TRICAM: THE TRANSPORTATION RISK AND COST ANALYSIS MODEL OR THE CIVILIAN RADIOACTIVE WASTE MANAGEMENT PROGRAM

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ABSTRACT

This is the second paper on the subject of the application of optimization techniques to decision making in the Transportation Program of the Office of Civilian Radioactive Waste Management (OCRWM). The first paper (1) described at a conceptual level the optimization approach and its application to decision making. The earlier paper also presented a general description of TRICAM, under development at that time, which would enable the comparison of transportation system alternatives on the basis of the optimal costs and risks achievable under each alternative. TRICAM has since been completed and the present paper is intended to document its features and capabilities at a detailed level.

INTRODUCTION

While the 1987 amendment to the Nuclear Waste Policy Act of 1982 (2) gave a new direction to the overall radioactive waste disposal program, the transportation component of the program remained virtually unchanged in scope but with increased attention to potential impacts, reflecting the reality that however the rest of the program develops, the radioactive waste will need to be transported safely and cost-effectively from reactors to the disposal site.

Moreover, since the sources of the waste are located predominantly in the East, and the permanent disposal facility is likely to be located in the West, the waste will have to be transported across wide sections of the country. Thus, transportation remains an important component of the waste management system and one in which there is a great deal of interest among the public, the Congress, and the utilities.

During the next several years, the OCRWM transportation program will need to make significant system, equipment, and operational decisions. This will require the evaluation of a wide range of options, from which the option to be implemented will be selected. A rational and defensible decision-making process is critically needed, to ensure that the transportation system eventually selected will receive the approval and support of the public, the Congress, and the utilities, all of whom will undoubtedly continue to scrutinize the program closely.

Thus, it is important that the decisions made in the selection of the transportation system are sound, and demonstrably based on defensible comparisons of alternatives. Furthermore, the basis of selection must give due regard to the two policy objectives of safety and cost-effectiveness. Optimization techniques provide a basis for accomplishing this.

THE OCRWM SYSTEM AS MODELED IN TRICAM

TRICAM is designed to optimize the transportation component of the OCRWM system which consists of the transportation system, one or more repositories, and possibly monitored retrievable storage (MRS) or some other interim storage facilities. Although reactors are not part of the OCRWM system, they are, nevertheless, modeled in TRICAM. The spent fuel to be transported by OCRWM is generated and stored there so inclusion of the reactors is necessary to "close" the system modeled in TRICAM. Recognizing that the focus in TRICAM is on transportation, however, the costs and risks incurred at the reactors and the other OCRWM components are modeled in general terms compared to transportation costs and risks which are modeled in considerable detail.

Figure 1 is a schematic representation of the OCRWM system as modeled in TRICAM. It depicts, for a single year, the various 'paths' available to move the SNF from a reactor pool to the repository, which is the permanent disposal site. Fuel discharged from reactors is placed in a storage pool for cooling. After it has been cooled sufficiently, it can be placed into dry casks stored in the open at the reactor site. The transfer of SNF into the dry casks takes place in the pool. Under existing technology, the SNF would be transferred back into the pool for loading into a transport cask for shipment. As an alternative to extended storage at the reactor, SNF can be shipped to the repository directly,

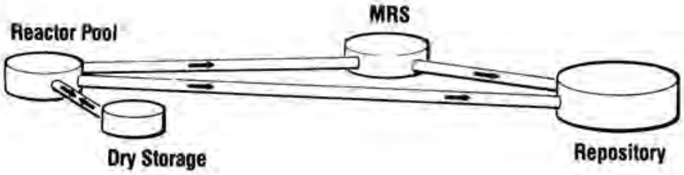

Fig. 1. Schematic Representation of Spatial Network Modeled in TRICAM (Single Reactor Shown).

or to a temporary storage facility from which it can be shipped to the final disposal site at a later date.

Inventories in the reactor pools, in dry storage at reactors, at the MRS, and at the repository provide the year-to-year linkage in TRICAM. The combined spatial-temporal network (for a single reactor) may be depicted schematically as shown in Fig. 2. Clearly, there are innumerable 'paths' through space and time along which SNF from a reactor can reach its final destination at the repository. The number of paths run into the millions for the complete network containing all the reactors. TRICAM searches for the set of paths that would involve the least risk and/or cost for accomplishing the transfer of the SNF to the repository. Obviously, capacity limits at the facilities constrain the solution space.

