# GLOBAL TRANSPORTATION COST MODELING FOR LONG-RANGE PLANNING*

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## SUMMARY

The U.S. Department of Energy (DOE) is preparing to perform significant remediation activities of the sites for which it is responsible. To accomplish this, it is preparing a corporate global plan focused on activities over the next decade. Significant in these planned activities is the transportation of the waste arising from the remediation. The costs of this transportation are expected to be large. To support the initial assessment of the plan, a cost-estimating model was developed, peer-reviewed against other available packaging and transportation cost data, and applied to a significant number of shipping campaigns of radioactive waste. This cost-estimating model, known as the TEn-year Plan TRAnsportation cost Model (TEPTRAM), can be used to model radioactive material shipments between DOE sites or from DOE sites to non-DOE destinations. The model considers the costs for (a) recovering and processing of the wastes, (b) packaging the wastes for transport, and (c) the carriage of the waste. It also provides a rough order-of-magnitude estimate of labor costs associated with preparing and undertaking the shipments. At the user's direction, the model can also consider the cost of DOE's interactions with its external stakeholders (e.g., state and local governments and tribal entities) and the cost associated with tracking and communicating with the shipments. By considering all of these sources of costs, it provides a mechanism for assessing and comparing the costs of various waste processing and shipping campaign alternatives to help guide decision-making. Recent analyses of specific planned shipments of transuranic (TRU) waste which consider alternative packaging options are described. These analyses show that options are available for significantly reducing total costs while still satisfying regulatory requirements.

## INTRODUCTION

A large quantity of radioactive, mixed, and non-radioactive hazardous waste has accumulated at various sites within the United States as a result of the activities of DOE and its predecessor organizations. DOE has a mandate to undertake remediation (i.e., cleanup) of this waste. This cleanup will entail some or all of the following activities: recovery, processing, packaging, storage, transport and disposal.

During 1996 and 1997, an extensive Environmental Management Integration (EMI) effort was undertaken by DOE and its support contractors to define how to accomplish this remediation in a safe, yet cost-effective, manner. The wastes were categorized, at each of the main DOE sites by waste stream subject matter experts (SMEs), in terms of specific waste flow streams which must be moved from their current locations to processing, storage and ultimately disposal. Through this process, estimates of the quantities of wastes which can be remediated over the next 10 years with the anticipated funding were quantified. The categorization of the wastes included identifying characteristics of individual waste streams, and then aggregating these together to facilitate the top-level planning.

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As the development of the *Ten Year Plan*—now called the *Accelerated Cleanup Plan* (DOE, 1997)—and the EMI effort proceeded, it became apparent that one of the critical elements in remediation was going to be the packaging and transportation of these materials. Furthermore, one significant factor identified, which needed to be addressed in the planning process and used in making decisions, was the cost involved in the shipments of individual waste streams. The packaging and transportation costs needed to be evaluated relative to both baseline and alternative planning cases in order to identify opportunities for accelerating remediation or accomplishing remediation at lower costs. Oak Ridge National Laboratory (ORNL) has developed and tested a cost-estimating model—TEPTRAM—in support of the 10-year planning and EMI activities.

## DEVELOPMENT OF TEPTRAM COST ESTIMATING MODEL

The initial version of TEPTRAM was developed as the first phase of the Ten Year Plan was approaching completion in 1996. The model, which was developed at the direction of the DOE Environmental Management organization, was based upon cost-estimating algorithms developed in 1994 for a packaging and transportation needs assessment (Pope et. al., 1995; Pope and Blalock, 1996). The first version of TEPTRAM was completed and placed into use in September 1996.

The algorithms used in the model were automated using the Excel™ spreadsheet software, and many waste transportation cases were run using this first version of TEPTRAM. Because the TEPTRAM cost-estimating approach includes a number of simplifying assumptions, validation of the TEPTRAM model was desirable. It was validated using cost estimates previously made for shipments of TRU wastes in the TRUPACT-II container. The developers of TEPTRAM compared its results with those obtained by separate methodology for the TRU waste shipments and found agreement to within about 20%. In a separate and an independent analysis, Argonne National Laboratory (ANL) personnel compared the costs for a hypothetical shipping campaign obtained from TEPTRAM with methodology used by ANL for environmental risk assessments, and it was determined that the TEPTRAM and ANL results also were in agreement to within about 20%. It was felt that these results demonstrated that TEPTRAM was sufficiently accurate for long-range management planning, particularly when relative costs of alternative shipping scenarios are being considered.

