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GASP IV SIMULATION OF NUCLEAR WASTE

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ABSTRACT

The current governmental research and development program for the disposition of high-level nuclear wastes from both defense and commercial sources is modelled using a discrete GASP IV based simulation. The simulation utilizes, as input, actual and current data from various DOE management information systems. A sampling of disposition data contained within these systems are milestones, storage facility capacities, and predecessor and successor relations. Decision variables include facility capacities and on-line times. Results indicate the time scheduling for bringing interim and final storage facilities on-line and the capacities of these facilities. An accident analysis module provides a probabilistic methodology to quantify intangibles such as congressional approvals and societal demands. The objectives of the simulation are to provide an effective management tool where the impact of alternative decisions can be evaluated and to gain visibility of existing and related data on waste disposition.

The generation of nuclear waste in the United States presents an important and highly visible management problem. Alternative disposition solutions exist and informed decisions are needed. Information covering all aspects (e.g., milestones, storage facilities capacities and handling rates, and location of facilities and waste generation points) of waste disposition is contained in several comprehensive Department of Energy (DOE) management information systems (MIS), in various documents, and in comprehensive data bases. These MIS's are continually updated and employed in the monthly reporting cycles of DOE. The successful solution to this disposition problem can only be achieved when existing data, residing in the MIS's and the documents, become structured logically for management decisions. To achieve the goal of successful waste disposition, simulation of the problem and its alternative solutions was undertaken. The General Application Simulation Program (GASP IV) based simulation accesses the various data sources; retrieves data such as milestones and storage facility capacities; structures them into events and parameters; extracts the decision variables; accepts DOE policy as input; and generates results which depict alternative and combinative dispositions. The model is deterministic in that the model portrays the results of structuring specific data by predetermined logic. When operating on current and real data, the model portrays exactly the result that will occur if no milestone, capacity, or handling rate changes are implemented. As is explained later, selected changes in data and decision policies can be performed to assess the impact of these changes.

In the United States, nuclear wastes are generated from both the defense and the commercial programs. The wastes must be properly disposed. There are many waste processes pertaining to each program which remain separate until the final process steps. The identification and evaluation of alternative processes have been continuing sporadically for years. Executive policies of the past several administrations have heavily influenced and/or halted various disposition plans. Figure 1 illustrates the available alternatives, their process steps, and the relationships between them. This figure includes the larger but less visible defense waste program, the combinatorial and the competitive repository step, the once-through alternatives, and the cycle alternative which is absolutely necessary for the realization of the breader reactor. This figure is explained in the following paragraphs.

The various processes in both the defense waste and commercial waste programs are symbolized as either circles or rectangles. The process is identified above the line within the symbol and the information source for that process is identified below the line. A circle represents a source of data extracted from a comprehensive MIS developed and maintained for the DOE by Virginia Tech. A rectangle represents a source of data obtained from a DOE document, direct conversation with a DOE official, or a centralized data base. Virginia Tech has developed the MIS's containing data on waste form and packaging studies carried out under the High Level Waste (HLW) Technology program at DOE's Savannah River Operations Office (SRO) and on interim spent fuel management (ISFM) studies performed under the Spent-Fuel Project Office at SRO. Other sources of information include the Integrated Data Base maintained at the Oak Ridge National Laboratory (ORNL), documents produced by the Office of Nuclear Waste Isolation (ONWI), and the commercial spent fuel data base developed and maintained by the S. M. Stoller Corporation. The Integrated Data Base provides data on the amounts and locations of high level defense wastes. Information covering geologic repository capacities and on-line times is provided by ONWI. Finally, the comprehensive Stoller data base yields detailed commercial spent-fuel discharges. This information is listed by individual reactor and includes the years from the present through 2003.

