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The Utility of System-Level Ram Analysis and Standards for the U.S. Nuclear Waste Management System

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March 1992

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute



PNL-8039

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

PNL--8039

DE92 011916

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AND STANDARDS FOR THE U.S. NUCLEAR WASTE
MANAGEMENT SYSTEM

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Pacific Northwest Laboratory
Richland, Washington 99352

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EXECUTIVE SUMMARY

The Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) is responsible for developing a system to manage spent nuclear fuel and high-level radioactive waste in accordance with the Nuclear Waste Policy Act of 1982 and its subsequent amendments.

Pacific Northwest Laboratory (PNL) is assisting OCRWM in its investigation of whether system-level reliability, availability, and maintainability (RAM) requirements are appropriate for the waste management system and, if they are, what the appropriate form should be for such requirements. Based on the results of a literature search, a facility survey, and RAM modeling of the waste management system, PNL offers the following recommendations:

- System-level RAM standards and analyses should be considered as appropriate aids in designing the waste management system. They can be valuable early in the system definition and design processes as long as they accurately reflect the state of knowledge about the system.
- Fundamental system performance objectives (e.g., the most basic schedules, waste priority/acceptance criteria, throughput, dose limits, cost targets) should be established before system-level RAM standards are written. However, system-level RAM-type analysis can be a valuable tool when applied early to help establish practical system performance objectives.
- System-level RAM standards should be few and concisely stated. For each major system element (e.g., individual facilities), an overall availability standard should be set. More detailed RAM analysis can then be used to help design smaller system components in conformance with system-level standards.
- Detailed RAM analysis for the waste management system is not immediately necessary in view of ongoing work to further define the basic system configuration and performance objectives. Detailed RAM analysis must proceed in an iterative manner in conjunction with system design through increasing levels of specificity.
- DOE does not need to develop generic RAM tools and guidance materials. Ample resources (instructional materials, computer programs, analytical services) are available. RAM models tailored to the waste management system should be developed from available generic tools.

Most of the RAM studies done on large, complex systems are part of either classified government projects or business-sensitive industrial projects. Little documentation is publicly available, but several organizations, including architecture and engineering firms, construction contractors, electrical utilities, and industry groups, were willing to describe their experience with system-level RAM standards and analyses. The consensus among the surveyed organizations follows:

- System reliability, availability, and maintainability should be considered from the start of a project as part of good engineering practices.
- RAM standards created at a project's conceptual stage are typically few and broadly stated, and should be derived directly from basic operational objectives.
- RAM requirements established at any subsequent design stage must be derived from the system or subsystem operational objectives.
- A clear, logical, rational hierarchy of RAM requirements must be maintained, with each level of RAM standards derived from those of the next higher level.
- RAM analysis is more general, qualitative, and varied in its application at early phases of major systems development projects than at later design stages.
- RAM analysis is appropriate only to the level of detail for which adequate supporting data are available.

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ACRONYMS AND ABBREVIATIONS

A&E	Architectural and engineering
CAMDS	Chemical agent munitions disposal system
CEA	French Atomic Energy Agency
CHB	Container handling building
CSDP	Chemical stockpile disposal program
DOE	U.S. Department of Energy
EPRI	Electric Power Research Institute
FMEA	Failure modes and effects analysis
GE	General Electric Corporation
HLW	High-level radioactive waste
IAEA	International Atomic Energy Agency
INEL	Idaho National Engineering Laboratory
ISFSI	Independent spent fuel storage installation
JACADS	Johnston Atoll Chemical Agent Disposal System
LWR	Light water reactor
MDB	Main demilitarization building
MRS	Monitored retrievable storage
MTU	Metric ton uranium
NPRDS	Nuclear Plant Reliability Data System
NRC	U.S. Nuclear Regulatory Commission
NSSS	Nuclear steam supply system
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
OECD	Organization for Economic Cooperation and Development

PNL Pacific Northwest Laboratory
PRA Probabilistic risk assessment
PWR Pressurized water reactor
RAM Reliability, availability, and maintainability
RESAR Reference safety analysis report
RHR Residual heat removal
RMP Ralph M. Parsons Company
SWI Southwest Research Institute
WVNSC West Valley Nuclear Service Corporation

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) is responsible for developing a system for managing high-level radioactive waste and spent fuel in accordance with the Nuclear Waste Policy Act (NWPA) of 1982 and its subsequent amendments. OCRWM responsibilities include integrating and coordinating the design and development of system elements to ensure that they can be deployed on schedule, achieve reliable system performance, and meet cost objectives.