During 1997, in further developments related to detailed planning for accelerated cleanup activities, transportation SMEs began looking at alternatives for shipping the wastes in order to reduce system-wide, life-cycle costs. The original TEPTRAM model was adapted to the needs of this study by improving the "user-friendliness" of the model's interface using Excel's Visual Basic™ for Applications Macro capability.* In addition to the improvements to the user interface, the capability to calculate costs of leased packages was added. Detailed calculations of costs were then undertaken to demonstrate whether TEPTRAM could provide rough order-of-magnitude cost estimates for various waste stream shipping campaigns involving different packaging and shipping alternatives. Detailed calculations of costs were then undertaken to demonstrate this capability.

### Description of TEPTRAM Cost Estimating Model

The total transportation cost provided by TEPTRAM is the sum of several cost factors. They include the following: :

***Packaging Acquisition Cost***—This cost factor provides the cost of purchasing the packages needed for a given campaign. The number of packages required for the campaign is calculated based on the travel time, loading and unloading times, refurbishment downtime, capacity of package, and the amount of material to be transported in a given period of time. It is assumed that each campaign requires new

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* Excel and Visual Basic are trademarks of Microsoft Corporation.

packagings, which may overestimate the costs associated with a campaign where the packagings can be used in other campaigns or when the packagings are already available at no, or reduced, cost.

*Packaging Lease Cost*—This cost factor is the alternative to acquiring packagings. This factor provides the cost per month to lease a packaging, and the model includes lease costs for the times involved in transit between facilities and in loading and unloading the packagings.

*Packaging Maintenance Cost*—This cost factor provides the estimated cost of refurbishing the package after a predetermined number of uses. This would include periodic inspections, parts and labor for seal replacement, minor damage repair, painting, fastener replacement, etc. This value is assumed to be zero when a packaging is leased because the maintenance costs for each packaging are assumed to be included in the lease cost.

*Vehicle Lease Cost*—This cost factor provides the cost of leasing the vehicle for the campaign. It is based on the number of vehicles needed for the campaign (calculated) and the lease cost per vehicle.

*Carriage Cost*—This cost factor provides the 'per mile' charge of the carrier and the round trip mileage. This includes fuel, driver labor, vehicle wear, vehicle maintenance, etc.

*Labor Cost*—This cost factor provides a rough order-of-magnitude estimate of the labor costs for package preparation, loading, unloading, and securing package to vehicle.

*Management and Administrative Cost*—This cost factor provides a rough order-of-magnitude estimate of administration and management costs including contracting for carriers, hazardous material shipping document preparation, record keeping, etc. A complexity factor is used in this algorithm to account for differences in time and effort required for different kinds of shipments.

*Institutional Cost* (Optional)—This cost factor provides the cost of preparing an environmental assessment before the commencement of the shipping campaign and the costs of interfacing with the affected states and tribal governments. This estimate assumes that the entire additional cost is borne by the campaign being assessed. Two or more shipping campaigns operating simultaneously would ultimately share the costs; therefore actual costs would often be lower than those estimated by this model.

*Retrieval Cost* (Optional)—This cost factor provides the estimated cost to retrieve the material when it 'retrievably stored' at the originating location.

*TRANSCOM Cost* (Optional)—This cost factor provides the cost of staffing the TRANSCOM satellite tracking and communication control center for second and third shifts during each weekday, and during the weekends (as necessary) during the campaign. This estimate assumes that the entire additional cost is borne by the campaign being assessed. Concurrently, operating campaigns would ultimately share the costs; therefore, actual costs would often be lower than those estimated by this model.

