WASTES: A WASTE MANAGEMENT LOGISTICS/ECONOMICS MODEL

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ABSTRACT

The WASTES logistics model is a simulation language based model for analyzing the logistic flow of spent fuel/nuclear waste throughout the waste management system. The model tracks the movement of spent fuel/nuclear waste from point of generation to final destination. The model maintains inventories of spent fuel/nuclear waste at individual reactor sites as well as at various facilities within the waste management system. A maximum of 14 facilities may be utilized within a single run. These 14 facilities may include any combination of the following facilities: 1) federal interim storage (FIS), 2) reprocessing (REP), 3) monitored retrievable storage (MRS), 4) geological disposal facilities (GDF). The movement of spent fuel/nuclear waste between these facilities is controlled by the user specification of loading and unloading rates, annual and maximum capacities and commodity characteristics (minimum age or heat constraints) for each individual facility. In addition, the user may specify varying levels of priority on the spent fuel/nuclear waste that will be eligible for movement within a given year. These levels of priority allow the user to preferentially move spent fuel from reactor sites that are experiencing a loss of full-core-reserve (FCR) margin in a given year or from reactors that may be in the final stages of decommissioning.

The WASTES model utilizes the reactor specific data available from the PNL spent fuel database. This database provides reactor specific information on items such as spent fuel basin size, reactor location, and transportation cask preference (i.e., rail or truck cask). In addition, detailed discharge data is maintained that provides the number of assemblies, metric tons, and exposure for both historic and projected discharges at each reactor site.

INTRODUCTION

The WASTES model simulates a user defined system of nuclear waste transportation and storage at both temporary and long-term storage facilities. The model is written in FORTRAN 77 as an extension to the SLAM commercial simulation package (Pritsker and Pegden 1979). SLAM (Simulation Language for Alternative Modeling) is utilized in a discrete event mode to model the passage of spent fuel through the system.

The system is initiated with individual reactor discharges of spent fuel as described in the reactor discharge data file or as supplied by the user. The reactor discharge file contains deterministic information on the date (year/month) and quantity of spent fuel discharges. From this point, the model is controlled by a combination of source originated and destination originated transfers.

Source driven transfers occur when a reactor pool violates the full core reserve (FCR) storage margin or when a reactor is decommissioned. At these times, destination facilities are checked to see if they can accept material. A dry storage facility is assumed to exist for each reactor and is allowed to grow as necessary to contain spent fuel which cannot be shipped to any other facility. In this way the FCR margin is always maintained.

Destination driven transfers occur when the annual capacity of receiving facility will not be met by full core reserve or decommissioning shipments. An attempt is made at the end of each calendar year to schedule enough shipments of spent fuel from facilities with noncritical storage capacity to fill the annual capacity of each destination facility. Allowable facility types are reprocessing plants, federal interim storage (FIS), monitored retrievable storage (MRS), and repositories. The number, capacities, location and priority for receipt of spent fuel is user specified.

WASTE GENERATION SOURCE MODELS

The primary driving data for the WASTES program is contained in two files. The first contains site specific information for present and planned future commercial reactors in the U.S. This file contains such information as the accessibility to rail transportation, the latitude and longitude of the site, the type of reactor and its startup and decommissioning dates.

The second file describes the estimated characteristics of fuel discharge batches and is sorted by time of reactor discharge. It contains information on the fuel burnup, batch size in number of assemblies and weight in metric tons. A sub-batch is defined as a group of fuel assemblies with similar exposure history, i.e., the same reactor discharge date and initial enrichment and discharge burnup (within ten percent). This file is the driving force behind the simulation model. It is used to determine the rate of arrival of material into the simulation as the program executes.

WASTE FACILITY MODELS

The model accepts input statements which describe each of the major storage/processing facilities to be included in the simulation. Four types of storage/processing facilities (FIS, MRS, Reprocessing Plants, and Repositories) are allowed in the simulation up to a maximum of twelve facilities. The code uses a major ID and minor ID to uniquely identify the different facilities. The major facility IDs are 1, 2, 3, and 4 which stand, respectively, for reprocessing plants, monitored retrievable storage facilities, repositories, and federal interim storage facilities. The minor ID is determined by the number of facilities of each major type. Thus, if there are two repositories to be analyzed, the code would expect the facility IDs to be 3.1 and 3.2. The facilities are further identified by the location of the facility in latitude and longitude and a 20 character facility title.

The user can also enter an operations schedule for each facility which determines the facility gross capacity, its yearly capacity, its maximum yearly unloading rate, its yearly sprint capacity (capacity not included in the nominal annual capacity which is reserved for forced discharges) and whether it accepts material based on age since discharge or heat content. The user also enters the minimum amount of time which materials must remain at the facility and the minimum age since discharge for each facility.

TRANSPORTATION MODEL

WASTES incorporates logic for handling truck as well as rail transportation between reactors and storage or processing facilities and allows user specification to mandate either mode in order to perform alternative analysis of the transportation costs. By default, the model will preferentially ship by rail if both origin and destination facilities have rail access. In all cases it is assumed that processing/storage facilities have rail access. Reactor rail access is defined based on data collected by PNL and tabulated in DOE/RL-84-1.

The model also calculates total transportation costs incurred for shipping material by either legal weight truck or general freight rail transportation modes. The three types of casks allowed in the model are truck, rail, and dry storage casks. The user may specify the following parameters for each cask: empty weight, the number of usable days/year, the turn around time for loading/unloading, the usable cask life in years, the daily rental rate for the cask, the purchase price, the annual operating and maintenance cost, and the number of PWR or BWR assemblies that the cask may contain. Shipment quantities always occur in multiples of the appropriate shipment cask capacities.