Pacific Northwest Laboratory (PNL)^(a) is assisting OCRWM in investigating whether a system-level operational reliability requirement is appropriate for the national radioactive waste management system and, if it is, in defining the appropriate form for such a requirement.

1.1 OBJECTIVES

The goals of this investigation were to determine whether reliability, availability, and maintainability (RAM) standards at the system level are useful and/or necessary for the waste management system to meet its performance objectives and to describe the appropriate RAM standards and how they should be applied. This report describes the results of three activities that have been conducted to date: 1) a system-level RAM literature search (described in Section 3.0), 2) a survey of organizations and facilities that have performed RAM analyses and/or set high-level RAM standards (Section 4.0), and 3) preliminary RAM calculations performed on a model of the U.S. nuclear waste management system as it is presently envisioned (Section 5.0 and Appendix B). Conclusions and recommendations can be found in Section 2.0, while survey resources are contained in Appendix A.

The literature search and facility survey were conducted to identify nuclear-related organizations and facilities that have incorporated RAM

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standards into their design and to assess how RAM standards can assist waste management facilities in meeting their performance objectives.

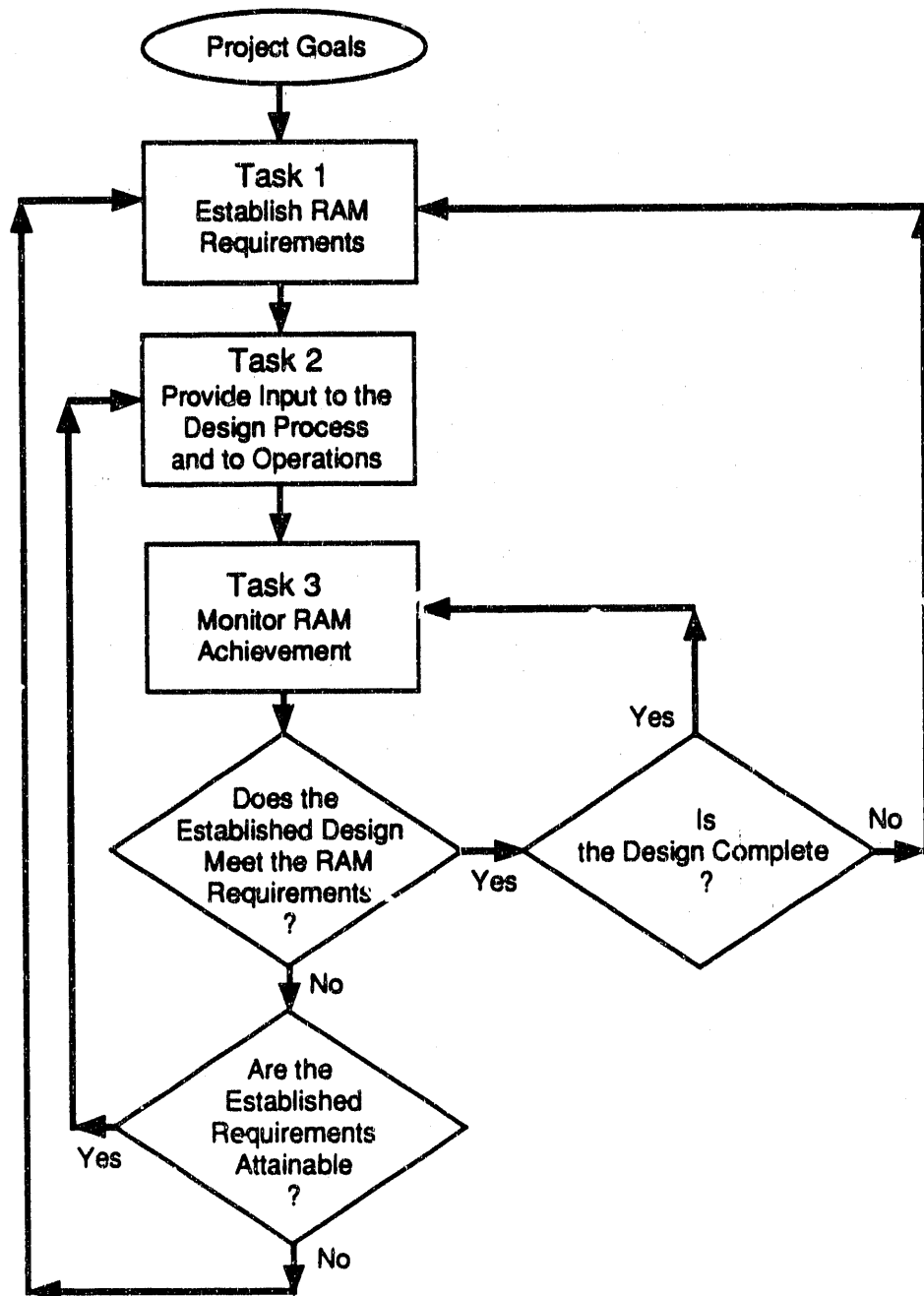
2.0 CONCLUSIONS AND RECOMMENDATIONS

The consensus of the cognizant engineers, analysts, and project managers interviewed in the course of this study was that large projects can benefit from consideration of RAM issues in the early stages of development. While early RAM standards will necessarily be general and qualitative, early consideration of RAM issues is considered to be good engineering practice. The degree of detail of resulting RAM standards should match the degree of completion of the overall design. All the organizations that regularly include RAM analysis and/or RAM standards in their system design procedures outlined a RAM process similar to the one shown in Figure 2.1 (Guthrie et al. 1988a).

2.1 CONCLUSIONS

The points of consensus on complex, multiple-facility system development that emerged from this study are these:

- System reliability, availability, and maintainability should be considered from the start of a project. Consideration of RAM issues is part of good engineering practice.
- RAM standards created at a project's conceptual stage should typically be few, broadly stated, and derived directly from basic mission statements (e.g., schedule, throughput, safety, and economic objectives).
- RAM requirements established at any subsequent design stage must be derived from the system or subsystem operational objectives (schedule, throughput, safety, cost).
- A clear, logical, rational hierarchy of RAM requirements must be maintained, with each level of RAM standards derived from those of the next higher level:
 - mission statement and operational objectives for the overall system
 - system-level RAM requirements (pertaining to interacting facilities)
 - facility-level RAM requirements
 - RAM standards for major plant operations



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FIGURE 2.1. Simplified Flowchart of the RAM Process (Guthrie et al. 1988a)

