditions are adverse.

In short, the method is both "vertically" (different levels of data detail can be substituted at different stages of the routing process) and "horizontally" (different data sources can be accommodated in different route elements) integrated -- any combination of environmental data sets can be used to obtain the dose characterization of alternative routes. Virtually any available data set can be incorporated into the route composite dose/alternative route analysis at any phase of the HLW transportation routing process; thus the data collection and analysis efforts can be tailored to the level of detail at which routes are being studied.

A HYPOTHETICAL APPLICATION

The overall methodology described in the preceding paragraphs provides a generalized approach for incorporating the consideration of radiological impacts from accidents in HLW route selection. Technical characteristics of any detailed approach will depend on data and resource availability and the status of the routing process itself. In order to examine the potential utility of the composite dose approach, however, a simple model was applied to a hypothetical data base to demonstrate some of the model's capabilities and to demonstrate that meaningful results can be obtained using very generalized data.

Figure 1 provides a schematic of the hypothetical route matrix, environmental conditions, and population distributions used in the demonstration; both atmospheric and liquid releases and were considered.

Atmospheric dispersion was modeled using the equation (1)

$$DF = \frac{1}{Pi\ sy\ sz\ u} \quad \text{(Eq. 4)}$$

where

Pi = 3.14159

s_y,s_z are standard deviations describing Gaussian concentration distributions in the crosswind and vertical directions, respectively

u = average wind speed.

The terms s_y and s_z have the form

$$s = 10^{C_1 + C_2 \log(x) + C_3 [\log(x)]_2} \quad \text{(Eq. 5)}$$

where x is the distance downwind from the point of release and the constants C_1, C_2, and C_3 depend on the Pasquill stability class (2); values for these constants were taken from those published by the Atomic Energy Commission.

The following meteorological conditions were assumed to apply in each of the three dispersion zones (wind speeds are given in meters/second).

Dispersion Zone	Stability Class	WindSpeed
1	D	2
2	D	5
3	F	5

Wind roses in each of the dispersion zones were assumed to be equi-directional, i.e., the probability of wind blowing in a given direction is the same as that for any other direction. Population levels for each of the three hypothetical population centers are given on Fig. 1.

Liquid releases are diluted by receiving river flow volume, by mixing with the flow from tributary streams between the point of release and the point of exposure, and by radioactive decay in transit. In practice, detailed streamflow data would be used to model these environmental transport phenomena. For the hypothetical application, this process was represented by assigning each river segment an assumed dilution factor which would apply to liquid releases in transit from an accident location to the drinking water withdrawal point; population doses were calculated based on the assumption that the river at this point is the sole drinking water source for Population Center 3.

Using the assumptions and analytical methods described above, the hypothetical study area was subdivided into grid cells, and the population dose resulting from releases in each grid cell calculated; the results of this process are depicted on Fig. 2. It will be noted that doses peak dramatically near the population centers, indicating, as expected, that routes proximal to them are unfavorable. It will also be noted that noticeable differences in calculated population dose also occur in areas away from the centers; this indicates that some composite dose advantage may be gained by judicious routing in these areas, as well.

In order to investigate the routing possibilities, an analysis was run to search for the optimum (least cumulative dose) route which connects the endpoints of the alternative route matrix. Results of this evaluation are shown on Fig. 3. As expected, the optimum cumulative dose route avoids the population centers, but, less intuitively, the least-dose route follows a relatively indirect path on the upper portion of the hypothetical study area.

The optimal route identified in the areal analysis depicted in Fig. 3 does not necessarily conform with existing transportation corridors, as is clearly shown when the assumed route matrix is overlaid on the "suitability surface". To determine the relative favorability of the four transportation routes which actually exist, population dose values for grid cells lying along each alternative were summed. Results of this procedure are presented in Table I; Route 1 has the lowest cumulative dose, and therefore is the most favorable of the "real" routes.