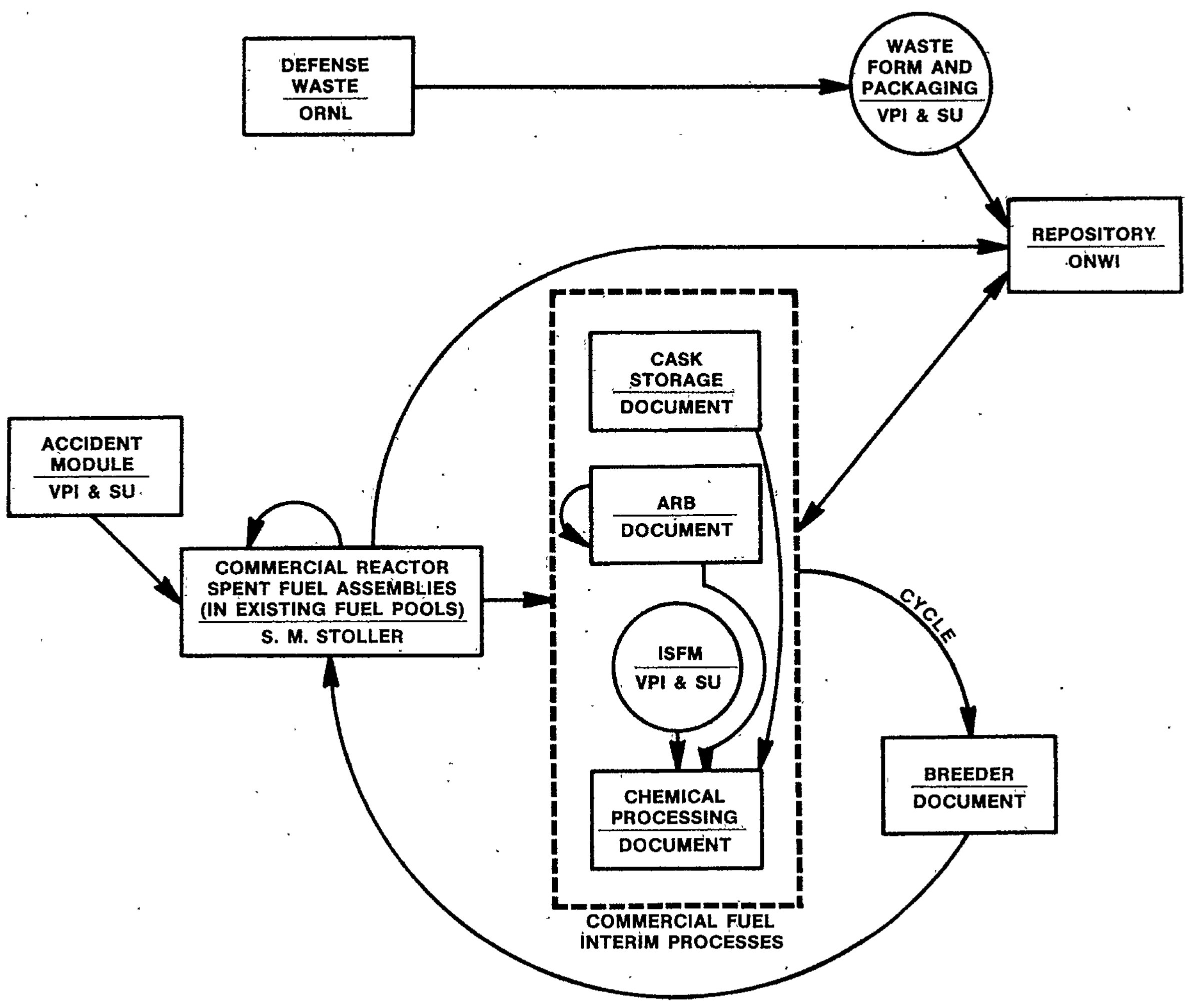

Figure 1. Available Alternatives for the Disposition of Nuclear Waste

By examining Figure 1, the relationship between all of the sources of data can be ascertained. Within the dotted lines are the commercial waste interim processes. Included is the chemical processing (reprocessing) step. Cask storage in specialized non-transportable casks is depicted as a separate input. Current plans are to include cask storage studies within the ISFM system. Acting upon the Stoller data is an accident analysis module. This module is an original effort to incorporate societal or congressional efforts into a technical problem and is explained later.

Figure 1 shows the flow of both commercial and defense wastes. The wastes originate either as defense wastes or as commercial reactor spent-fuel assemblies which are stored in existing at-reactor pools awaiting a disposition selection. From the existing fuel pools the potential alternatives for movement of fuel include storage in fuel casks, storage in at-reactor basins (ARB), storage in dry vaults, and/or some type of chemical processing. Additionally, if necessary, intrashipment and intershipment between existing fuel pools of reactors of the same utility or of other utilities can be undertaken. Also, wastes can be redistributed within any single alternative, as shown for the ARB's. To provide fuel for the breeder reactor, the fuel process must include chemical processing; and fuel cycled through the breeder then is assumed to be recycled through the system.