- RAM standards for work stations
- RAM standards for individual machines.
- RAM analysis is more general, qualitative, and varied in its application at early phases of major systems development projects than at later design stages, when formal RAM analyses are regularly performed on specific subsystems, plant components, work stations, and machines.
- RAM analysis is appropriate only to the level of detail for which adequate supporting data is available. RAM analysis should be performed in conjunction with system component design as work proceeds, in an iterative manner, increasing the detail of the analysis as more specific and accurate RAM data is made available for components that interact within the system.

2.2 RECOMMENDATIONS

Based on the findings of the literature search, facility survey, and RAM analysis, PNL offers the following recommendations:

- System-level RAM standards and analyses are recommended as appropriate aids in designing the waste management system. They can be valuable early in the system definition and design processes as long as they accurately reflect the state of knowledge about the system.
- Fundamental system performance objectives (e.g., the most basic schedules, waste priority/acceptance criteria, throughput, dose limits, cost targets) should be established before system-level RAM standards are written. However, system-level RAM-type analysis can be a valuable tool when applied early to help establish practical system performance objectives.
- System-level RAM standards should be few and concisely stated. For each major system element (e.g., individual facilities), an overall availability standard should be set. More detailed RAM analysis can then be used to help design smaller system components in conformance with system-level standards.
- Detailed RAM analysis for the waste management system is not immediately necessary in view of ongoing work to further define the basic system configuration and performance objectives. Detailed RAM analysis should proceed in an iterative manner in conjunction with system design through increasing levels of specificity.

- DOE does not need to develop generic RAM tools and guidance materials. Ample resources (instructional materials, computer programs, analytical services) are available. RAM models tailored to the waste management system should be developed from the available generic tools.

3.0 LITERATURE SEARCH

For many years, U.S. and international organizations involved in nuclear waste management have studied RAM requirements for small- and medium-scale facilities. The literature search and review conducted for this study focused on 1) identifying appropriate principles for developing RAM standards and RAM computational models, 2) identifying and locating essential RAM data, and 3) identifying operating facilities with experience in RAM requirements, RAM testing, or other relevant topics. Both domestic and international data sources were searched, including databases at DOE, the U.S. Nuclear Regulatory Commission (NRC), national laboratories, the U.S. utilities, foreign government sources [foreign equivalents of DOE, the U.S. Environmental Protection Agency (EPA), and foreign national power authorities], and international organizations, such as the International Atomic Energy Agency (IAEA) and the Organization for Economic Cooperation and Development (OECD).