Table I is a summary of the risks and costs that are included in TRICAM, indicating the scope of the optimization performed in TRICAM. As indicated above, TRICAM is designed to optimize only the transportation component of the OCRWM system, and not the total OCRWM system. Therefore, certain risks and costs that may be important in a system-wide optimization are specifically excluded from TRICAM. An example of such excluded risks and costs are those associated with repository and MRS operations.

TRICAM INTERFACE WITH OTHER OCRWM CODES

An important feature of TRICAM is that it utilizes data generated by existing models which have been developed for OCRWM by other contractors. While this approach requires careful integration of extensive data from several external models, it has the advantage of ensuring consistency across the OCRWM program and of minimizing duplication. For example, Oak Ridge National Laboratory

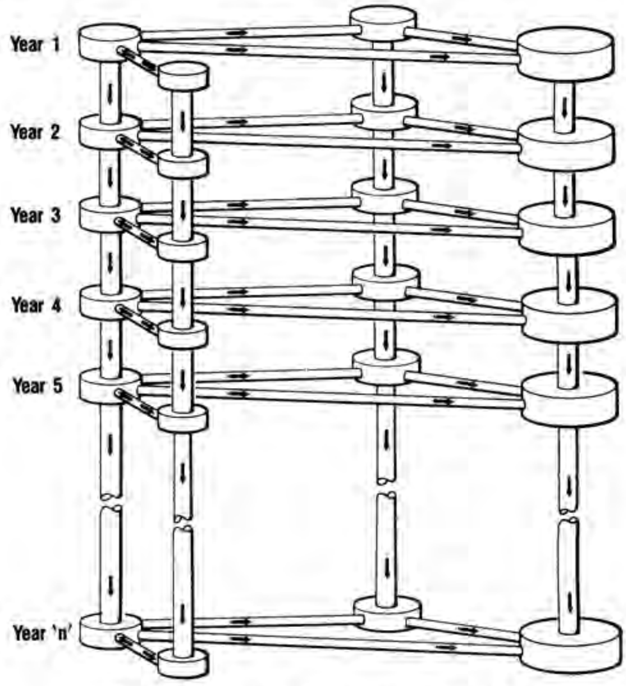

Fig. 2. Schematic Representation of Spatial-Temporal Network Modeled in TRICAM (Single Reactor Shown).

(ORNL) has generated rail and highway routes for the OCRWM program for many years using the INTERLINE (3) and HIGHWAY (4) models. ORNL is the source of route-specific data in TRICAM. Risk data are presently obtained from Argonne National Laboratory (ANL). Reactor data, comprising reactor names, pool capacities, locations, and historical and projected discharges are obtained from Battelle's Pacific Northwest Laboratories (PNL), which has had the responsibility of maintaining this database for the OCRWM program for many years (5). Only the transportation cost data, for which Battelle's Office of Transportation Systems & Planning (OTSP) has the responsibility, is generated internally. Figure 3 is a schematic representation of the interfaces between these various models and the integration of the external data in TRICAM.

CODE DESCRIPTION

In this section, the five modules comprising TRICAM (see Fig. 4) are described in terms of their input requirements, the outputs, and their operation. The following section is a more detailed description of TRICAM's menu-driven user interface through which a user defines the scenario to be analyzed, including the data to be used. The five modules in TRICAM are:

- The SCREENER module which is the menu-driven user interface used to define the scenario to be analyzed.

TABLE I

Risks and Costs Included in TRICAM

Risks and Costs Associated with Transportation:

Loading
Shipping
En-route Security
Cask Maintenance (cost only)
Cask Capital Cost (cost only)
Unloading

Other Risks and Costs at Reactors:

Transfers between pool and dry storage casks
Dry Storage Inventory (cost only)
Pool Inventory (post-decomissioning costs only)

Other Risks and Costs at an MRS:

Placement in yard storage
Yard Inventory (cost only)
Removal from yard storage

- The MAKERSF module which calculates the route-specific risk and cost data for the user-defined scenario.
- The RDBB module which condenses the detailed route-specific data provided by ORNL. The condensed route database is accessed by MAKERSF.
- The OPTIMIZER module* which performs the optimization and outputs the results of the analysis in a series of tables.
- The CATALOG module which is an archiving system for the scenarios defined and analyzed using TRICAM. It is TRICAM's tracking and retrieval system for all analyses conducted using TRICAM.