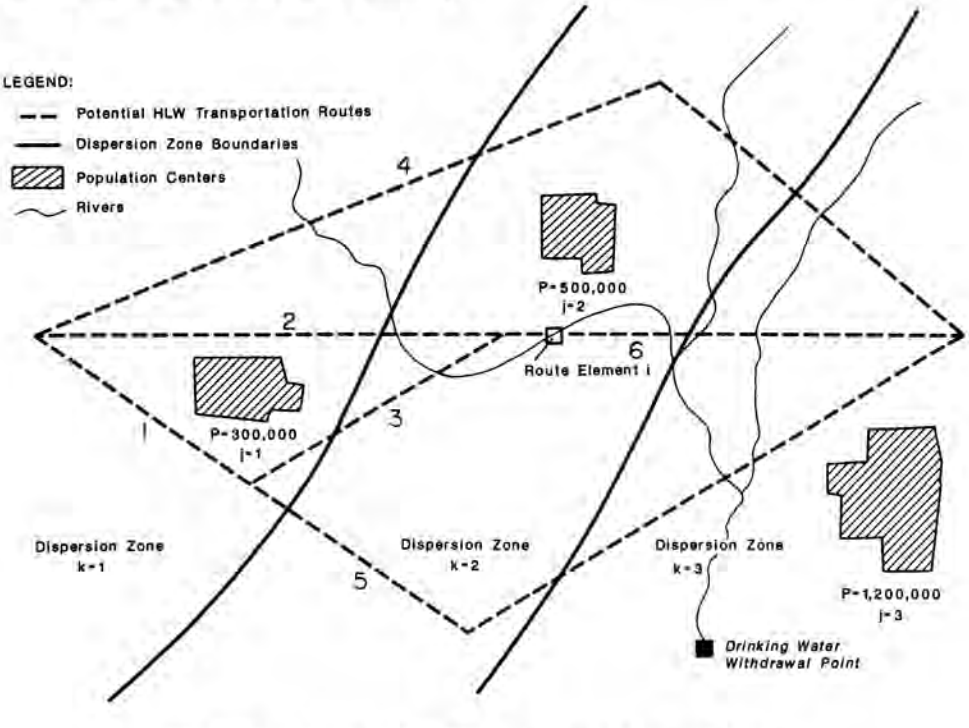

Fig. 1. Hypothetical HLW Transportation Route Matrix.

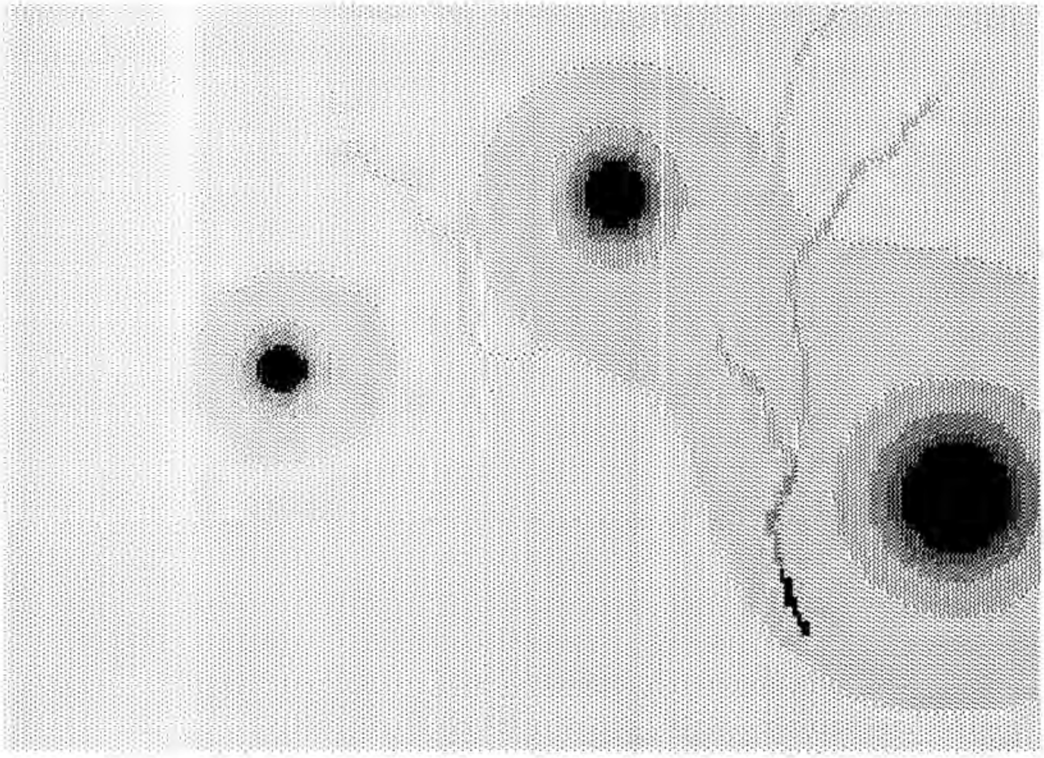

Fig. 2. Population Dose From Atmospheric and Liquid Releases.