The two sources of information maintained at Virginia Tech (represented by circles in Figure 1) contain some of the most detailed and comprehensive data employed in the simulation. These sources contain information concerning the generation and interim storage of high-level nuclear wastes from both defense and commercial reactors. The following two paragraphs review these two sources in order to indicate the type and comprehensiveness of the data employed in the simulation model. This same completeness is characteristic of both the Integrated Data Base and the Stoller data base.

Because of its extreme radiation levels, high level wastes (as opposed to low level wastes, airborne wastes, or long-lived transuranic wastes) pose the greatest threat to the public, and must be isolated from the human environment. The defense wastes are stored in several locations across the country, are in various forms, and are up to thirty five years old. Expecting short-term storage, the storage tanks and wastes have deterioriated over the years resulting in a high-priority problem. To solve this problem, the wastes are to be solidified and stored in underground repositories. The DOE program for the selection of waste form and packaging of defense wastes (HLW Program) utilizes an MIS which assists in the management of the research and development of various alternative waste forms for solidification of HLW. Current research in various waste forms and their associated chemical and mechanical processes includes work on borosilicate glass, concretes, ceramics, clay, calcines, synroc, and metal matrixes. In late 1981 or early 1982, a selection of one or two of the more promising forms will be accomplished. After detailed studies a single waste form will be selected. The MIS contains all aspects associated with the various waste forms and associated processes, including management activities such as licensing. The progress of the selection process is maintained within the MIS. The type of solidification process selected impacts the amounts of solid waste materials, and the heat generation of the materials. In turn, the capacities of the repositories can be determined through the simulation.

The DOE program for the research, development, and demonstration of advanced storage techniques for commercial reactor spent fuel (ISFM Program) utilizes an MIS which assists the managers in gaining experience and analytical data necessary to provide sound technical bases for licensing new storage concepts. Expecting a chemical processing stage to provide for recycling spent fuel, the nuclear industry provided for little interim storage capacity. The lack of chemical processing places great emphasis on alternative storage techniques to ensure that no nuclear reactor shuts down due to a lack of storage space for spent fuel. Increased storage capacity will result from either greater utilization of (e.g., reracking, rod consolidation, double-tiering) or the addition of (e.g., away-from-reactor facilities; silo, cask, or vault storage; additional at-reactor basins) storage space. The MIS for the commercial high level nuclear waste program contains data from which the progress of alternative techniques can be monitored.

The logic which overlays the process steps, illustrated in Figure 1, includes decisions, priorities, and preferences. This logic has been simulated in a GASP IV model which interfaces the various sources of data. This simulation model of waste disposition is divided into two systems as shown in Figure 2. The modules of System One correspond to the sources of information depicted in Figure 1. This information is accumulated and formatted through a master interactive program. In employing such an interactive system, the user has real-time access to the various processes and sources of information. After the interactive program formats the information, said information is fed into System Two which is orchestrated by GASP IV. The simulation can be employed by the DOE managers in three different modes. The first mode is to analyze current status; the second, to analyze the effects of an accident upon disposition; and the third, to allow the managers to play "what-if" games. Each mode attacks the input data in a different fashion. Once the GASP IV event file is created and finalized, the time-advancing simulation commences. This function is exactly the same for all three modes. The separate modes are reviewed and the differences explained. Next, the time-sequencing phase of System Two is discussed.

In the first mode of operation, the first phase of the simulation involves the tracking of interrelated milestones/activities through the two MIS's maintained at Virginia Tech. An activity is defined to be a specific unit of work characterized with a start date, an end date, predecessor relationships, and successor relationships. An example of two related activities is rerack design and rerack licensing. By the relationship, the effects of a delay in the design acitiviy on the licensing activity can be determined. Similarily, delays in licensing impact storage capacity on-line times. This first phase of the simulation tracks