The OPTIMIZER is the only module that uses large amounts of computer memory and requires a computer system with virtual memory, like the VAX family of computers. All the other TRICAM modules have been designed for implementation on an IBM Personal Computer. Once the scenario is defined and the input files necessary for the OPTIMIZER constructed on a personal computer, control is presently transferred to a mainframe VAX where the OPTIMIZER is executed. This arrangement has been found

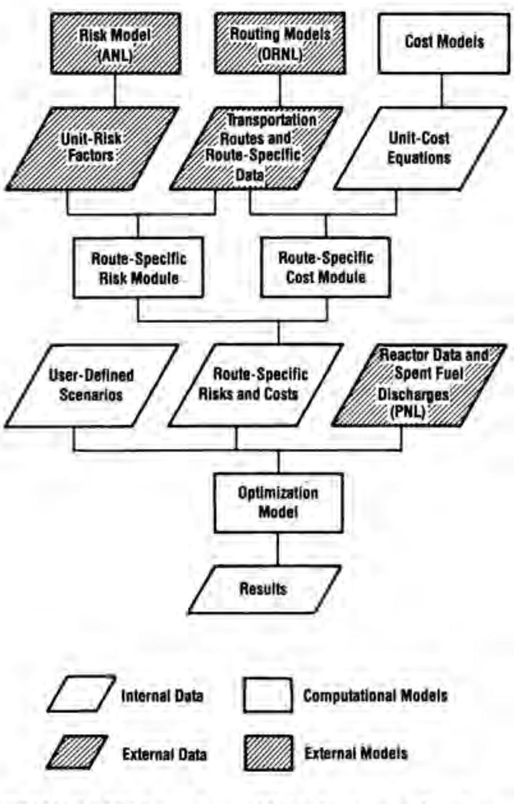

Fig. 3. TRICAM'S Interfaces With External Codes and Data.

* This module was developed for OTSP by Battelle's Pacific Northwest Laboratories.

