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A RISK-BASED DECISION-AIDING TOOL FOR WASTE DISPOSAL

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Abstract

N-CART (the National Spent Nuclear Fuel Program Cost Analysis and Risk Tool) is being developed to aid in low-risk, cost-effective, timely management of radioactive waste and spent nuclear fuel, and can therefore be used in management of mixed waste. N-CART provides evaluation of multiple alternatives and presents the consequences of proposed waste management activities in a clear and concise format

N-CART's decision-aiding analyses include comparisons and sensitivity analyses of multiple alternatives and allows the user to perform quick turn-around "what if" studies to investigate various scenarios. Uncertainties in data (such as cost and schedule of various activities) are represented as distributions. N-CART centralizes documentation of the bases of program alternatives and program decisions, thereby supporting responses to stakeholder concerns.

The initial N-CART design considers regulatory requirements, costs, and schedules for alternative courses of action. The final design will include risks (public health, occupational, economic, scheduling), economic benefits, and the impacts of secondary waste generation. An optimization tool is being incorporated that allows the user to specify the relative importance of cost, time, risks, and other bases for decisions. The N-CART prototype can be used to compare the costs and schedules of disposal alternatives for mixed low-level radioactive waste (MLLW) and greater-than-Class-C (GTCC) waste, as well as spent nuclear fuel (SNF) and related scrap material.

Introduction

Disposal of radioactive waste involves decisions that have a number of conflicting attributes. For example, minimizing cost may result in increased risk, meeting a stringent schedule for disposal can increase costs, minimizing public health risk may result in increased occupational exposure, and so on. These decisions are therefore excellent candidates for multiattribute decision analysis of the alternative paths to waste disposal and the alternative methods of waste disposal involved (Keeney and Raiffa, 1986).

Multiattribute decision analysis independently includes (1) the ranking of decision alternatives with respect to attributes and (2) the weighting of the attributes, i.e., the relative importance of the attributes to the decision-maker. Ranking and weighting are themselves complex procedures made up of many steps and requiring the assistance of a number of substantive and normative experts; an example of a radioactive waste-related decision analysis that illustrates the complexity of the process is given in U. S. Department of Energy (USDOE, 1986). As multiattribute decision analysis has become more widely used, analysts have sought to computerize decision-aiding tools that can perform at least part of such an analysis. N-CART is such a decision-aiding tool. While its initial focus is the USDOE-owned and managed spent nuclear fuel (SNF), it has broad application to waste management in general.

Decisions that are supported and assisted by the initial version of N-CART (Version 1.0) include:

- what is the optimum combination of characterization methods to use, considering only cost and schedule?
- if processing is needed before disposal, what is the most cost-effective processing method?
- is use of existing transportation containers or construction of new ones more cost-effective?
- must new transportation casks be certified in order to meet regulatory requirements and schedules?
- what programmatic risks are entailed in a particular set of alternative actions?

Decisions that will be supported by subsequent versions of N-CART include

- what is the optimum combination of cost, public health risk reduction, and occupational risk reduction?
- does processing waste before disposal reduce health risk significantly?
- what is the tradeoff in processing between risk reduction and secondary waste generation?
- do any waste handling processes result in significant economic benefit?

Risk considered in N-CART analyses includes risks to public health from both transportation and disposal of spentnuclear fuel (and eventually of other mixed waste), occupational risk, and programmatic risk entailed in alternative actions.

The N-CART Scheme

N-CART facilitates the on-line analysis and processing of multiple alternative means for handling, processing, packaging, and and transportation of spent nuclear fuel. The program presents the user with graphical representations of costs, schedules, uncertainties, and capacity utilization for each alternative. The initial scheme on which N-CART is based is shown in Figure 1, which is an example of several alternate "cradle to grave" pathways for SNF: sequences of steps that the SNF may go through between current storage and ultimate disposal. The potential steps in such a pathway are characterization (and any treatment, like drying, that must be done prior to characterizing, conditioning or processing, packaging, interim storage, and transportation to a disposal or retrievable storage facility. Interim storage at intermediate facilities and local transportation to and from such facilities also plays a part. Each of these potential steps can be carried out in a number of alternative ways, and each alternative has associated costs, schedules, and risks, as well as potential secondary waste generation and economic benefits. Version 1 considers costs and schedules and, indirectly, displays programmatic risk. The current discussion therefore deals only with the attributes of cost and schedule.

The N-CART engine reflects the current-storage-to-disposal path by moving fuel through the processes that comprise the path; some sample paths are shown in Figure 2. The user selects the fuels and the processes that make up the path (as discussed below), and the N-CART engine puts a counter on each fuel handling unit that tracks the movement of the fuel handling unit along the path. The engine also adds the costs and elapsed time of each process each time the process handles a batch of fuel. Because N-CART is an ACCESS program and can therefore link directly to any ACCESS database, and because the SNF database is an ACCESS database, N-CART uses information on fuel type, fuel condition, and number of fuel handling units directly from the SNF database.