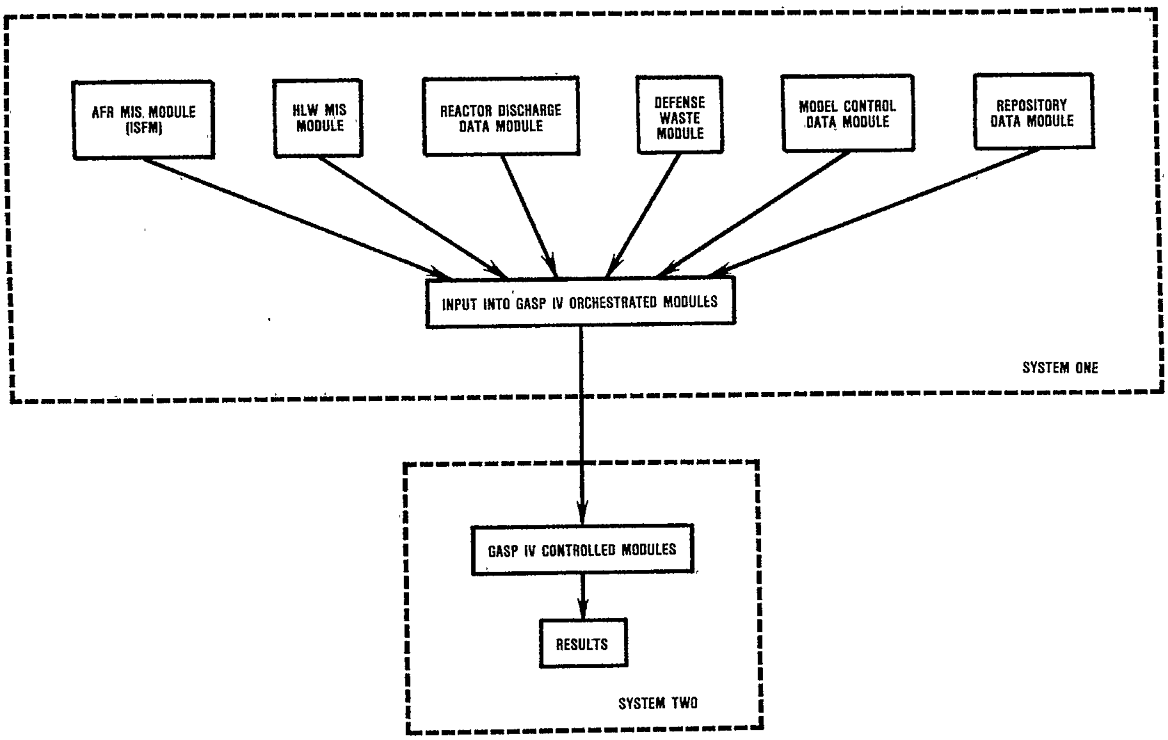

Figure 2. Flow Diagram of the Simulation Model

the milestones yielding culminative milestones representing the events of the GASP IV orchestrated simulation. Examples of such culminative milestones include environmental impact statement approvals, congressional legislative approval, and facility construction completion. Since these MIS's are continually updated by the different DOE program offices, the events of the simulation represent current status.

The second phase of mode one is the accumulation of information from the remaining sources (i.e., those sources not developed and maintained at Virginia Tech; for example, commercial spent fuel discharges). This comprehensive package of data covering all aspects of high level waste disposition is structured in parameters, events, and decision variables. Control is then turned over to GASP IV.

In the second mode of operation, the first and second phase described above still apply. After the accumulation of the data into a GASP IV event file, an accident analysis module is invoked before the time-advancing simulation begins. Nuclear waste disposition is beset with uncertainties and intangible events such as public opinion, environmental suits, and nuclear plant accidents. These uncertainties fall into the category of complete ignorance; that is, there exists neither subjective nor objective knowledge of the probabilities of future events. To quantify the uncertainties and intangibles events, an accident analysis module was developed. Here the term accident is used in its broadest sense: any undesirable occurrence. An accident affects the individual storage demands (i.e., yearly commercial reactor discharges). The user inputs a suggested yearly accident rate. Then, through a random number generation scheme, this module determines the years in which an accident will occur. For these years, two parameters are required: 1) the percentage of reactors which are affected by the accident and 2) the number of years that the discharge from these reactors are delayed. For example, the module predicts that in 1986 an accident occurs at one plant which results in governmental action against all similar reactors. Thus, reactors are shutdown for two years while adjustments are performed. The two parameters are determined by a series of exponential and linear equations. The user selects the coefficients of these equations in order to tailor the module to his beliefs. After the calculations, the GASP IV event file is altered to reflect the effects of the accident and control is returned to GASP IV.

