A Transportation Risk Assessment Tool for Analyzing the Transport of Spent Nuclear Fuel and High-Level Radioactive Waste to the Proposed Yucca Mountain Repository

Thomas McSweeney,[1] Thomas Winnard,[1] Steven Ross,[2] and Ralph Best[3]
[1]Battelle Memorial Institute, 505 King Avenue, Columbus, OH, 43201, USA, 614.424.4877
[2]Battelle-Denver, 8614 East Dillard Place, Denver, CO, 80231
[3]Jason Associates Corporation, 12 Kentucky Ave., Suite 203, Oak Ridge, TN, 37830

SUMMARY

The Yucca Mountain Transportation Database was developed as a data management tool for assembling and integrating data from multiple sources to compile the potential transportation impacts presented in the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (DEIS). The database uses the results from existing models and codes such as RADTRAN, RISKIND, INTERLINE, and HIGHWAY to estimate transportation-related impacts of transporting spent nuclear fuel and high-level radioactive waste from commercial reactors and U.S. Department of Energy (DOE) facilities to Yucca Mountain.

The source tables in the database are compendiums of information from many diverse sources including: radionuclide quantities for each waste type; route and route characteristics for rail, legal-weight truck, heavy haul truck, and barge transport options; state-specific accident and fatality rates for routes selected for analysis; packaging and shipment data by waste type; unit risk factors; the complex behavior of the packaged waste forms in severe transport accidents; and the effects of exposure to radiation or the isotopic specific effects of radionclides should they be released in severe transportation accidents.

The database works together with the codes RADTRAN (Neuhauser, et al, 1994) and RISKIND (Yuan, et al, 1995) to calculate incident-free dose and accident risk. For the incident-free transportation scenario, the database uses RADTRAN and RISKIND-generated data to calculate doses to offlink populations, onlink populations, people at stops, crews, inspectors, workers at intermodal transfer stations, guards at overnight stops, and escorts, as well as non-radioactive pollution health effects. For accident scenarios, the database uses RADTRAN-generated data to calculate dose risks based on ingestion, inhalation, resuspension, immersion (cloudshine), and groundshine as well as non-radioactive traffic fatalities.

The Yucca Mountain EIS Transportation Database was developed using Microsoft Access 97™ software and the Microsoft Windows NT™ operating system. The database consists of tables for storing data, forms for selecting data for querying, and queries for retrieving the data in a predefined format. Database queries retrieve records based on input parameters and are used to calculate incident-free and accident doses using unit risk factors obtained from RADTRAN results.

The next section briefly provides some background that led to the development of the database approach used in preparing the Yucca Mountain DEIS. Subsequent sections provide additional details on the database structure and types of impacts calculated using the database.

BACKGROUND

Performing risk assessments of transportation systems has never been an easy task because data from many diverse sources have to be input into the integrated assessment tool. Initially, two options for estimating the transportation impacts were considered. In option one, input data could be assembled and placed in RADTRAN, a tool designed for performing transportation risk assessments. The results from the RADTRAN runs would then be presented in the DEIS.

In option two, RADTRAN output could be considered as another source of data and another tool, such as a spreadsheet, could be used for calculating impacts. Using this approach, RADTRAN input would be formatted to calculate impacts of transporting a waste shipment 1 kilometer in urban, suburban, and rural areas having a population density adjacent to the route of 1 person per square kilometer. Use of the three population zones enables the effects of differences in travel speeds and traffic counts among the zones to be included in the analysis. A second set of RADTRAN runs would be made to determine the radiological dose when 1 curie of each isotope present in the waste forms is released in an area having a population density of 1 person per square kilometer. These sets of RADTRAN runs would produce unit risk factors that would be source data for a spreadsheet-type integrated assessment tool. Various worksheets would calculate various elements of the assessment and the results would be placed in a master worksheet containing all the results used in the DEIS.

Given the complexity of the Yucca Mountain analysis, it was concluded that neither approach would be workable. The analysts determined that using RADTRAN as an integrated assessment tool, could require thousands of case runs. Furthermore, extracting the data from these runs for use in the EIS would have been time consuming to perform and validate. While the spreadsheet approach would be more feasible, the major concern was the requirement to independently verify the correctness of large numbers of cell equations.