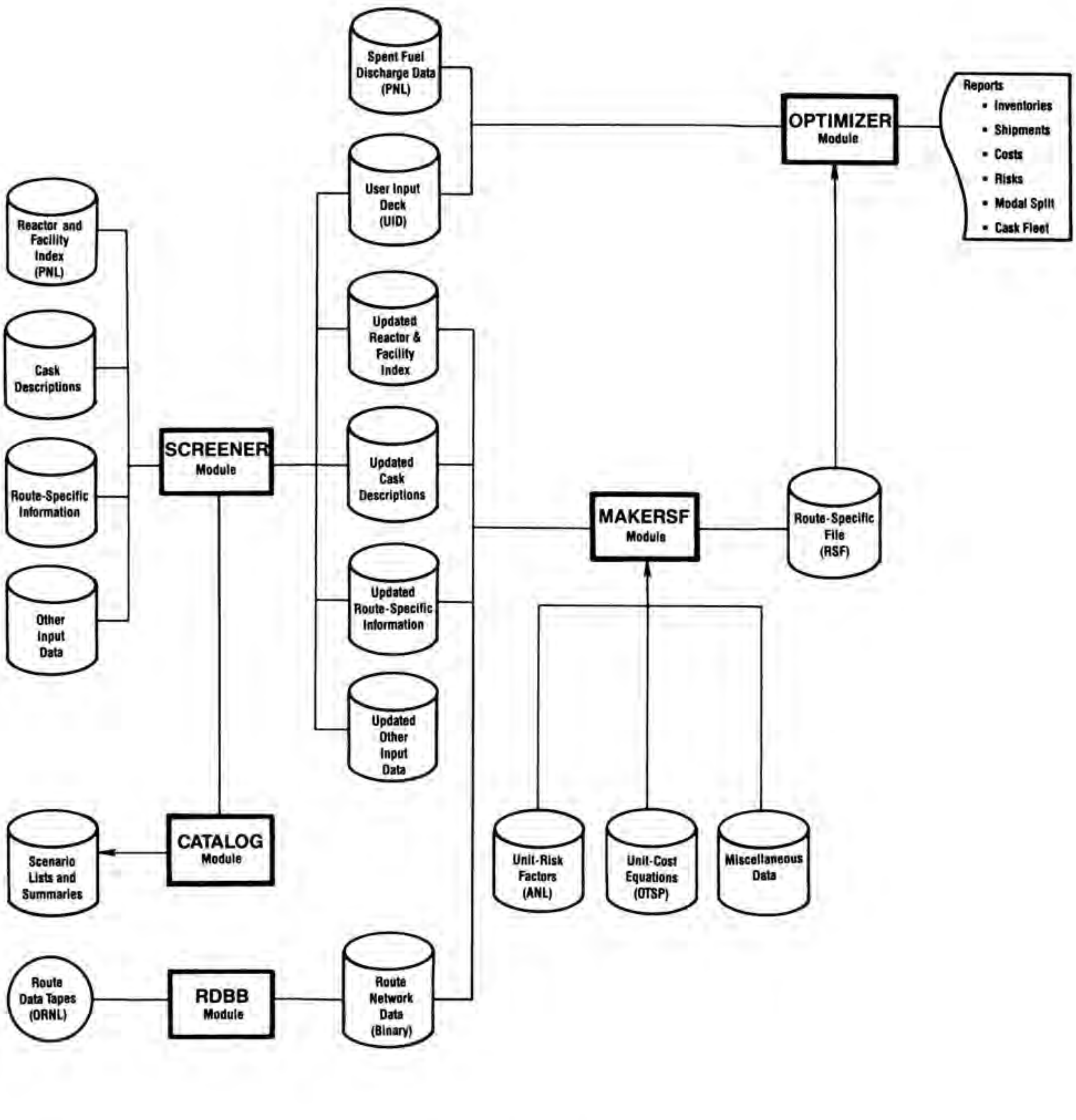

Fig. 4. TRICAM Data Flow Structure.

very cost-effective, especially during the developmental stage. It is also convenient from an application standpoint, since analysts can specify and set up a TRICAM analysis entirely on their personal computers. TRICAM has been developed in a manner to simplify transfer to a VAX, should potential users express interest an all-VAX version of TRICAM.

The Screener Module

SCREENER is a menu-driven editor through which a user defines the scenario to be analyzed. Recognizing that users will often want to analyze variants of a basic scenario, SCREENER is designed for creating entirely new scenarios, as well as modifying previously defined scenarios quickly and conveniently. A complete TRICAM scenario definition involves specification of the following four sets of data:

- The OCRWM system, including the OCRWM facilities to be considered, the spent fuel discharge forecast to be used, and the reactors to be included in the scenario,
- The CASK system,
- The TRANSPORTATION system, including the origin-destination (O/D) network, and the available modes, service options, and number of casks per shipment,
- Other input data, such as the minimum age of fuel to be transported, the relative weighting of the optimization criteria, namely risk and cost, the period of analysis, and the specification of the level of output detail desired, etc.

SCREENER generates four output files, corresponding to the scenario defined by the user, one of which is used in the OPTIMIZER module and the other three in the MAKERSF module. These are:

- A User Input Deck (UID) file. This file contains the user-defined data required to run the OPTIMIZER module.
- A facility and reactor index, used by the MAKERSF module. The index maps individual reactors located at the same geographic coordinates into a common site index. This mapping is required because while discharge and other data is reactor specific, the transportation routes from collocated reactors are identical.
- A Route Specific Information (RSI) file, used by the MAKERSF module. The default RSI contains separate records for all possible O/D pairs for each of the two available modes, rail and truck. The records define each O/D pair in terms of the following data:
- INIS number of the originating reactor
- Identification code for the destination
- Service option, such as regular or dedicated rail service
- Transportation mode (truck or rail)
- Number of casks per shipment
- Cask identification code (CASK ID)
- Route identification code
- A file containing data on the cask systems defined by the user in the current scenario. These data are used in the MAKERSF module.

The data flows from SCREENER to the MAKERSF and the OPTIMIZER modules are depicted in Fig. 4. The operations performed in the SCREENER module are described in further detail in the next section, using sample screens.

The MAKERSF Module

The MAKERSF module generates, for the specified scenario, a route-specific file (RSF), which is one of the two data files required by the OPTIMIZER module. The input data used by MAKERSF include the following:

- The three files generated by SCREENER, as described above
- A set of unit-risk factors
- A set of unit-cost equations
- O/D-specific mileage data generated by RDBB, described below
- A set of miscellaneous data

Unit-risk factors. Only the route-specific transportation risks, i.e., risks associated with shipping between a given O/D pair are used in the MAKERSF. The other risks listed in Table I are associated with activities at the reactors and the facilities and are incorporated directly in the OPTIMIZER module.

For each of the two modes (truck and rail) eight categories of route-specific risk are required as inputs to the MAKERSF module. Six of these pertain to radiological exposure and two to non-radiological risks.** The route-specific risk data consist of a set of Unit Risk Factors (URFs) for

** In the current version of TRICAM, optimization can be performed only for radiological risk. To combine radiological risk (measured in person-rem) with non-radiological risks (measured in fatalities), the former needs to be converted to fatalities. While this transformation is simple, presently the risks not directly associated with transportation (see Table I) are hardcoded in units of person-rem. Thus, some (minor) recoding is required to enable optimization on combined risk. This capability will be provided in TRICAM if it is found to be of interest to users.