The third mode of opeartion permits a user to create a scratch file consisting of the MIS's and various documents. This scratch file not only includes the MIS's developed at Virginia Tech, but all of the sources depicted in Figure 1. Any desired change or changes can be made to this scratch file. An example of this mode is to determine the effects of a six months delay in the approval of the final generic enviornment impact statement concerning dry storage techniques. All that is required is for the manager to identify the appropriate activity in the MIS and alter the milestone date. In a similar fashion, a repository capacity can be changed or a new ARB added to the scenario. After all such changes are performed, the simulation commences. At this point, the method reverts back to mode one, with the exception that the data bases on the scratch disk are employed. In using the third mode of operation, the simulation will ascertain the effects of any desired change or changes throughout the entire disposition program for the next forty years.

As previously mentioned, the three modes reviewed above are differentiated in the manner in which they access the MIS's and input documents and then manipulate the GASP IV event file. After the event file is finalized, the time-sequencing begins. From this point on there is no difference in operation between the three modes. The logic is controlled by various event codes. There exist six major event codes: 1) storage demand (e.g., spent fuel); 2) storage supply (e.g., a reprocessing facility coming on-line or an additional ARB); 3) fuel removal (e.g., fuel transfer from a repository to a reprocessing facility); 4) statistics on various storage facilities; 5) output data; and 6) commercial reactor discharges (i.e., bypass the S. M. Stoller program which does same). Event code six is employed if the user does not have access to the actual Stoller program, but does have access to the Stoller data base. As each discrete event is realized, the logic of waste disposition is simulated.

Figure 3 shows the sequencing of actions when an event of commercial waste discharge (event code one) is encountered. This sequence simulates the storage priorities. Whenever shipment is off-site, a shipping cask module is evoked. This module checks the availability of a shipping cask or casks and calculates the amount of time required for cask utilization by using the distance travelled and mode of transport (truck or rail). Detailed statistics on all aspects of cask availability and utilization are recorded.

Many reactor complexes have multiple reactors at the same site. Each reactor usually has its own storage pool. If an individual pool is filled to capacity, the possibility exists to store spent fuel in an adjacent reactor's pool. This intrashipment does not require extensive governmental approvals. The simulation model performs this function by utilizing the latitude, longitude, and individual pool capacities of each reactor complex. Intershipment between reactor complexes is presently limited to complexes within the same utility. This is based upon governmental regulations and can be altered at any time.

Each of the remaining sequence steps shown in Figure 3 is handled by a separate module. For example, the change in the capacity of an away-from-reactor (AFR) facility is flagged by a separate event code. This code leads the simulation to a module which incorporates the change into the model. In this manner, additional options can be easily incorporated into the simulation.

In an analogous fashion, the other events are logically simulated. After the simulation is terminated, the various outputs are produced. The outputs include detailed listings of individual spent fuel shipments, statistical evaluations of storage alternatives, and summary graphical supply versus demand curves. Figure 4 represents the form of the graphical output. The combination of each alternative with the total facility capacity is shown as the difference between the curve which first includes that alternative and the curve below it. The cumulative curve includes all alternatives. The projected demand for capacity is shown and the variance with capacity is represented by the shaded portion of the curve.

Employing the first mode of operation against data bases and documents current on July 1981 yielded numerous outputs. Two summary graphs are reviewed to explain the present disposition policies. These graphs are produced from a graphics package designed by the authors which replaces the standard GASP IV supplied graphs. The package interacts with the simulation model, gathers the necessary data points, and automatically produces the desired plots. Figure 5 shows the supply and demand curves for commercial spent fuel. This is based upon two reprocessing facilities (first on-line in 1991) and two repositories (first on-line in 1998). Notice that between 1988 and 1994 that demand exceeds supply. In studying the detailed output, one can ascertain that a limited supply of storage casks can alleviate this problem area. Figure 6 shows the repository space requirements resulting from the same input data. Shown in this figure are the three types of wastes--commercial HLW resulting from a reprocessing facility, commercial spent fuel, and defense HLW. The space requirements are based upon waste heat calculations. Due to the heat of new commercial spent fuel, this fuel accounts for almost an order of magnitude more space than the voluminous older, and hence cooler, defense wastes. Additional specific graphs and detailed listing provide the DOE managers with a mechanism to analyze this particular scenario in great detail.