Data Input

N-CART has three distinct types of data input: (1) the spent fuel (or radioactive waste) data base, hereinafter called the "waste data base," (2) the cost and schedule estimates (and, ultimately, risk, economic benefit, and secondary waste estimates) for the methods used to treat the waste, and (3) any documentation or constraints on waste treatment that apply.

The waste data base establishes the framework of questions in which the decisions about the waste are to be made. The SNF data base, a part of which is shown in Figure 3, illustrates this framework. There are 650 different spent nuclear fuel types under current or potential DOE management (USDOE 1996). About 450 fuel types, comprising about 220,000 fuel handling units, are currently stored in the United States: 280 fuel types (about 150,000 fuel handling units) in water pool storage and the remaining 170 types (about 70,000 fuel handling units) in dry storage. Fuel is stored primarily at the Idaho National Engineering and Environmental Laboratory (INEEL), the Savannah River Site (SRS), and the Hanford Reservation (Hanford), with relatively small amounts stored at Oak Ridge, Brookhaven, Sandia, Los Alamos, and Argonne National Laboratories and at university research reactors. At the very least, these fuels must be packaged for disposal and transported to the disposal site. Meeting transportation and disposal acceptance criteria may require characterization of some (if not all) of the fuel, and transportation will require drying at a minimum. The minimum decision framework for the fuel thus includes drying, on-site and off-site transportation, characterization, possible conditioning or treatment, and appropriate packaging both for transportation and disposal. Interim storage may also be necessary.

The modeling paradigm of the storage-to-disposal path of spent fuel is that each step in the path represents an action taken, or transformation, of the fuel. These transformations are generally referred to as "activities." The transportation, characterization, conditioning or treatment, packaging, and interim storage are classes of activities, or activity groups. Examples of activities for each activity group are shown in Table 1.

Table 1. N-CART Activities and Activity Groups

Activity Groups	Activities
Characterization	Confirmation of quality assurance (QA), Qualification of existing data Non-destructive evaluation (NDE): radiography ultrasound Non-destructive assay (NDA): gamma spectroscopy neutron interrogation passive neutron gross gamma count Calorimetry
Treatment/Conditioning	Drying Dilution of enrichment Vitrification Electrometallurgical separation Ceramification
Packaging	Dual-purpose canister Standard canister Co-disposal package with commercial SNF
Transportation	On-site transportation (dry) On-site transportation (wet) Off-site transportation Transportation casks
Interim Storage	On-site dry storage Dry storage at another site Interim centralized dry storage

Each activity has associated costs:

- One-time or fixed costs that include capital costs, research and development costs, and, ultimately, decommissioning costs.
- Periodic costs that include operation and maintenance costs that are independent of waste that the facility handles, and the cost of facility operation per waste handling unit or waste batch.

Cost is calculated by the following equation:

$$C = c_{onetime} + c_{periodic} * time$$

Each activity also has an associated capacity, defined as the number of fuel handling units that the activity can process in a single cycle, as well as construction, research and development, and throughput schedules. Other input data for each activity includes the wastes or SNF which apply and the capacity of the activity. Both the costs and the throughput schedule are associated with the capacity. The waste handling system modeled by N-CART is analogous to a batch production system. All of the cost and time variables in N-CART are entered into the program as input data and can be represented by one of several distributions that show the knowledge uncertainty of the variable. Figure 4, an input screen from N-CART, shows cost quartile distribution for a set of activities.

Each activity group also has associated parameters that can be selected by the user. Particular characterization activities are applicable to the characterization of particular properties (e.g., calorimetry is used to determine decay heat), particular packagings are suitable for transporting certain wastes, particular treatment methods apply to certain waste forms, and so on. When the user builds alternative paths for the waste in order to evaluate the relative costs and schedules, he or she selects activities from a menu that shows only those activities appropriate to the waste that is the subject of the scenario and applicable to the processes being evaluated.

N-CART includes a dynamic engine that applies the selected activities to the selected waste in sequence. In the present SNF model, any fuel can be coupled to any activity. However, N-CART can be set up so that, at the user interface, only those activities appropriate to the selected SNF will be available. The engine handles wastes in the priority order indicated by the user when the user sets up the alternatives that are to be evaluated. Alternatives that apply five activities to five fuels take between 5 and 15 minutes to run on a Pentium-type computer, although the time depends to some extent on the computer's available RAM. When the systemprocesses a large number of different fuels or many units of a single fuel, and when considerable detail is desired in the output, the engine may run for an hour or a little more. However, the input data base can be structures so as to aggregate wastes so that fewer single waste "units" are acted on by the engine.

Results

Figures 5, 6, and 7 show some typical N-CART results. Figure 5 shows the total median cost of the particular path modeled and the total median costs of each activity in the path. Figure 6 shows the movement of fuel through activities over the time period of the particular alternative path, and illustrates where "choke points" can occur in the system. By looking at Figures 6 and 7, the decision maker can determine whether the cost of adding capacity to relieve a choke point is prohibitive. He or she can also determine where other choke points may occur if one is relieved by added capacity.