3.1 RAM GUIDELINES AND RAM ANALYSIS TOOLS

Guidelines and instructions for performing RAM analyses can be found in textbooks on the relevant basic techniques and, for project-specific applications, basic RAM guidance reports written for DOE's nuclear waste management program (Orvis et al. 1981). Sufficient instructional and tutorial material is readily available within the existing collection of RAM guidance materials for DOE and its contractors to execute any desired RAM analysis of the OCRWM system.

The literature search located numerous system modeling and/or analytical tools, commercial and proprietary software, and RAM analysis services that apply to the OCRWM system and its components. The offerings include generic industrial modeling, RAM analysis programs, and analytical programs specifically designed for use with particular systems. Examples of generic tools include GPSS (Minuteman Software) (Schriber 1974), @RISK (Palisade Corp.) (Palisade 1988), SIMAN (Systems Modeling Corporation) (Pegden 1985), and RAM analysis service offered by Ralph M. Parsons Company. Examples of system-specific programs include RAMSIM/NWSI (Sovers 1987) and FACSIM/MRS-2 (Huber et

al. 1987) at PNL for the OCRWM system; proprietary models developed by Ralph M. Parsons Company for various systems (RMP 1982, 1985, 1987a, 1989); and two proprietary models of the MITRE Corporation for the U.S. Army's Chemical Stockpile Disposal Program (Goldfarb 1987; Rod and Klingener 1989).

3.2 RAM DATA

Reliability data for small machines and machine components (used to support RAM calculations of small, relatively simple systems) were abundant in both domestic and international databases; however, reliability data on larger system components (needed to support RAM analysis or to form the basis for RAM requirements for large, complex systems) were almost totally unavailable. The notable exception was data on nuclear power plants as part of the Nuclear Plant Reliability Data System (NPRDS) (SWI 1980).

3.3 RAM EXPERIENCE

The literature search revealed innumerable examples of RAM analyses that had been performed on small elements of systems (e.g., individual machines and work stations) and several examples of factory-scale and facility-level RAM analyses, but no examples of formal, quantitative RAM analyses or standards applied to multiple-facility systems.

4.0 SURVEY OF ORGANIZATIONS AND FACILITIES

The purposes of the facility survey were to 1) identify nuclear waste handling facilities that have incorporated RAM standards into their design and operation (as well as those that have not), 2) identify and collect RAM data found (by field experience) necessary to characterize and support developing and implementing RAM standards, and 3) assess how RAM standards can help large-scale radioactive waste management facilities meet their performance objectives, as revealed by published data and field experience.

A national nuclear waste management system includes waste sources (e.g., numerous commercial nuclear power plants, research and test reactors, government-owned reactor facilities, and other nuclear material production facilities), interim fuel storage facilities, waste processing/packaging facilities, a transportation system, possibly an interim waste storage facility [e.g., monitored retrievable storage (MRS) facility], and at least one permanent waste disposal facility. Several of these system elements have been developed and are operating. For example, the system in France, which consists of fuel reprocessing, waste packaging, interim high-level radioactive waste (HLW) storage, and an internationally licensed transportation system, has been operating for several years. Great Britain, Germany, Sweden, the Netherlands, and Japan, among others, have some portion of a nuclear waste management system either operational or under field-scale study.

Based on the literature search, follow-up contacts were made at major nuclear waste management facilities and architecture and engineering (A&E) companies with nuclear experience. Table 4.1 shows the principal sources of relevant RAM data and/or design standards. Interviews and requests for data and reports were conducted by letter or telephone or through arranged site visits. All necessary concurrences, approvals, and clearances were obtained from the appropriate authorities before contact was made in each case.

TABLE 4.1. Sources of RAM Information^(a)

<u>System Element</u>	<u>U.S. Commercial Sources</u>	<u>U.S. Gov./Defense Sources</u>	<u>Foreign Commercial Sources</u>	<u>Foreign Government Sources</u>
Reactors	Contacted	Contacted	--	Contacted
Transportation	--	Contacted	--	--
MRS	Contacted	--	Contacted	--
Reprocessing/ Consolidation/ Packaging	Contacted	--	Contacted	--
Disposal site	--	Contacted	--	Contacted
Regulation	--	Contacted	--	--
Design/ Construction	Contacted	--	Contacted	--

(a) See Appendix A, Section A.2 for additional sources.