Two major objectives are achieved through the model. The first objective is to provide an effective management tool where the impact of alternative decisions can be evaluated. The second is to gain visability of existing and related data on waste disposition. By interfacing the official DOE MIS's, this objective is realized. The model capitalizes on existing living data without the requirement to develop new data bases to support the simulation. The simulation tracks the effects of any change, through detailed interrelationships, on the entire waste disposition scheme. In such a manner, the DOE program managers can implement policy decisions which the simulation model predicts will have the most favorable results, or at least will have the minimum negative impact.

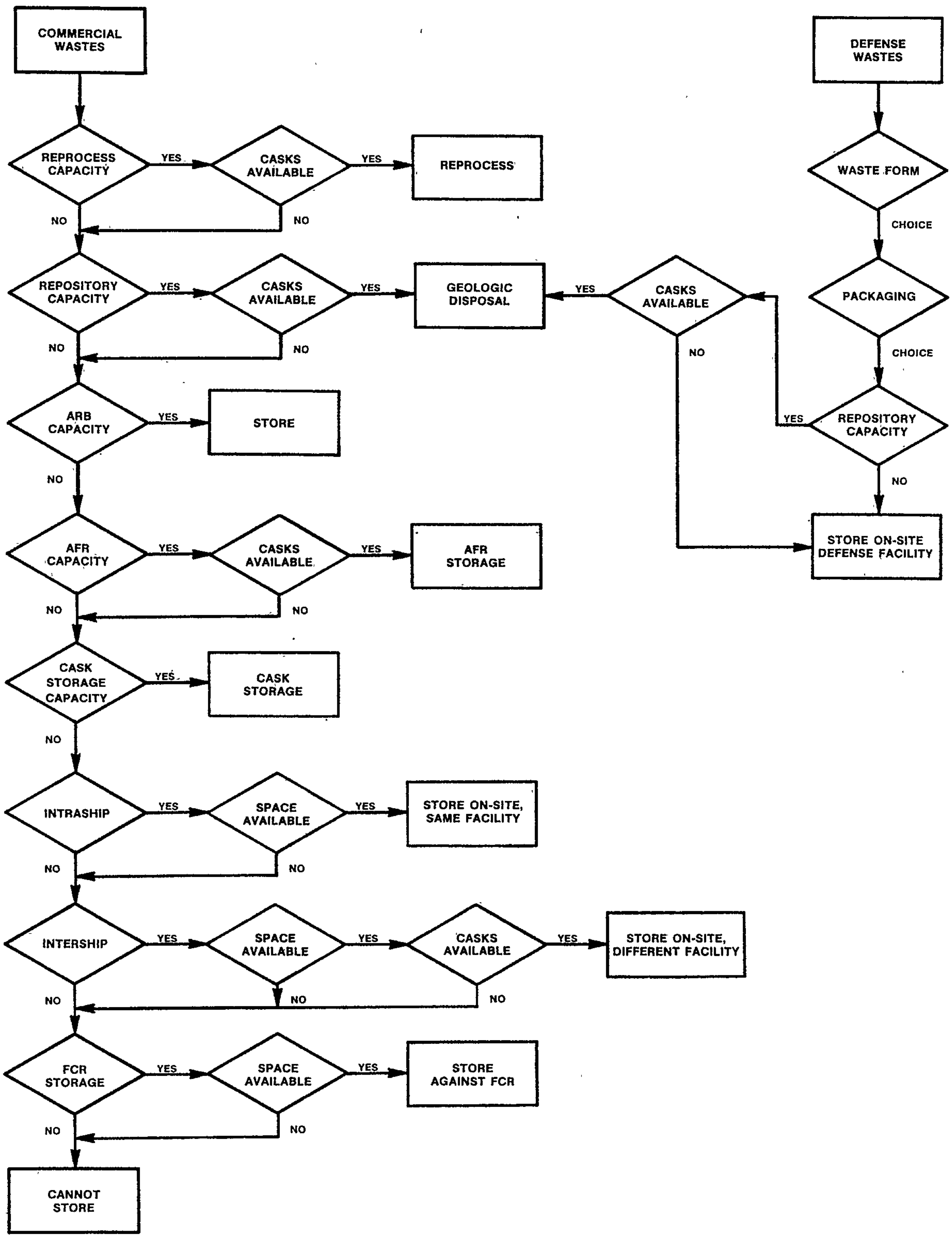

Figure 3. Nuclear Waste Disposition Logic Diagram

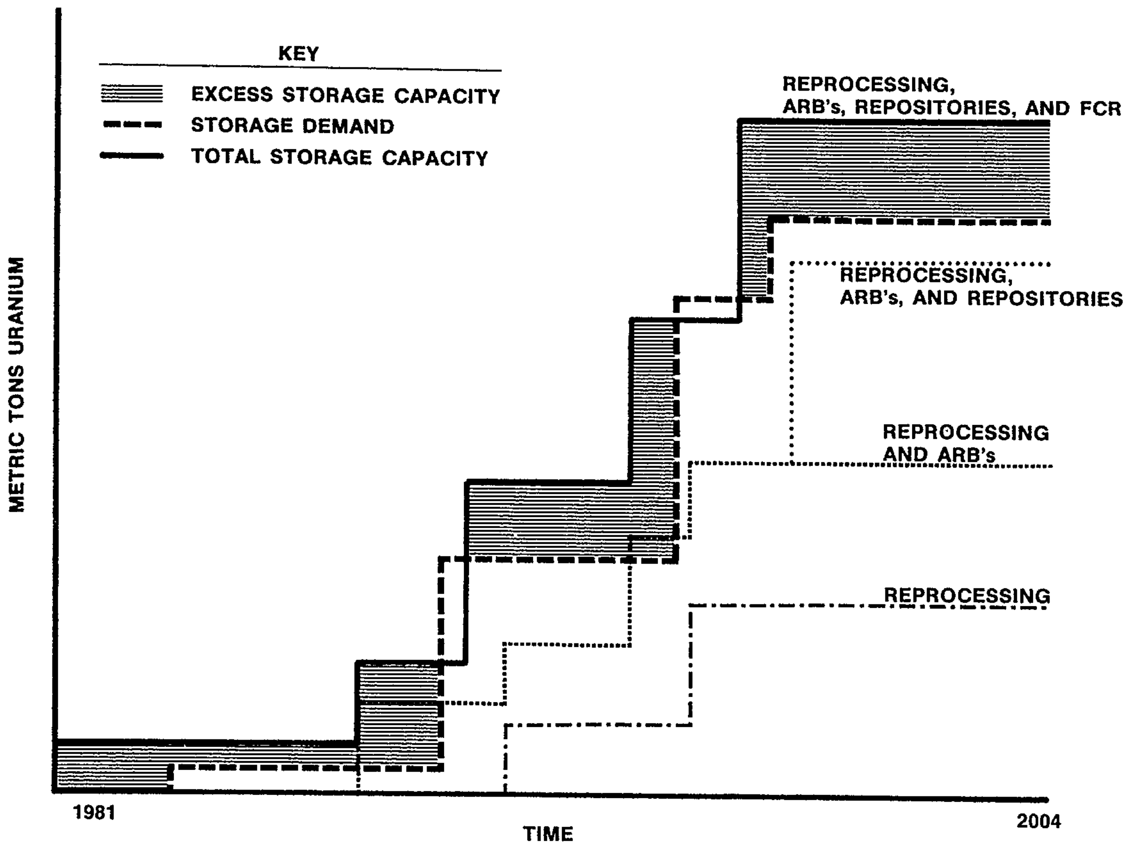

Figure 4. Typical Simulation Result

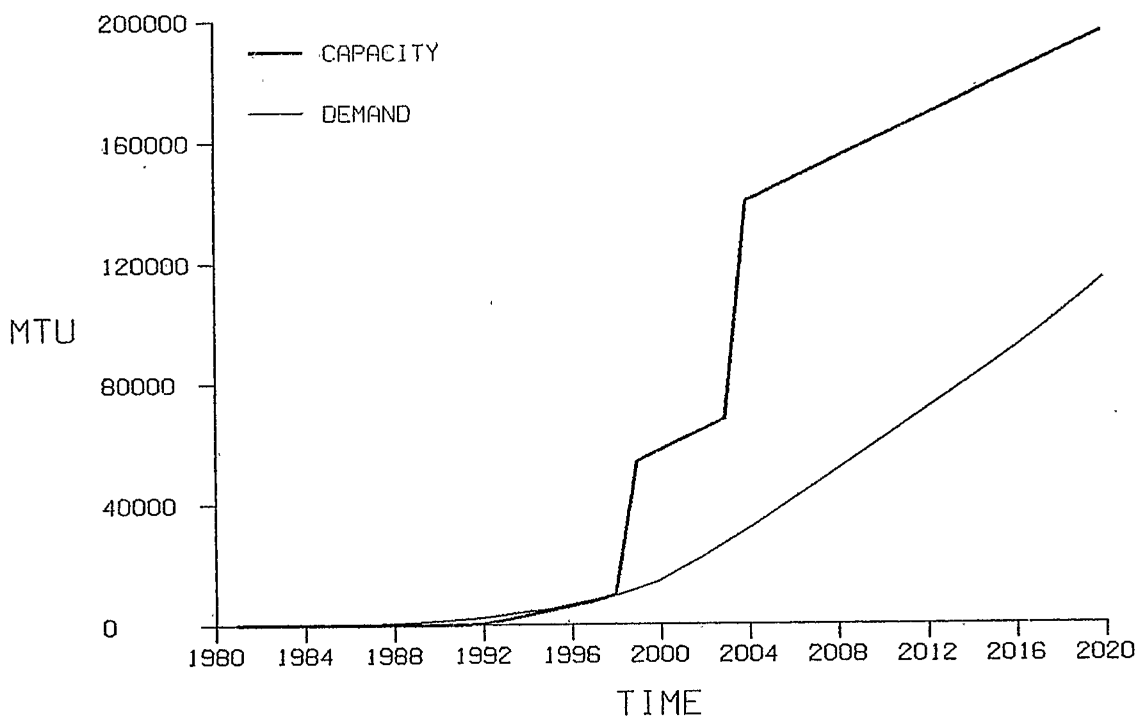

Figure 5. Commercial Spent Fuel Storage Supply and Demand

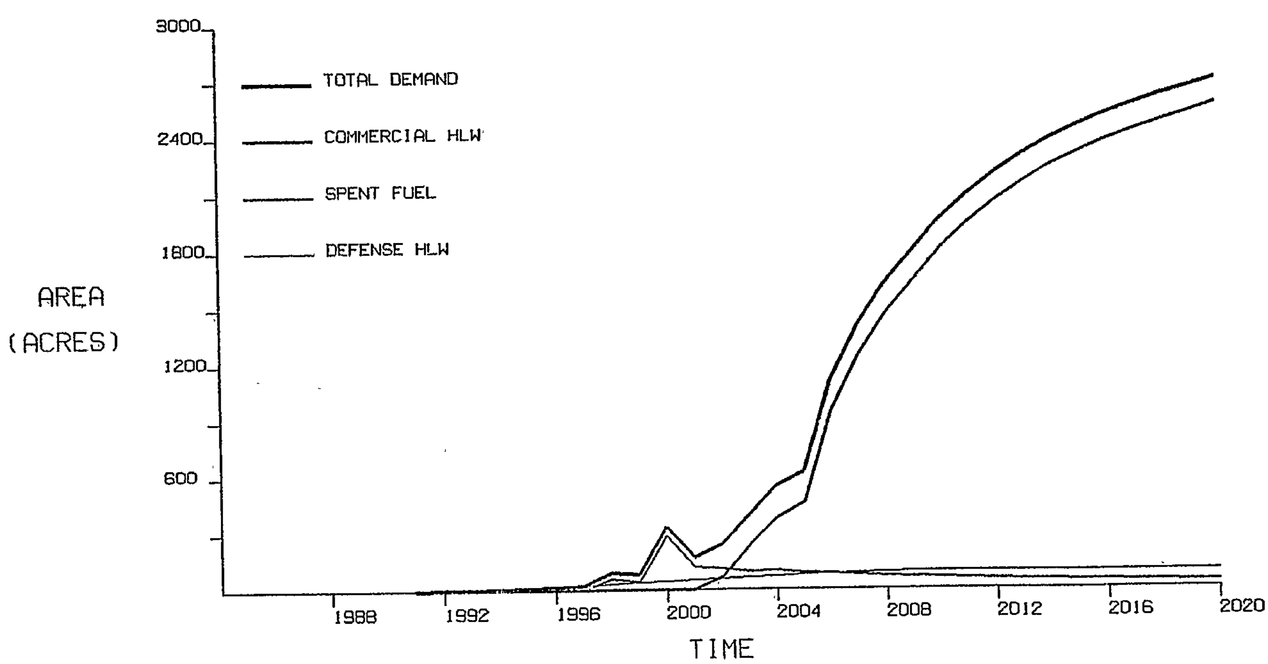

Figure 6. Repository Space Requirements