Figure 7 shows the "drawdown:" the total time needed for fuel or waste to be transported off the site where it is now stored. This figure also shows when removal of waste from the site is linear and when there are overall delays (flat areas). The information in this figure is somewhat redundant with the information in Figure 6.

Documentation (records of decision, pertinent regulations, etc.,) can also readily available to the user.

Conclusion

The software tool described here is the first working prototype of the N-CART model It lacks some necessary features: capability of adding probability distributions, capability of aggregating throughput to decrease running time, more sophisticated rules for the engine, and capability of fast-turn-around sensitivity analyses. The present advantages of the system are (1) an accessible user interface, and (2) presentation of the waste flow in the system.

References

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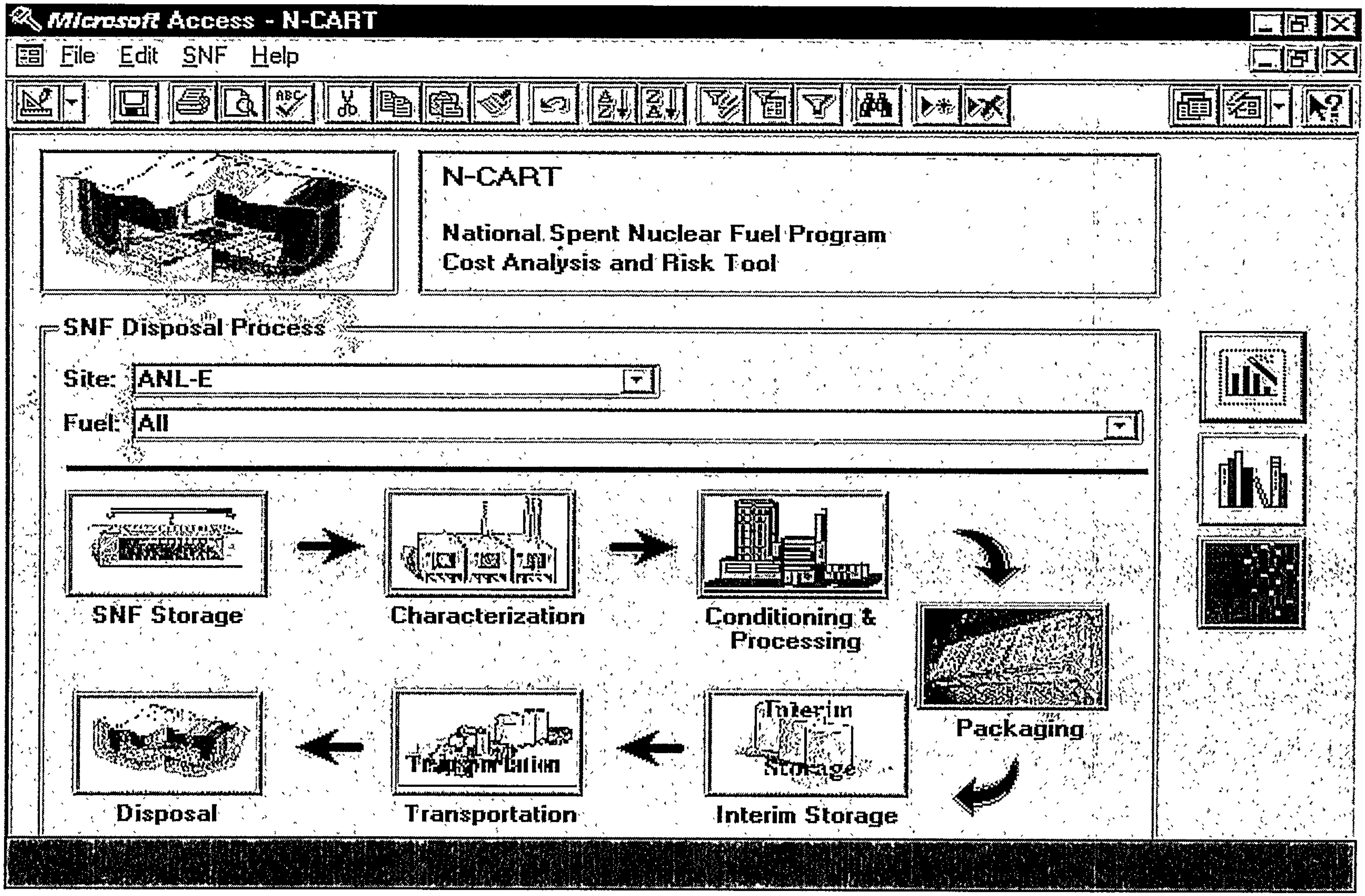

Figure 1. The opening screen of the N-CART program. The sequance shown in the bottom half of the screen is the overall storage-to-dsiposal ("cradle to grave") sequence for the disposition of DOE-managed spent nuclear fuel.