A third option was then considered. It was decided to use a database instead of a spreadsheet as the framework for assembling and compiling data that would be presented in the EIS. As will be described in the remainder of this paper, a database can be an effective tool for performing transportation impact assessments that are complex because of the many parameters and options that must be considered.

SOURCE DATA AND DATABASE DESIGN

The first step in designing the database was to import all the source data into database tables. In many cases source data were already in table form. It was a simple matter to import these tables into the database. For example, the dose conversion factors contained in Federal Guidance Reports 11 and 12 (U.S. EPA) are used in several other parts of the DEIS and others had summarized the data in tabular form. Tables of state- and mode-specific accident rates were extracted directly from electronic versions of the source report (Saricks and Thompson). Unit risk factors for routine travel derived from RADTRAN and RISKIND analyses were combined in a single table and then imported into the database. RISKIND was used only to develop unit risk factors used to estimate exposure to inspectors and escorts. Isotope-specific accident risk factors developed using RADTRAN were imported into a separate table. Results estimated using the CALVIN computer code were compiled in a table of numbers of shipments for three alternative repository capacity limits, termed the Proposed Action, Module 1, and Module 2 in the DEIS.

In some cases, a considerable amount of data manipulation was required. The analysis used the codes HIGHWAY and INTERLINE to calculate routes for estimating impacts of shipments by truck and rail modes, respectively. Results from HIGHWAY and INTERLINE list the kilometers in each of 12 population density zones in rows and the columns and present the kilometers traveled in each zone by state. The distances in each of the 12 zones had to be collapsed into three segments - rural, suburban, and urban. The distances reported for the first four zones were summed to obtain the distance that would be traveled in rural areas, the next four were summed to obtain suburban travel distances, and the last four urban travel distances. At the same time, the population density for each segment was calculated based on the fraction of travel in each of the zones that made up the segment. Other manipulations were also necessary for efficient design of the relational database.

The Yucca Mountain EIS Transportation Database, using RADTRAN and RISKIND results, calculates the risks for four transportation modes – legal-weight truck, heavy-haul truck, rail, and barge – which are then combined to create the Mostly Legal-Weight Truck Case, the Mostly Rail Case, and the Barge Case. In the Mostly Legal Weight Truck Case, all material considered for disposal is assumed to be shipped by legal weight truck except for the naval reactor cores, which are assumed to be shipped by rail. In the Mostly Rail Case, if the commercial generator site has the capability to load rail casks, the spent fuel is assumed shipped by rail. However, sites capable of loading rail casks but not having direct rail access, heavy-haul trucks are used to ship the spent fuel to a nearby railhead. The analysis assumed sites that could not load rail casks would ship spent fuel to the repository via legal weight truck. For sites that would use heavy-haul trucks to haul rail casks to nearby railheads that also have access to navigable waterways, the analysis also evaluated barge transport of rail casks to nearby railheads.

The next step was to build the logic that relates the source data tables together into an integrated assessment tool. Join tables are an essential element in this process because it is these tables that specify which routes and shipments go with which transport modes for which cases. The database join tables ensure that the correct mode, route, and shipment data are used for the Mostly Truck and Mostly Rail. The join tables eliminate the need to have multiple, redundant files of routing and shipping information to be able to analyze different scenarios.

YUCCA MOUNTAIN EIS TRANSPORTATION DATABASE STRUCTURE

Standard relational database design was used to create and develop the database tables and relationships between tables. This section describes the structure of the tables, the sources for the data stored in the tables, the procedures for entering data into the tables, and the relationships between tables.

Tables are used to store data in the database and are defined as lookup (typically, small standardized sets of data), join (data from lookup tables joined together where appropriate), or calculated values tables. The tables are normalized so only the data related to the primary key or primary use of the table are stored in the table. Due to the processing time required to calculate some database values and the relatively static nature of the data stored in the database, calculated values such as shipment kilometers and accident doses are stored in tables.