BASIC TRANSPORTATION SCHEME

Within the WASTES model there are two different criteria which may be used in determining the order in which material is shipped from a facility. If the age basis criterion is selected, the oldest material is shipped first. If the heat basis criterion is selected, the coolest material is shipped first. Material will only be shipped if it meets the user supplied minimum residence time for that facility.

The availability of destination facilities is determined by their remaining capacity in that year and whether or not the material meets the minimum age or maximum heat rate acceptance criteria for that facility.

The WASTES model contains three shipping algorithms which are user-specifiable options. These include optimal, proximal, and sequential determination of transport source/destination pairs. Each major class of facility may be specified to be filled in a different manner. The optimal routing allows a true mileage minimization to be done where proximal routing provides an approximate minimization to be done. Sequential filling of facilities allows for no optimization as each facility is filled according to its facility sequence number (minor ID). Descriptions of these algorithms follow:

1. Optimal Algorithm: This optimization algorithm is operational only when there are exactly two facilities in the destination facility type. If only one facility is available, the sequential shipping algorithm is used. If more than two facilities of the same type are available, the proximity algorithm is used. The algorithm examines all material to be shipped to a given facility type within a calendar year. This material is then allocated to source/destination pairs such that the total shipping miles are minimized in that year.

2. Proximal Algorithm: In this algorithm the distances from the source facility to the alternative destination facilities are determined at the time each material transfer is to occur. The closest facility which has the capacity to accept the material is chosen and the source/destination pair is determined immediately.

   This suboptimal method handles cases with more than two facilities of a given facility type. No allowance is made for material which will require shipment later in the year and which may incur a larger reduction in shipping distance. The proximity algorithm does not reallocate earlier shipment assignments to minimize the impact of this situation.

3. Sequential Algorithm: In this algorithm no attempt at optimization is made and the source/destination pairs are determined in a sequential manner based on the individual facility identification number assigned by the user.

TRANSPORTATION COSTING

The transportation costs calculated in the WASTES model are the costs that would be incurred for shipping spent fuel by either legal weight truck or general freight rail modes of transport under current tariffs. The equations utilized in calculating these costs were a result of curve fitting the results of research currently ongoing at PNL to determine the costs for shipping spent nuclear fuel. The equations are based on the distance traveled (DIS) and the full and empty weight incurred (FWT and EWT) for each shipment. Separate equations are given for both truck and rail shipments for one-way distances less than and/or greater than 1,000 miles. In addition, the equations provide an estimate of the safeguards and security charges that would be incurred for each shipment. The equations used are shown below.

<u>Legal Weight Truck</u>

(one-way mileage less than 1,000 miles)

$$\text{Shipping Cost (\$)} = (1.493 + 0.0033*DIS)*FWT + (0.428 + 0.0034*DIS)*EWT$$

(one-way mileage greater than 1,000 miles)

$$\text{Shipping Cost (\$)} = (0.0049*DIS - 0.16)*FWT + (0.0040*DIS - 0.19)*EWT$$

(for all mileages)

$$\text{Safeguards/Security Cost (\$)} = 7.93*DIS^{(0.8145)}$$

General Freight Rail

(one-way mileage less than 1,000 miles)

Shipping Cost ($) = (2.44 + 0.0071*DIS)*FWT + (2.26 + 0.0066*DIS)*EWT

(one-way mileage greater than 1,000 miles)

Shipping Cost ($) = (5.34 + 0.0042*DIS)*FWT + (4.97 + 0.0039*DIS)*EWT

(for all mileages)

$$\text{Safeguards/Security Cost (\$)} = 291.65 * DIS^{(0.4013)}$$

where

DIS = one-way great circle route (miles)
FWT = loaded weight of cask (cwt)
EWT = empty weight of cask (cwt).

The number of days that a cask will be utilized for each individual shipment is also estimated in order to calculate lease costs. The number of cask-days utilized for a shipment is a function of the transit speed and the cask turnaround time (as shown below). Again, data from ongoing PNL research was used. The lease costs are then calculated by multiplying the total number of days that each cask is utilized by the daily lease charge for that cask type.

Transit Speed

Total Distance from Origin to Destination (miles)	Distance Traveled/ Day (miles)	
	Truck	Rail
0 - 300	840	47
301 - 1100	840	88
1100 - 1900	840	143
1900	840	182

The total number of cask-days utilized for a given shipment is calculated as shown below:

Cask-Days = [(2*DIS)/SPEED] + 2*TATIME

where

DIS = one-way mileage (miles)
SPEED = transit speed (miles/day)
TATIME = average turnaround time at each facility (days).

LEVELIZED CASK PURCHASING

The levelized cask purchasing algorithm is a first order approximation to a cask purchase/replacement methodology in which the "peak requirements" in a given year may be transferred into a earlier year. The methodology acts as a "levelizer" by moving cask requirements from years having peak requirements to prior years having minimum requirements.

The algorithm examines the cask requirements which were previously calculated on an annual basis and compares the number of casks required in a given year with the number of casks previously purchased. If the required number of casks exceeds the number of casks previously purchased, additional casks are purchased in that year. If the required number of casks are less than the number of casks available, the excess casks become available to remove spent fuel from a future year in which the number of required casks will exceed the amount then available. The algorithm allows up to 10% of the combined annual capacity of the storage/processing facilities in the future year to be available for peak year transfer requirements.

The algorithm ensures that a cask will be available only during its prescribed lifetime (user input). Once a cask has reached the end of its assumed lifetime, it is either replaced (new purchase) or retired.

SUMMARY

Documentation of the WASTES model is in final review and will be released to the public in the near future. Development of the model will continue with emphasis on transportation equipment dispatching and queueing. Input data regarding facility turnaround times and equipment operating assumptions will also be refined and added to the model to increase the accuracy of predicted equipment requirements and costs.