TABLE II

Transportation Unit-Risk Factors

	Incident Free	Accident Related
Radiological Risk:		
Off-Link Exposure	URF1	URF4
On-Link Exposure	URF2	URF5
Exposure at Stops	URF3	--
Ingestion	--	URF6
Non-Radiological Risk:	URF7	URF8

each of the eight categories of risk included. The eight unit-risk factors, denoted URF1 to URF8, are classified into two categories relating to incident-free transportation and accident-related conditons, as shown in Table II.

Separate URFs are provided for three land-use zones (urban, suburban, and rural), reflecting the differing construction and traffic density patterns, etc., in these zones. (For a detailed discussion of how these differences are incorporated, see Ref. 6). Additionally, the accident-related URFs are state-specific as they are based on state-level accident data for the 48 contiguous states.

Unit-cost equations. The route-specific transportation costs, i.e., the costs associated with shipping (which includes hauling, inspection at origin, and detention), and en-route security are used in the MAKERSF. Cask-specific costs, namely maintenance and capital cost, and the costs associated with activities at the reactors and the facilities (see Table I), are incorporated directly in the OPTIMIZER module.

Separate cost equations are available in the MAKERSF module for each of the two modes. Depending on the service option selected by the user for each O/D pair, truck costs can be calculated for shipments in individual trucks or in truck convoys. Likewise, rail costs can be calculated for regular or dedicated service.

Route data. The route data used in the MAKERSF provides a breakdown of the total mileage for the route by the States, road types, and population density categories traversed. The data is in binary form, and is created by the RDBB module (described below) from the route-data supplied by Oak Ridge. Although an exhaustive set of route data is computed, i.e., for all rail and truck routes from all origin sites (collocated reactors are combined into a single origin site) and destinations, MAKERSF operates on a subset of this data corresponding to the RSI file created for the user-specified scenario.

Miscellaneous Data. The miscellaneous data file used in MAKERSF contains the following data:

- A table assigning, for each state, the twelve population density categories used in TRICAM to one of the three zones (urban, suburban, and rural).
- Average values of population density for each of the twelve zones. It is these average values that are used in calculating the route-specific risk (described below).
- Miscellaneous constants and parameters, such as the intercepts and slopes for the cost, speed and stop-time equations.

The output of the MAKERSF module is the Route Specific File (RSF), one of the two files required by the OPTIMIZER module. The RSF consists of two parts. The first part contains data for each CASK ID, as defined by the user. The second part consists of a series of route-specific records for each mode and route activated in the RSI. For each route, the RSF contains data on the per-shipment costs, the per-shipment risks, round-trip transit time, number of casks per shipment, and one-way mileage.

MAKERSF generates RSF route records for those RSI records corresponding to the reactors included in the analysis. For each such RSI record, MAKERSF performs the following operations:

a. Reads the origin, destination, mode, and CASK ID specified in the RSI record.

b. For the given O/D pairs, identifies the corresponding site using the site index, and obtains the requisite route-specific mileage data (for the appropriate mode) from the route database. (At this point, all information required to calculate route-specific risks and costs is available in memory).

c. Calls the route-specific risk sub-program and calculates the per-shipment risk for the O/D pair.

d. Calls the route-specific cost sub-program and calculates the per-shipment costs for the O/D pair.

e. Writes the record pertaining to this O/D pair to the RSF file.

This process continuous until the RSI records are exhausted. At completion, there is one RSF record for every user-selected O/D pair, mode, and CASK ID.

The RDBB Module

The RDBB (route database build module) condenses route-data supplied by ORNL and stores it in binary form for use in TRICAM. This makes the input-output (I/O) operations direct and efficient.

The input to the RDBB module is in the form of magnetic tapes supplied by ORNL. These tapes contain route data from all possible origin sites (including generic reactor sites identified by PNL for the lower- and upper-reference spent fuel discharge projections). The route-data describes each link of every route, by the state in which the link falls, the road type, the mode, an urban/rural classification flag, and sundry other characteristics. In addition, the total mileage on each link is provided, and this is further disaggregated into the miles traversed through each of the twelve population density categories. This results in an extremely large data base, which would be difficult to manipulate in its received form.

The link-by-link data supplied by ORNL is intended to support other OTSP activities other than TRICAM analyses, such as map generation. All TRICAM calculations can be performed if the route mileage data is available by state, road type, and population density. Therefore, the extensive ORNL data is aggregated by state, road type, and population density, and translated into two binary files. The first file contains a multidimensional table that holds the address of the data stored in the second file. The second file contains the actual mileage data.