The database structure makes use of the relational capabilities of MS Access™. Rather than a flat file that contains all the information for each generator site, there is a table that provides routing (Kilometers) for each origin, end node, mode, and state that are not repeated if the analysis assumes that different cask or fuel types would be transported over the same route. For example, the Nevada distance and population density distributions for the alternative corridors being considered are entered once and any shipment that lists a specific rail end node as its final destination is assumed to travel along the alternative routes from that rail end node to the repository. The relationship among tables is shown in Figure 1.

The lines between the tables define relationships. The lines can indicate either a one-to-one or a one-to-many relationship. The infinity symbol represents "many" in the one-to-many relationship. Typically, "one" in a one-to-many relationship is defined as coming from a lookup table, and "many" is defined as going to a join table. For example, the Modes table contains the distinct list of modes (entered once) that can be used with many Accident Rates table records.

The relationships also maintain consistency in the process of updating and deleting records. For example, the values Barge, Heavy Haul Truck, Rail, and Truck in the Modes table can only be used in the Mode field of tables related to a field of the same name in the Modes table. Tables so related include Kilometers, Regional Corridors, Accident Rates, Accident Probabilities, Casks/Modes, and Unit Risk Factors. Referential integrity ensures that changes to values in the Modes tables are automatically updated in related tables. Also, if one of the values in the Modes table is deleted, the records in the related tables with that value in the Mode field will be automatically deleted as well.

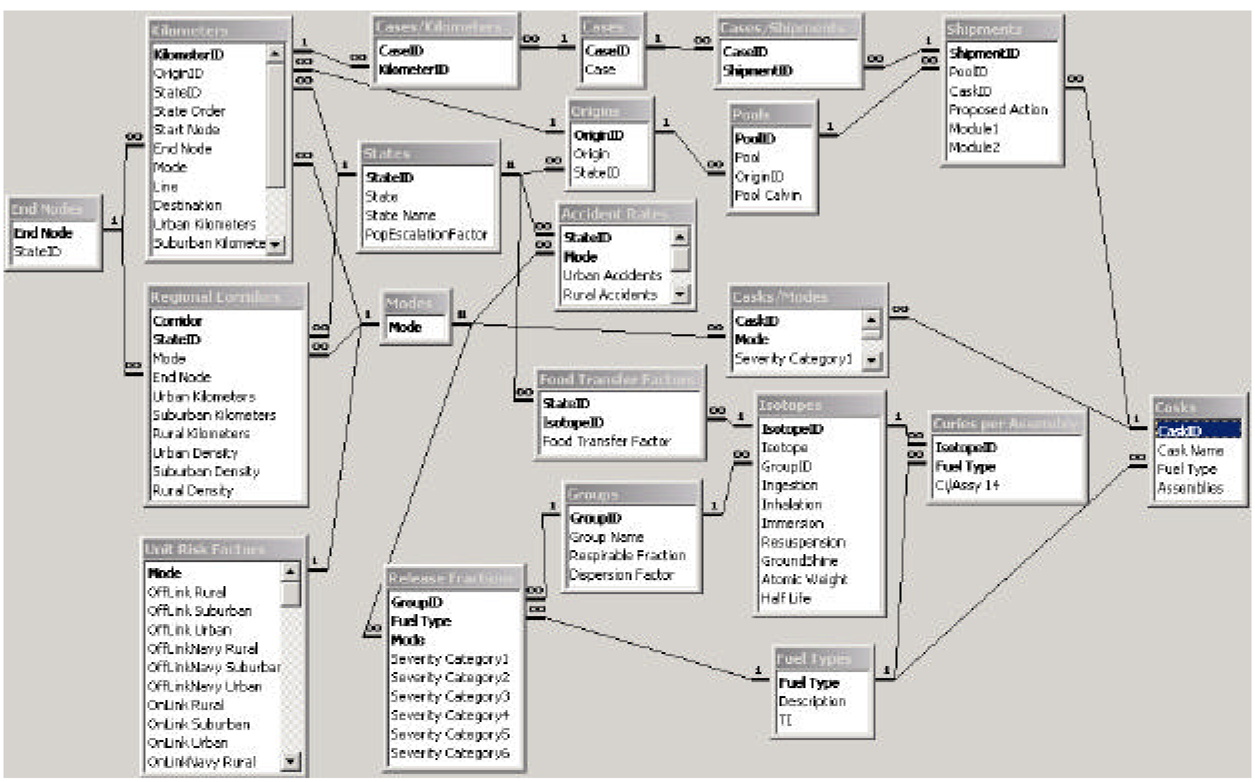

Figure 1. Relationships of Tables in the Yucca Mountain EIS Transportation Database