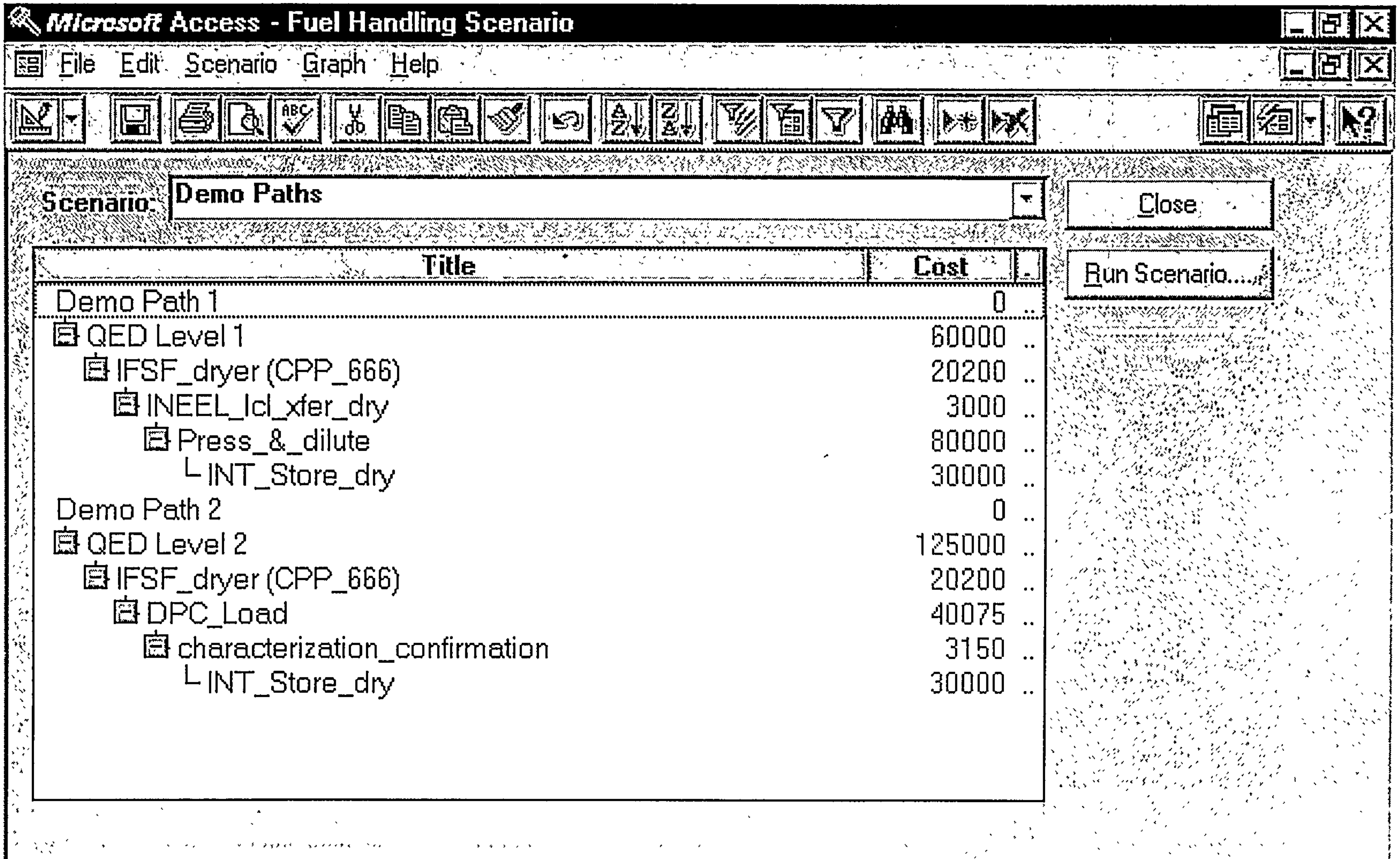

Figure 2 Two sequences of activities ("paths") taking spent nuclear fuel from its current storage to dry interim storage. "QED Level 1" is qualification od existing data by QE equivalence. "DPC" is a dual-purpose canister.