The OPTIMIZER Module

The algorithm used to perform the actual optimization in TRICAM is NETFLO, which is a network optimization model that has been documented in the literature (7). The inputs to the OPTIMIZER are:

- The RSF file generated by MAKERSF
- The UID file generated by SCREENER
- The reactor data and spent-fuel discharges provided by PNL. These data are updated annually by PNL. The latest of these series (5) is incorporated in TRICAM currently, and will be replaced when updated data becomes available.

With this data, the OPTIMIZER computes a solution that minimizes the value of the objective function which can range from pure-cost to pure-risk, or any weighted combination in between. A discussion of the objective function in TRICAM is provided in the earlier paper (1). The solution includes, in addition to the optimal risks and costs, information on the inventories at the reactors and the facilities in each year, annual shipment quantities, the transportation modes, modal split, and cask fleet mix. Through the SCREENER module, the user can either obtain this data in the form of annual summary tables or on a reactor-by-reactor basis. Due to limitations on manuscript length, a detailed description of the various tables generated by TRICAM is not provided here. Instead, interested readers are urged to write to the authors who would be happy to supply a complete sample set of the output tables.

The CATALOG Module

CATALOG is TRICAM's scenario archiving and tracking system that, in the authors view, will prove invaluable to users over the long run. In the OCRWM program, retrievability and duplicability of results is an important consideration. In that sense, CATALOG serves as a "QA manager" for analyses conducted using TRICAM.

This module collects and catalogs information describing the TRICAM scenarios. Once a scenario has been defined, the user can elect to catalog it. This action causes CATALOG to prompt the user for a brief description characterizing the scenario which is stored along with the scenario name in a text file.

This text file is the single output of the CATALOG module. Associated with this scenario, CATALOG keeps all the input files constructed by the user for this particular scenario, including the UID which defines the reactor and spent fuel discharge data used in the scenario.

TRICAM USER-INTERFACE

One of the prime design objectives for TRICAM was to expand the user base as much as possible. This has been accomplished by designing a menu-driven user-friendly interface for TRICAM, referred to as the SCREENER module. Some codes developed for OCRWM in the past require extensive data input in a manner that is quite cumbersome. Thus, few people outside the code development teams have found these codes practical to use. By making its codes accessible and user-friendly, OCRWM can facilitate the use of common data and models by its various contractors, as well as other interested groups. In the author's view, this will engender confidence in OCRWM's analyses and facilitate reconciliation of any parallel analyses that different groups may perform.

The SCREENER module has been described in general terms above. In this section, the reader is "walked" through an exemplary session, using examples of some of the menus available to specify a TRICAM run.

After the welcome screen (Fig. 5), the main menu (Fig. 6) appears. This screen allows the user to modify a previously defined scenario, generate a new scenario, or review any scenario. In the example shown on Fig. 6, the user has chosen to create a new scenario named "SAMPLER". When the "Create New Scenario" option is selected, the

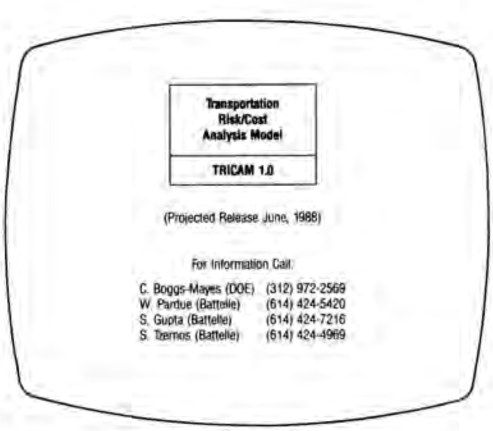

Fig. 5. Welcome Screen.

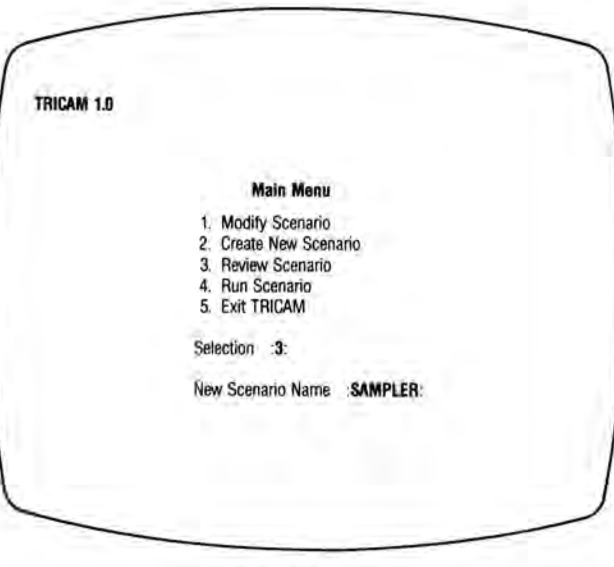

Fig. 6. Main-Menu.

screens come up with the set of default data which represents the "reference" transportation system.