## Example Calculations with the TEPTRAM Cost Estimating Model

The EMI effort has resulted in aggregated flow descriptions of waste streams. These were one of the primary inputs used by the SMEs in the EMI transportation activity. A number of transportation-related "opportunities" or "options" were identified during 1997 (Dickman, Frandsen, Holmes, et. al., 1997), where it was estimated that significant financial benefits could accrue by changing the manner in which the wastes are processed, packaged and transported. The initial estimates were made qualitatively without the benefit of a structured logistics cost model such as TEPTRAM. Since that time, the TEPTRAM model has been updated to accommodate assessment of options, and an example of the costs for transport from one site, applying and comparing one of these options to the baseline plan (DOE,

1997) has been processed using TEPTRAM. The results generally verify the earlier qualitative estimates of cost savings; indeed they show that greater cost savings are possible than were originally estimated. In this example calculation, none of the optional cost factors were included.

Many of the opportunities for cost savings identified by the EMI transportation effort are related to the remediation of TRU wastes. One example opportunity (Dickman, Frandsen, Holmes, et. al., 1997) relates to the type of package which is currently acceptable to the U.S. Waste Isolation Pilot Plant (WIPP). Currently, because of agreements in the Land Withdrawal Act, WIPP is allowed to receive only TRU wastes in Type B packages certified by the U.S. Nuclear Regulatory Commission (NRC). In interpreting this requirement, it has generally been assumed, for shipments to the WIPP, that all wastes will be transported in the TRUPACT-II, which is an NRC-certified Type B(U)F package design.

The opportunity identified is that consideration should be given to changing these requirements to allow TRU wastes to be shipped in packages which are consistent with the requirements set forth in both domestic [i.e., NRC (Title 10 of the U.S. Code of Federal Regulations, Part 71); and U.S. Department of Transportation (DOT) (Title 49 of the U.S. Code of Federal Regulations, Part 173)], and international (IAEA, 1990) regulations. Specifically, when the wastes to be transported can be qualified as low specific activity (LSA) material, or as surface contaminated objects (SCOs), they should be so classified and shipped in appropriate, uncertified packagings. Similarly, in the United States there is a requirement that whenever a package contains more than 0.74 TBq (20 Ci) of plutonium, the material must be a solid and must be shipped in a certified package which has two separate levels of containment (see Title 10 of the U.S. Code of Federal Regulations, Part 71.63). There are some limited exceptions to this, but the TRU wastes which will be shipped to WIPP will not, in most cases, satisfy these exceptions. When the TRU waste cannot satisfy the LSA material or SCO requirements but when the total plutonium in a single package is less than 0.74 TBq (20 Ci), then consideration should be given to shipment of these wastes to WIPP in a certified Type B package having only a single level of containment. Both of these packaging alternatives to the TRUPACT-II were initially viewed as offering adequate safety because they are fully compliant with transport regulations and also provide significant cost savings.

For the TRU wastes currently located in Oak Ridge, Tennessee, the EMI disposition maps (Dickman, Frandsen, Holmes, et. al., 1997) aggregate 14 waste streams into a single baseline plan case (each having two categories: "Legacy," and "Newly generated") which are to shipped by the year 2006 to WIPP as follows:

| | |
|---|---|
| Legacy (i.e., old) wastes | 2,205 $m^3$ |
| Newly generated wastes | 580 $m^3$ |
| Total wastes | 2,785 $m^3$ |

The following example analysis uses 5 of the 14 waste streams from the baseline plan case, which assumes that all of the waste in all of the waste streams considered are transported from Oak Ridge to WIPP. Costs are estimated assuming that (a) solids are either shipped without processing or they are processed prior to transport at Oak Ridge, where the solids are compacted with an average 50% reduction in volume, and that (b) sludges (i.e., wastes containing some liquids), are processed prior to transport at Oak Ridge where they are solidified with sacrificial cementing materials, resulting in an average 50 % increase in volume.

The assessments—when determining whether the materials could qualify for transport in either a single containment certified package, or in a non-certified package as LSA material—consider the changes in volumes, activity per package, and specific activities resulting from processing. It was assumed that the wastes would satisfy the packaging mass limits. The knowledge of the characteristics of the 14 waste streams, as they are currently stored and as they will exist at the time of transport, vary by waste stream and age. None can be assumed to be fully and adequately characterized at this time, and processing prior to shipment for disposal is likely. The estimated volume of each waste stream and the total quantity stored and generated through 2006 have been estimated for the EMI activity, these values were then rounded off to obtain the total volume of wastes assumed to require transport by the year 2006. The average characteristics of the 5 waste streams considered in this cost analysis are summarized in Table 1.