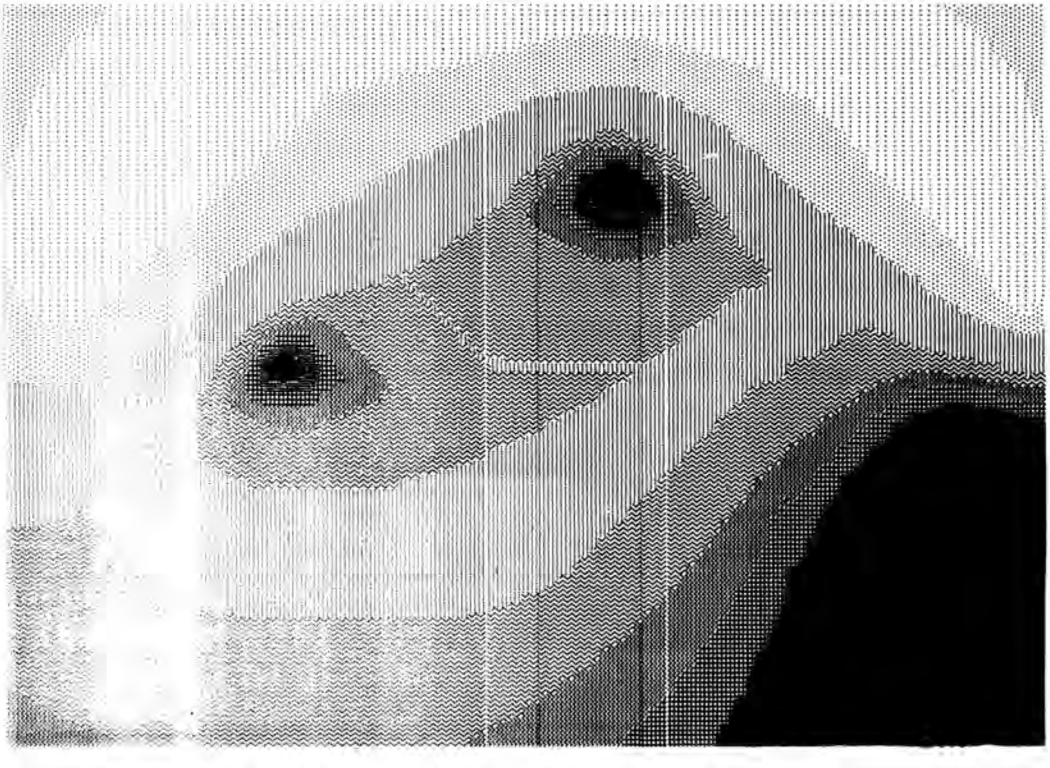

Fig. 3. Cumulative Population Dose (Route Suitability).

TABLE I
Alternate Route Ranking

Route	Length	Composite Poplation Dose
4	216	178.1
2-6	169	184.1
1-3-6	192	198.1
1-5	222	224.2

CONCLUSIONS

A methodology for assessing the relative suitability of alternative transportation routes for high-level nuclear waste by evaluating the radiological impact of accidents has been defined. It is capable of implementation in a variety of data availability scenarios, even in those where the same level of data detail is available neither for all points in the routing matrix, nor at all stages of the routing process.

A hypothetical application of the model reveals that meaningful input to the routing decision can be derived from analysis of cumulative dose impacts of alternative routes. However, additional investigation will be required to:

- Define appropriate dispersion model sophistication and data detail for use in each stage of the routing process
- Establish protocols for incorporating dose impact analysis results into the overall route selection decision process

REFERENCES

1. U. S. Atomic Energy Commission; Meteorology and Atomic Energy; David H. Slade, editor; 1968.
2. Gifford, F. A.; "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion"; Nuclear Safety, Volume 2, Number 4; June 1961.