The next screen starts the scenario definition process (Fig. 7). The scenario definition is complete only when all four options have been exercised. Figures 8 through 10 are the three main screens for defining the OCRWM system. With these screens, the user specifies the facilities and reactors to be included, and the spent fuel discharge forecast to be used in the analysis. The cask system is defined with the screen shown in Fig. 11. The transportation system is defined through two screens (Figs. 12, 13), which are repeated for every destination included in the scenario. The first screen allows the user to set default values for type of service, number of casks per shipment, and the CASK ID. The second screen comes up with these default values, which the user can change on a reactor-by-reactor basis, if necessary.

Finally, the screen shown in Fig. 14 is used to specify the remaining input data to complete the scenario and define the run parameters, such as the minimum age of fuel to be transported, cost/risk weighting factors, output tables, etc. Once this screen has been completed, the user is returned to the main menu. The user can review the scenario and/or select the "Run Scenario" option. This executes the MAKERSF module, which prepares the input files required to execute the OPTIMIZER module on the VAX computer.

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7. J.L. Kennington and R.V. Helgason, (1980), Algorithms for Network Programming, John Wiley & Sons, New York, NY.

Fig. 7. Scenario Definition Process.

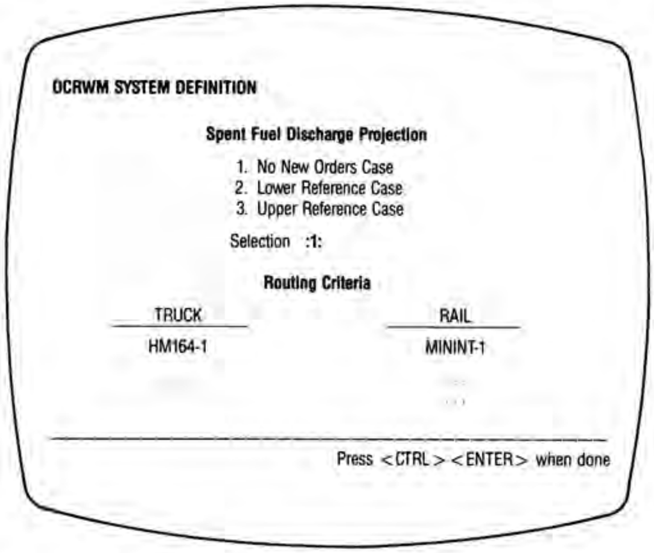

Fig. 9. OCRWM System Definition: Spent Fuel Discharge Forecast.

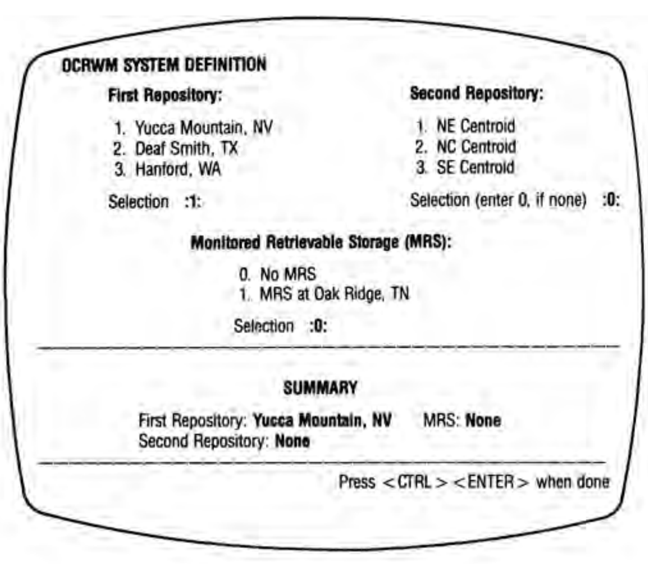

Fig. 8. OCRWM System Definition: Facilities.