Details of each waste stream were obtained from the TRU SME at Oak Ridge. These were used in defining packaging alternatives. It was noted that the radionuclide mixtures reported were those that existed when the waste was placed into storage. Since some of these wastes may be 15 to 30 years old, each radionuclide mixture will have changed significantly. A limited assessment of aging was undertaken to define whether aging of the waste could result in enhancing the packaging options.

Table 2 summarizes the detailed radiological characteristics for the OR-W100 waste stream, one of the five waste streams considered in this cost study. This table illustrates (a) that a large number of radionuclides may be present (in this case, 11 radionuclides), (b) that the individual specific activities of each radionuclide can vary from one to nine orders of magnitude, and (c) that the data need further evaluation since the typical values in some cases do not lie between the minimum and maximum values. The characteristics of some of the other waste streams are even more complex. For example, OR-W044 contains 34 radionuclides with a similar spread in the ranges of specific activities. Because the data supplied for each radionuclide provide a "typical" specific activity and a range of specific activities, the packaging options for each waste stream were assessed using three cases: (a) minimum specific activities for all nuclides, (b) typical specific activities for all nuclides, and (c) maximum specific activities for all nuclides. In addition, the effect of aging of the waste was considered using the ORIGEN code (Croff, 1980), and it was found that the specific activity of the TRU waste streams would be reduced, because of aging, by between 10 and 30% for each stream. However, because further detailed knowledge of the characteristics of the wastes were not available, this opportunity was not pursued further.

**Table 1. Characteristics of typical TRU waste streams at Oak Ridge, Tennessee**

| | | | | | Estimated | | | |
|---|---|---|---|---|---|---|---|---|
| Waste stream number | Type of TRU waste[a] | Physical type | RCRA present[b] | Liquids present | Activity content [TBq/ (Ci)] | Volume in storage ( $m^3$) | Volume generated[c] ($m^3$/y) | Total volume[d] as is/ processed ( $m^3$) |
| OR-W044 | CH, M | Debris | Yes | No | 418/(11,291) | 467 | 6.6 | 533/267 |
| OR-W093 | CH,NM | Debris | No | No | 2,957/(79,930) | 303 | 1.6 | 319/160 |
| OR-W100 | RH, M | Debris | Yes | No | 13/(361) | 136 | 1.1 | 147/74 |
| OR-W096 | RH, M | Sludge | Yes | Yes | 600/(16,214) | 165 | 0. 0 | 165/330 |
| OR-W098 | RH, M | Sludge | Yes | Yes | 2,321/(62,725) | 443 | 3.0 | 463/926 |

[a] CH = contact handled, RH = remote handled, M = mixed, and NM = nonmixed.

[b] RCRA = Resource Conservation Recovery Act materials (e.g., mercury, trichloroethylene, etc.).

[c] Volume generated is estimated generation rate of same category of waste in $m^3$/y.

[d] Assumes 50% reduction in volume when solids processed through compaction, 50% growth in volume when sludges processed into solid.

The various cases for each waste stream and assumed radionuclide mixture were run in a two-step fashion. First the Hazardous Material Expert System (HaMTES) software (Michelhaugh et. al. 1996) was used to define the minimum package requirements for shipment based on the waste characteristics. Second, TEPTRAM was then run to provide the estimated cost of shipping the specified quantity of waste in the minimum required packaging, and packagings having more robust design requirements, as appropriate.