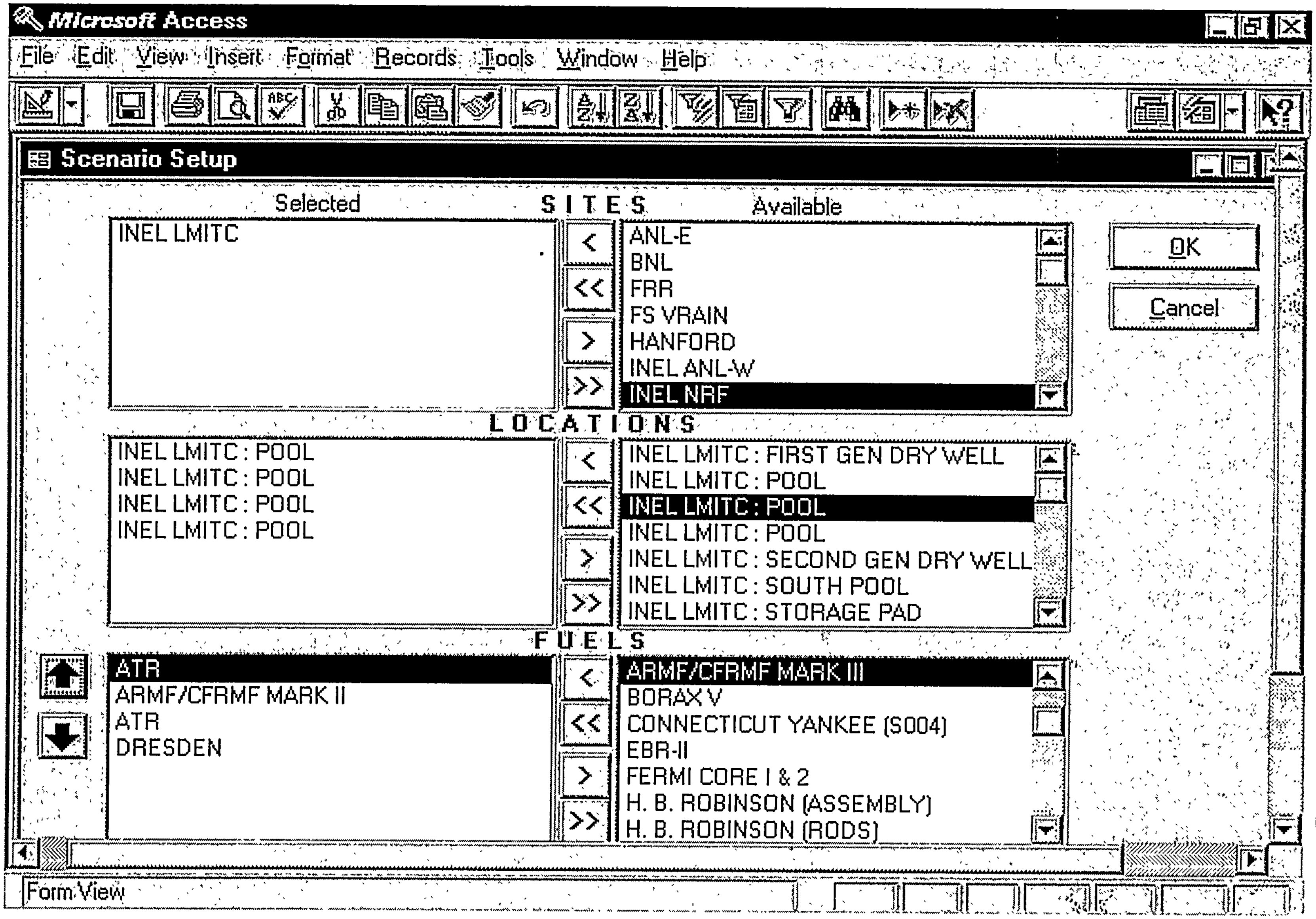

Figure 3. The three blocks on the right, titles "Available" indicate , from top to bottom, what SNF storage sites are available. When the user selects one or more sites by moving the selected sites from the left-hand box to the right-hand box, the locations and facilities at those sites appear in the middle right-hand box. The user then selects desired locations, and the fuels at those locations appear in the bottom right hand box. The user can then select the desired fuels.