The rail alternative can stop at one of four end nodes in Nevada and ten regional corridor alternatives are being considered as possible routes from the end nodes to the proposed Yucca Mountain repository. Rather than duplicate the data in every state for every route and alternative, the database is structured to contain two distinct sets of records, a set of records to the end node and a set of regional records from the end node to the repository. To further reduce the duplication in the national data, if the same mode of shipment is used for all the cases, then a join table (Cases/Kilometers) is used between the routing records (Kilometers table) and the Cases table to tell the code to use the same route for the three cases. The legal weight truck-only reactors fall in this category. When considering the potential for use of barges to ship from generator sites to nearby railheads, all the sites that would not use barges, for example sites having direct rail access or limited to using legal weight trucks, do not have duplicate routing records. The join table tells the code to use the proper route.

Queries were created in the database to use the data in data tables, for example RADTRAN calculated unit-risk factors, to calculate the accident risks and incident-free dose risks, as well as the many intermediate calculations required to calculate dose risks. Each box in Figure 2 is a query. The queries use input from the tables and other queries to perform the accident risk and incident-free dose risk calculations. Queries were developed in a hierarchical manner, where the results of one query are used as input to a higher-level query. The highest level queries are at the top of Figure 2 and produce the transportation impacts presented in the DEIS. In most cases, when a query at a higher level in the hierarchy is executed, all of the associated lower level queries are also executed. To provide flexibility in the data output, queries were developed in six categories: Outside NV Incident Free, Outside NV Accident (Figure 2), Nevada Incident Free, Nevada Accident, Incident Free Combined, and Accident Combined. Only the Outside NV Accident hierarchy is included here.

Queries identified in the hierarchies as “Parameter” use values for the parameters Case, Origin, State, Mode, End Node, Regional Corridor, and Fuel Type in combination to retrieve specific sets of data for output. Queries identified in the hierarchies with the initial characters “MT” create calculated values tables. The queries below the “MT” queries are run only when it is necessary to update the calculated values tables to incorporate updated or new source data. For example, if the number of kilometers from an origin through a state is updated, the calculated values tables storing the shipment kilometers and dose consequences also must be updated because they depend on that value. The use of the calculated values tables greatly speeds up the queries shown above them in Figure 2 because they use the values in the calculated values table and do not execute the queries below the “MT” query. By using these calculated values tables, the time to execute the highest level queries was reduced from several hours to a few minutes.

The Outside NV Incident Free and Outside NV Accident query hierarchies use input from, and calculate values for, all states in the database except Nevada. Both accident risk and incident-free dose calculations are based on shipment-kilometers that the shipments must travel to reach the Yucca Mountain disposal facility. The Nevada Incident Free and Nevada Accident query hierarchies use input from, and calculate values for, Nevada only, including the regional corridors. The NV to End Node Shipment Kilometers for the legal-weight truck mode and rail mode to the rail end nodes are combined with the regional corridor shipment kilometers in a union query to perform these calculations.