It was assumed that all waste is packaged for disposal in 210 litre drums. The packaging options for transport included:

(a) the baseline plan case which used the TRUPACT-II for all shipments and which is used when the analysis shows a Type B(U)F package with double containment is required, where each TRUPACT-II contains 14 drums of CH-TRU or 2 drums of RH-TRU, with 3 TRUPACT-II packages carried per truck;

(b) a single-containment Type B package [e.g., USA/9168/B(U)] capable of containing 8 drums of RH-TRU, with 1 package carried per truck;

(c) a single-containment Type B package capable of containing 4 drums of CH-TRU, with 4 packages carried per truck;

(d) an Industrial Package (IP) such as a 325 litre drum capable of containing one 210 litre drum of CH-TRU which is categorized as LSA material, with 43 IPs carried per truck; and

(e) an IP (e.g., USA/9176/A) capable of containing 14 drums of RH-TRU, which is categorized as LSA material, with one IP carried per truck.

**Table 2. Radionuclide data for waste stream OR-W100**

| Radionuclide | Estimated specific activity of each radinuclide | | | | | |
|---|---|---|---|---|---|---|
| | Range (Ci/m$^3$) | | | Range (TBq/m$^3$) | | |
| | Min | Typical | Max | Min | Typical | Max |
| $^{227}$Ac | 6.0E-04 | 7.4E-06 | 6.0E-04 | 2.2E-05 | 2.7E-07 | 2.2E-05 |
| $^{241}$Am | 3.0E-01 | 1.8E-01 | 9.0E+00 | 1.1E-02 | 6.7E-03 | 3.3E-01 |
| $^{252}$Cf | 6.0E-09 | 1.7E-01 | 3.5E+00 | 2.2E-10 | 6.5E-03 | 1.3E-01 |
| $^{244}$Cm | 2.4E-04 | 2.1E+00 | 4.9E+01 | 8.8E-06 | 7.7E-02 | 1.8E+00 |
| $^{60}$Co | 1.7E+00 | 5.2E-02 | 2.5E+00 | 6.3E-02 | 1.9E-03 | 9.3E-02 |
| $^{137}$Cs | 4.6E-01 | 6.6E-02 | 2.6E+00 | 1.7E-02 | 2.5E-03 | 9.6E-02 |
| $^{239}$Pu | 3.7E-02 | 4.0E-03 | 7.3E-01 | 1.4E-03 | 1.5E-04 | 2.7E-02 |
| $^{223}$Ra | 6.0E-04 | 7.4E-06 | 6.0E-04 | 2.2E-05 | 2.7E-07 | 2.2E-05 |
| $^{90}$Sr | 1.7E+01 | 8.2E-02 | 1.7E+01 | 6.3E-01 | 3.0E-03 | 6.3E-01 |
| $^{232}$Th | 6.0E-04 | 7.4E-06 | 6.0E-04 | 2.2E-05 | 2.7E-07 | 2.2E-05 |
| $^{233}$U | 6.0E-05 | 8.1E-03 | 6.0E-01 | 2.2E-06 | 3.0E-04 | 2.2E-02 |

The results of the cost analyses are summarized in Table 3. For the assessments of CH-TRU wastes, analyses were run for both unprocessed and processed wastes, whereas for the RH-TRU sludges, processing was assumed in order to satisfy waste acceptance criteria at WIPP. The data in Table 4 illustrate that significant differences in costs result from the application of different packaging options. In four of the five cases, it appears that costs can be saved if shipments are made in other than TRUPACT-II packagings. For the "typical" radionuclide mix for waste stream OR-W044, the costs were projected to increase if another packaging is used. This increase is caused by the relative inefficiency of the assumed Type B single-containment package assumed for CH-TRU; both the carriage and labor costs are higher for this package than for the TRUPACT-II. If a more efficient CH-TRU single-containment, Type B package design were available, additional cost savings might be realized.

The projected savings in cost that could accrue if the wastes could be shipped to WIPP in packagings other than the TRUPACT-II are summarized in Table 4. These data show that, for the five Oak Ridge TRU waste streams considered, the total projected cost savings could range from about $29 million to $31 million. The five waste streams considered represent 58% of the