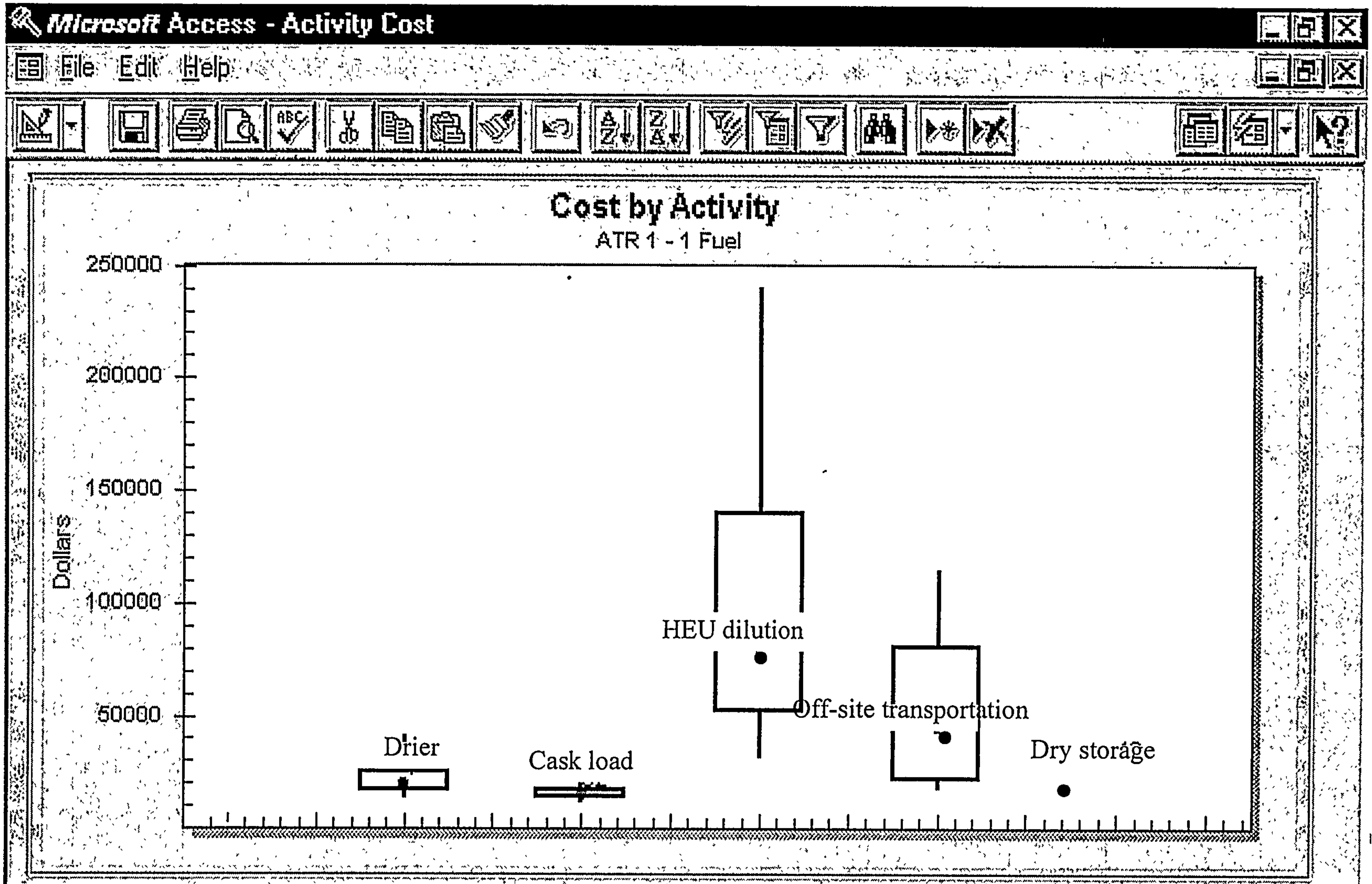

Figure 4. Cost distributions for a set of activities. The boxes are bounded top and bottom by the 75 %ile and 25 %ile , respectively. The upper and lower ends of the lines are, respectively, the maximum and minimum costs. The median cost is indicated by a dot. These are cost distributions for one cycle of the particular activity, rather than cost per fuel handling unit. Similar distributions can be displayed for the time needed for one activity cycle.