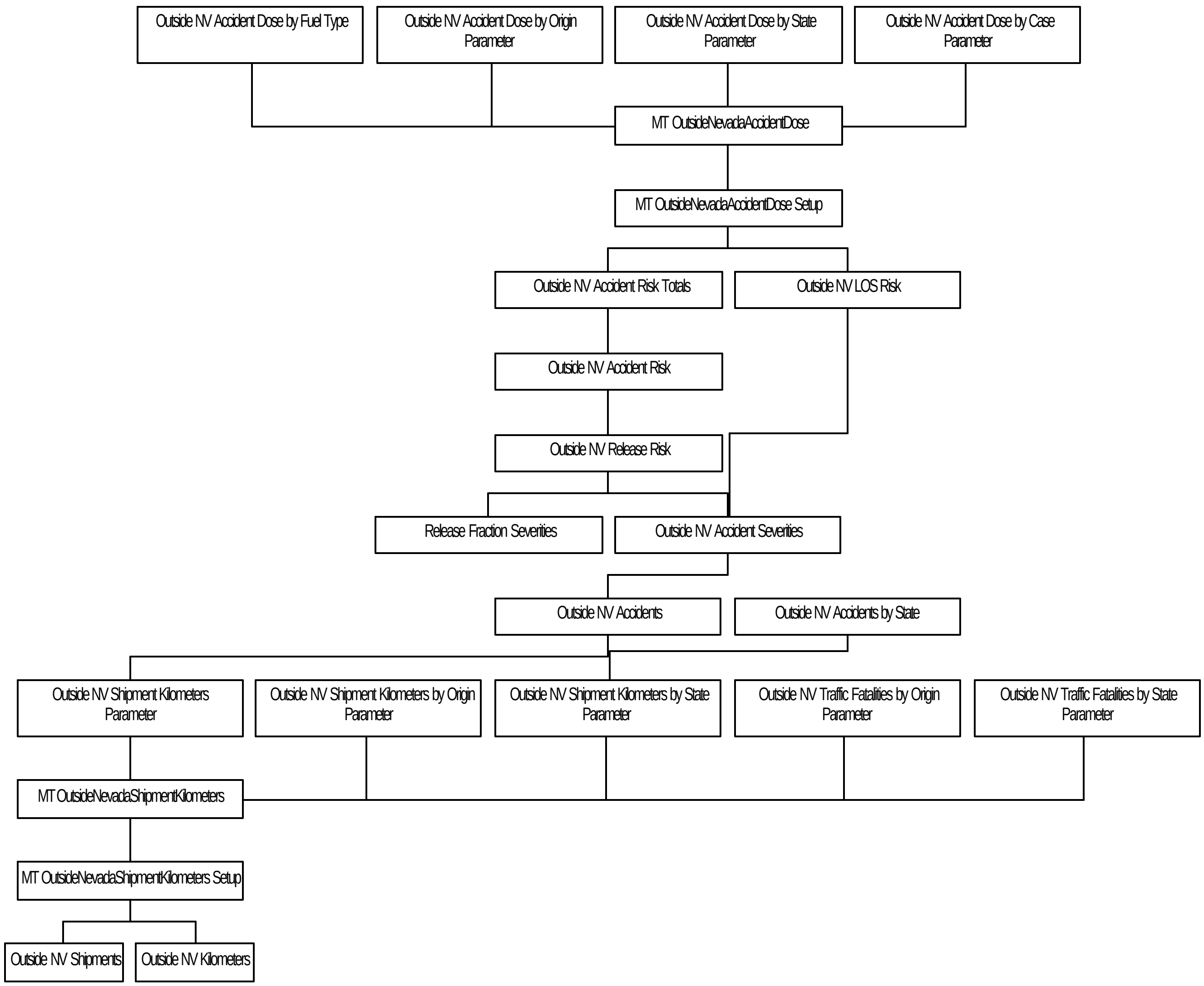

Figure 2. Outside NV Accident Query Hierarchy

The Incident Free Combined and Accident Combined query hierarchies combine the results from the Outside NV queries and the Nevada queries to produce results for all states in the database. Results in the Combined query hierarchies are reported using one of the ten regional alternatives; the one exception is the sites that do not have capability to load a rail cask and would not use rail as a transportation option are summed and reported as “Truck Only Sites.”

INCIDENT FREE IMPACT RESULTS

The approach taken in this analysis is to use the RADTRAN normal transportation impacts associated with transporting the various types of wastes for 1 kilometer in three population zones:

urban, suburban, and rural. One set of factors is used to estimate the occupational exposure realized by the truck, rail, or barge crew. The second set is used to estimate the exposure realized by the general population. One additional normal transport impact was considered, the impact associated with vehicle emissions. The database queries for each factor first calculates the dose to workers or the general public for that factor for a travel distance and population density specified for each origin, end node, cask, mode, route, state and fuel type. Additional queries then sum these results to obtain the total dose received by workers and the general public for the mostly truck and mostly rail options for the Proposed Action, Module 1, and Module 2.