Table 3. Cost estimates for various shipping campaigns of TRU waste transported from Oak Ridge, TN to WIPP

| Waste stream | Waste characteristics[a] | Package type[b] | Waste volume transported, $(m^3)$ | Estimated campaign cost ($US) |
|---|---|---|---|---|
| OR-W044 — Contact Handled TRU, debris with RCRA present | BASELINE, NP | TRUPACT-II | 533 | 3,070,000 |
| | Max, NP | B()F, DC, HRCQ | | 3,070,000 |
| | Typ, NP | B | | 4,978,000 |
| | Min, NP, LSA-II | IP | | 1,572,000 |
| | BASELINE, P | TRUPACT-II | 267 | 2,243,000 |
| | Max, P | B()F, DC, HRCQ | | 2,243,000 |
| | Typ, P | B | | 3,034,000 |
| | Min, P, LSA-II | IP | | 1,157,000 |
| OR-W093 — Contact Handled TRU, debris | BASELINE, NP | TRUPACT-II | 319 | 2,222,000 |
| | Max, NP | B()F, DC, HRCQ | | 2,222,000 |
| | Typ, NP | B()F, DC | | 2,222,000 |
| | Min, NP, LSA-II | IP | | 1,135,000 |
| | BASELINE, P | TRUPACT-II | 160 | 1,779,000 |
| | Max, P | B()F, DC, HRCQ | | 1,779,000 |
| | Typ, P | B()F, DC | | 1,779,000 |
| | Min, P, LSA-II | IP | | 1,054,000 |
| OR-W100 — Contact Handled TRU, debris with RCRA present | BASELINE, NP | TRUPACT-II | 147 | 4,953,000 |
| | Max & Typ, NP | B | | 1,922,000 |
| | Min, NP, LSA-II | IP | | 1,045,000 |
| | BASELINE, P | TRUPACT-II | 74 | 3,354,000 |
| | Max and Typ, P | B | | 1,192,000 |
| | Min, P, LSA-II | IP | | 704,000 |
| OR-W096 — Remote Handled TRU, solidified | BASELINE, P | TRUPACT-II | 330 | 8,854,000 |
| | Max & Typ, P, Fissile Excepted, LSA-II | IP | | 2,348,000 |
| | Min, P, LSA-II | IP | | 2,348,000 |
| OR-W098 — Remote Handled TRU, solidified | BASELINE, P | TRUPACT-II | 926 | 23,010,000 |
| | Max, Typ, & Min, P, LSA-III | IP | | 5,174,000 |

[a] Waste Characteristics defined by: Max = maximum radionuclide mix, Typ = typical radionuclide mix, Min = minimum radionuclide mix, P = processed, and NP = non processed. BASELINE is all waste shipped in TRUPACT-II.

[b] Package Types are: IP = Industrial Package, B = Type B with single level of containment, B()F = Type B Fissile where TRUPACT-II has been assumed for the BASELINE; DC = Type B package with double level of containment, and HRCQ = Highway Route Controlled Quantity as defined by U.S. regulations in 49 CFR Part 173.403).

TRU wastes which will require shipment from Oak Ridge, but represent only 1.9% of the TRU waste which must be shipped from all of the United States sites to WIPP.

## CONCLUSION

Because the results of this assessment show major cost savings could be achieved by allowing packaging other than TRUPACT-II to be used for shipment of TRU wastes to WIPP, it appears it would be useful

Table 4. Estimated cost savings resulting from using of correct package design

| Waste Stream | Maximum Potential Cost Savings[a] ($US) |
|---|---:|
| OR-W044 (CH-TRU) | 1,086,000 to 1,496,000 |
| OR-W093 (CH-TRU) | 725,000 to 1,087,000 |
| OR-W100 (CH-TRU) | 2,650,000 to 3,908,000 |
| Subtotal for CH-TRU | 4,461,000 to 6,491,000 |
| OR-W096 (RH-TRU) | 6,506,000 |
| OR-W098 (RH-TRU) | 17,836,000 |
| Subtotal for RH-TRU | 24,342,000 |
| **Total for CH-TRU and RH-TRU** | **28,803,000 to 30,833,000** |

[a] Range in cost savings for CH-TRU depends upon whether the waste is processed; RH-TRU must be processed prior to shipment.

to try to obtain relief from the WIPP Land Withdrawal Act requirement which precludes the use of the cost efficient package designs although they would be safe and fully compliant with the regulatory requirements for the wastes to be transported. Extrapolation of the cost data for the waste streams considered in this study indicates that savings well in excess of $100 million could be realized.

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