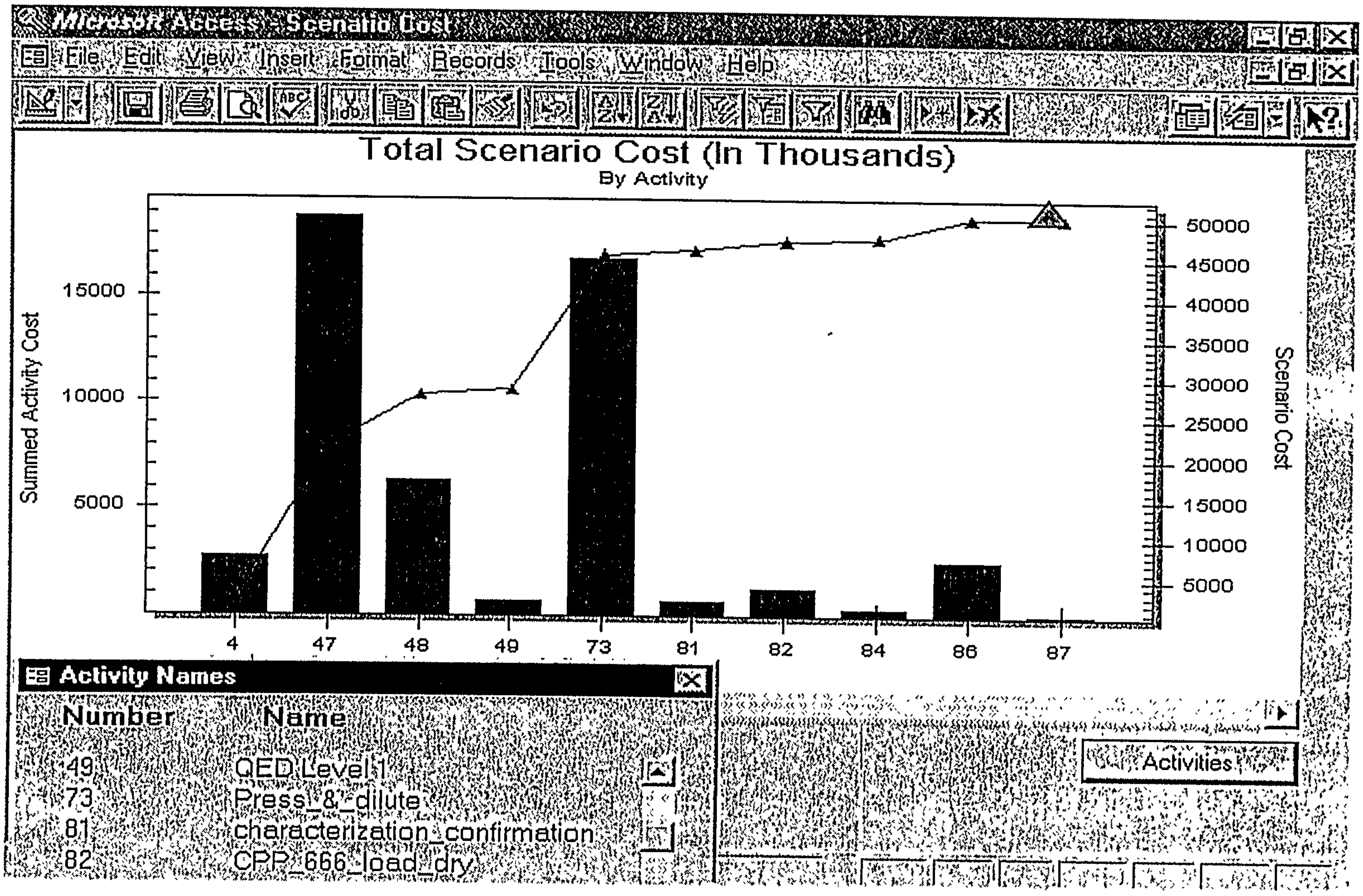

Figure 5. Output graph from N-CART showing the total cost of the particular sequence of activities (triangle at top right, right-hand scale) and the total cost of each activity (vertical bars, left-hand scale). Names of activities are shown in a scroll-down menu at lower left.