ACCIDENT IMPACT RESULTS

Accident risks fall into two categories. The first is associated with the violence of the truck accident where the impact can result in injury or death to those involved. The second category of risk is realized when the severity of the accident is sufficient to release radioactive materials from a shipping cask.

The accident risk values are dependent on several parameters in addition to total kilometers traveled by zone and the average population density in the zone. Since the consequences of a release are being assessed, the accident risk values are also a function of the isotopic inventory in the waste form being transported and the probability a given quantity of material might be released given a severe accident. The accident risk assessment considers both direct and indirect exposure pathways. The direct pathways consider the exposure to radiation being emitted from the passing plume and inhalation of isotopes from the passing plume. The indirect pathways include exposure from deposited material, termed groundshine, inhalation of material resuspended from contaminated soil, and ingestion. Dose factor tables are used to relate the exposures via these pathways to population health effects. All the factors are isotope specific. One, the ingestion dose risk, is dependent on the state in which the release occurred because food production varies from one state to another.

The database queries use isotopic-specific unit release factors developed using RADTRAN to calculate contributions to the accident risk for each origin, end node, cask, mode, route, state, and fuel type. Additional queries then sum these results to obtain the total accident risk for the mostly truck and mostly rail scenarios for the Proposed Action, Module 1, and Module 2.

SUMMARY

The MS Access™-based transportation risk assessment tool has been shown to be efficient for preparing the Yucca Mountain DEIS. The basic queries are useful for analyzing a wide range of scenarios without the need for frequent modification. Whenever input data were modified, it was a simple matter to update the database and present new results tables. Because it was easy to use queries on existing queries or tables, many questions that arose during the preparation of the DEIS were quickly answered. For example, it is very easy to total all the shipment kilometers or to calculate the total number of accidents that might be projected for any of the many alternatives being considered. Such facts are frequently placed in the text of the DEIS to give the reader a better picture of the proposed transportation alternatives. Such queries have also been shown to be invaluable to validate results.

In summary, the use of a database to perform transportation risk assessments for the Yucca Mountain DEIS was found to be a very effective in reducing the record keeping task for a complex risk assessment. The tool is easy to use, and can quickly produce assessment results.

REFERENCES

Johnson, P.E., D.S. Joy, D.B. Clarke and J.M. Jacobi, *HIGHWAY 3.1 – An Enhanced Highway Routing Model: Program Description, Methodology, and Revised User's Manual*, *Revision 1*, ORNL/TM-12124, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1993a.

Johnson, P.E., D.S. Joy, D.B. Clarke and J.M. Jacobi, *INTERLINE 5.0 – An Expanded Railroad Routing Model: Program Description, Methodology, and Revised User's Manual*, *Revision 1*, ORNL/TM-12090, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1993b.

Neuhauser et al, *Users Guide for RADTRAN 4,* SAND89-2370, Sandia National Laboratories, Albuquerque, NM, 1992.

Saricks, C. L., and M. M. Tompkins, *State-Level Accident Rates of Surface Freight Transportation: A Re-Examination,* ESD/TM-150, Argonne National Laboratory, Argonne, Illinois, 1999.

TRW (TRW Environmental Safety Systems Inc.), *User Manual for the CRWMS Analysis and Logistics Visually Interactive Model, CALVIN Version 1.0,* 30064-2003, Revision 00A, Systems Analysis and Integration Department, Vienna, Virginia, 1998.

U.S. Environmental Protection Agency, "External Exposure to Radionuclides in Air, Water and Soil – Federal Guidance Report No. 12," EPA 402 R-93-081, Washington, D.C., 1993.

U.S. Environmental Protection Agency, "Limiting Values of Radionuclides Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion – Federal Guidance Report No. 11," EPA-520/1-88-020, Washington, D.C., 1988.

Yuan, Y. J., S. Y. Chen, B. M. Biwer, and D. J. LePoire, *RISKIND - A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel*, ANL/EAD-1, Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois, 1995.