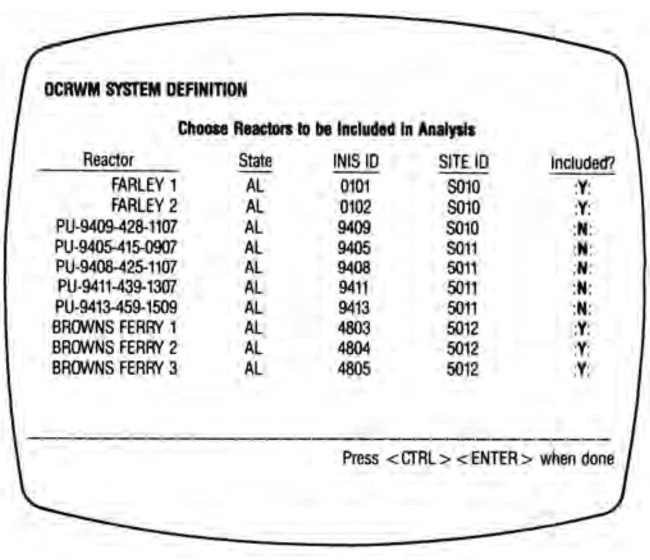

Fig. 10. OCRWM System Definition: Reactors Included.

CASK SYSTEM DEFINITION

CASK ID	T28	R100	R150T
Mode (TRUCK or RAIL)	TRUCK	RAIL	RAIL
Capacity (BWR assemblies)	7	48	140
Capacity (PWR assemblies)	3	21	56
Capacity (MTU)	1.35	9.38	25.94
At-reactor Queue Time (days)	0.0	0.0	0.0
At-reactor Process Time (days)	1.75	3.0	5.0
At-MRS/Rep. Queue Time (days)	0.0	0.0	0.0
At-MRS/Rep. Process Time (days)	1.25	2.0	4.5
Purchase Price (1986 $)	800000.00	2000000.00	2750000.00
Annual Maintenance Cost (1986 $)	75000.00	125000.00	125000.00
Useful Life (years)	20	20	20
Annual Availability (days)	310	280	310
At-reactor Processing Cost ($)	5018.00	8298.00	15000.00
At-MRS/Rep. Processing Cost ($)	3000.00	6000.00	10000.00
At-reactor Processing Dose (p-rem)	0.289	0.510	0.827
At-MRS/Rep. Processing Dose (p-rem)	0.277	0.466	0.473
Loaded Weight (cwt)	560	2000	3000
Empty Weight (cwt)	515	1680	2150

Press <CTRL> <ENTER> to scroll
Press <ESC> <ESC> when done

Fig. 11. Cask System Definition.

TRANSPORTATION SYSTEM DEFINITION
Destination: **YUCCA MOUNTAIN, NV**

Edit Default Values for each origin, if desired

	TRUCK			RAIL		
Origin	Serv Opt.	# of Casks	Cask ID #	Serv Opt.	# of Casks	Cask ID #
FARLEY 1	:R:	:1:	:1:	:R:	:1:	:2:
FARLEY 2	:R:	:1:	:1:	:R:	:1:	:2:
BROWNS FERRY 1	:R:	:1:	:1:	:D:	:3:	:2:
BROWNS FERRY 2	:R:	:1:	:1:	:D:	:3:	:2:
BROWNS FERRY 3	:R:	:1:	:1:	:D:	:3:	:2:

Press <CTRL> <ENTER> when done

Fig. 13. Transportation System Definition by Individual Origin-Destination.

TRANSPORTATION SYSTEM DEFINITION
Destination: **YUCCA MOUNTAIN, NV**

Specify Global Default Values

TRUCK

Service Option :**R**:
- N—No Truck Service
- R—Regular Service
- D—Dedicated Service

Number of casks per shipment :**1**:

Cask ID # :**1**:

RAIL

Service Option :**R**:
- N—No Truck Service
- R—Regular Service
- D—Convoy Service

Number of casks per shipment :**1**:

Cask ID # :**2**:

Enter L for List of CASK ID #s : :

Press <CTRL> <ENTER> when done

Fig. 12. Transportation System Definition: Global Defaults.

OTHER INPUT DATA

Minimum Fuel Age :**10**:

Optimization Criteria Weights (%) Cost :**30**: Risk :**70**:

Last Year of Analysis :**2030**:

Ouput Level
1. Summary Tables
2. Detailed Tables

Selection :**1**:

Ending Inventories at Which Reactors?
1. All
2. None
3. Specify

Selection :**1**:

Press <CTRL> <ENTER> when done

Fig. 14. Other Input Parameters.