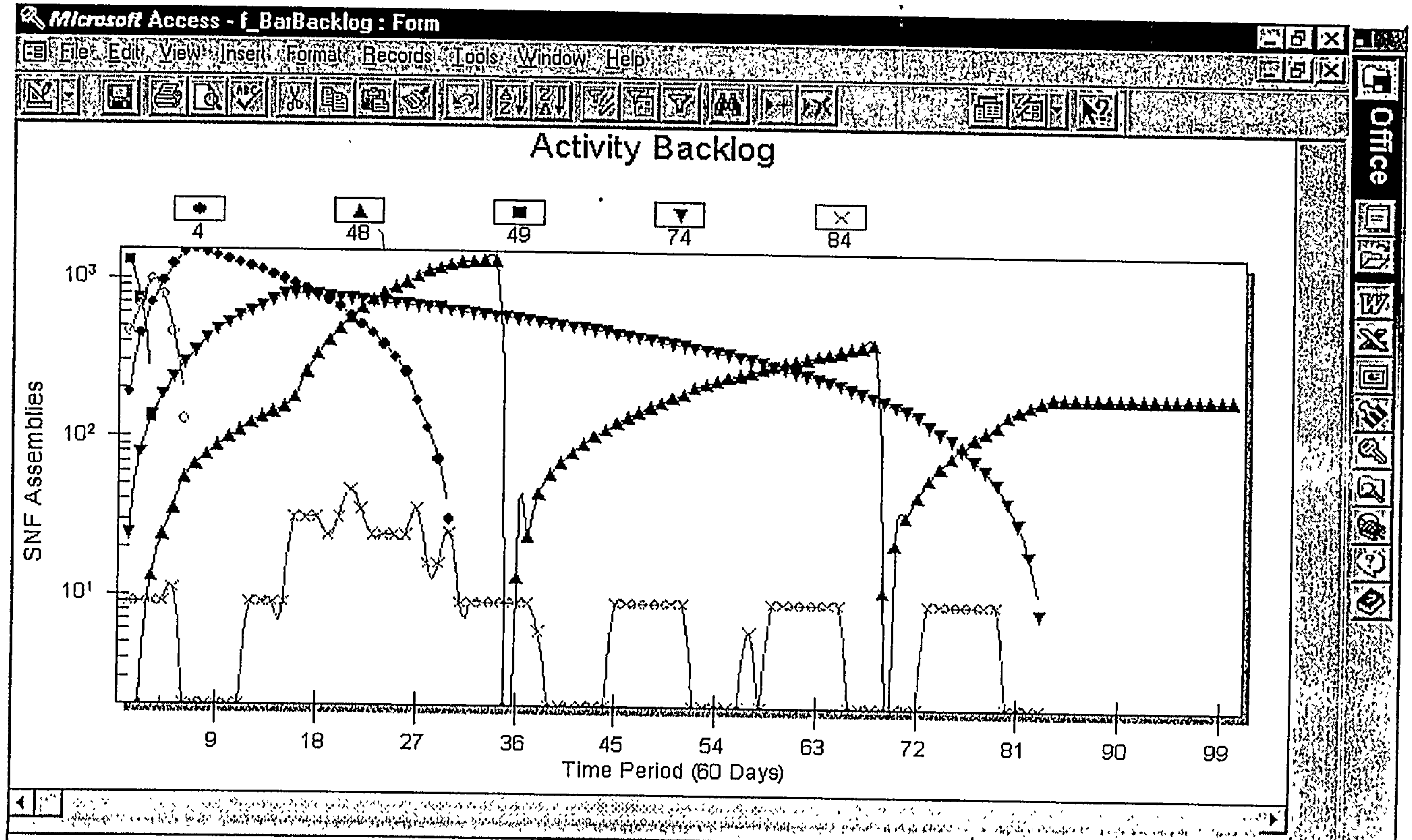

Figure 6. Time sequence of activities in a typical path showing buildup and drawdown for each activity. The total time for the scenario is 5940 days, or 16.3 years. Activities shown are Activity 49: qualify data by QA equivalence, Activity 4: drier, Activity 74: loading dual purpose canister, Activity 48: interim storage, Activity 84: local dry transportation.

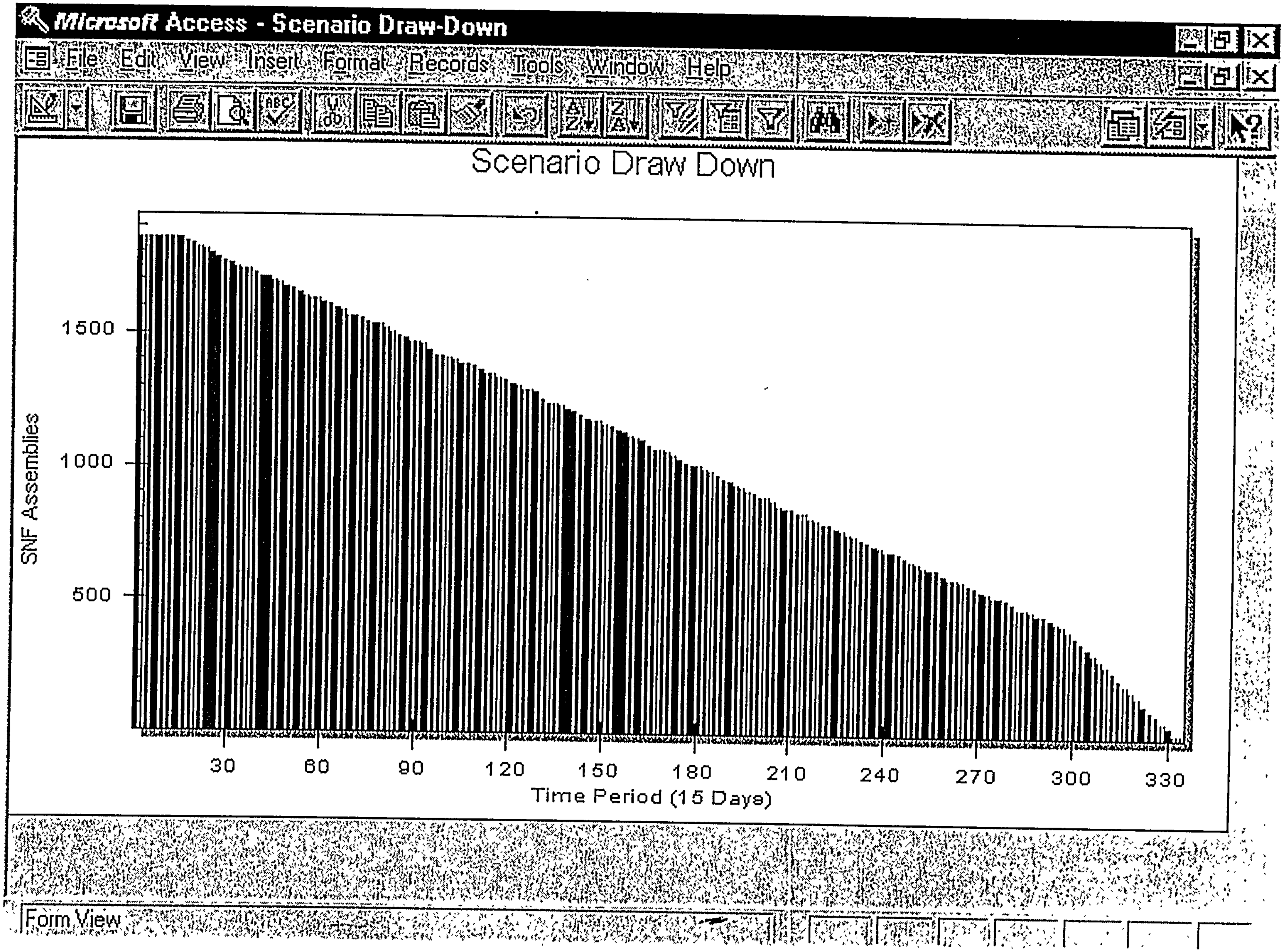

Figure 7. Overall movement of the fuel assemblies through the entire path. The scale on the x-axis is the number of time periods; each time period is 15 days, so that movement through the entire path takes 4950 days, or about 13.5 years.