4.1 COGEMA INC. AND NUMATEC INC.

COGEMA is a private industrial company that is wholly owned by the Commissariat à l'Énergie Atomique (CEA), the French Atomic Energy Commission. Its purpose is to provide comprehensive nuclear fuel processing services from uranium mining to permanent waste disposal. NUMATEC, a subsidiary of COGEMA, provides engineering support to the parent company. COGEMA and NUMATEC representatives discussed RAM issues and approaches with regard to two key elements in their nuclear fuel processing system: the spent fuel reprocessing facilities at La Hague and Marcoule and a planned deep geologic repository for HLW.

4.1.1 French Spent Nuclear Fuel Reprocessing

Construction of the first French industrial reprocessing facility for irradiated nuclear fuel, the UP₁ plant, began in 1955 at Marcoule, and active operation began in 1958. Basic data for UP₁ design and construction were provided by a pilot plant that had been operating since 1954. There is no recollection of formal RAM analyses being conducted or RAM standards being set for

the UP₁ plant at Marcoule during design and construction; however, RAM data have been collected continuously on UP₁ (Delange 1987; Regnault et al. 1989) and have been used in designing the subsequent UP₂ and UP₃ reprocessing plants at La Hague. The UP₂ plant at La Hague opened in 1976 to reprocess light-water reactor (LWR) fuel, while UP₃ started operating in 1990. Reliability, availability, and maintainability data collection and feedback to system and equipment performance improvements continues (Bern and Chabert 1989; Dreyfus and Le Blaye 1989).

No quantitative system-level RAM analysis was performed before operations began at UP₂ and UP₃ at La Hague. RAM-type analyses were performed on the plants' major operations, components, and machines as part of the design phase to identify critical processing paths and redundancy needs; but specific, quantitative RAM standards were not established for the reprocessing systems or their components. Instead, COGEMA set broad standards in terms of "guaranteed production capacity" [metric tons of uranium (MTU) processed during a campaign of fixed duration], target "individual dose rates," and general requirements such as "high equipment reliability" (Hutchison and Lemaistre 1987; Bastien-Thiry and Justin 1988). Studies were conducted to maximize utilization and throughput of facilities and minimize plant size. Plants were designed to meet overall performance objectives, but detailed RAM standards were absent.

Once plants opened, improvements in reliability, availability, and maintainability were made through a three-phase operation/observation/feedback approach: 1) demonstration of process feasibility, 2) progressive increase in throughput, and 3) operation at nominal capacity. The following schedule for UP₂ at La Hague provides an example (COGEMA 1990):

Operation begins	1976
Demonstration of process feasibility	1976-1978
Progressive increase in throughput	1979-1983
Operation at nominal capacity	1983-present.

For the UP_3 plant, maintainability of plant components was considered in the plant's conceptual design. NUMATEC performed analyses to minimize the "mean time to replace" components and settled on a broad design philosophy of modular operating units that would be used for a predetermined time and replaced before they failed. Once this scheduled replacement approach was implemented, data on the modules and plant maintainability were compiled. Recently, after eight years of data collection, various analyses of the maintenance policy were conducted, and the existing replace-and-dispose procedure is now being replaced with off-line rehabilitation and recycling of used plant modules.

4.1.2 French Nuclear Waste Disposal

CEA plans to dispose of HLW by deep burial. COGEMA and NUMATEC are developing conceptual designs for a deep geologic repository, and system-level RAM studies are being done as part of the process. A study currently under way at NUMATEC involves investigating the effects of failures of critical repository components on the entire nuclear fuel processing system. This critical component analysis will be used in preparing a more detailed design. The study is not publicly available, but the following scenario was cited by NUMATEC as an example of the type of results obtained.

A critical component in the current conceptual design of the deep geologic repository is an elevator platform for lowering waste canisters to the emplacement area. A catastrophic failure of the elevator could result in the entire repository being unavailable for as long as three to four years (the estimated time required for complete replacement of the elevator system). The consequences of repository unavailability then propagate back through the fuel cycle. This result will be considered in subsequent, more detailed design stages.

4.2 U.S. DEPARTMENT OF ENERGY

Handling HLW and spent fuel in the U.S. comes under the authority of the DOE. Within DOE are a number of organizations that have specific goals and

duties related to nuclear materials production and waste. The research is frequently performed by numerous private companies across the country under contract to DOE.

4.2.1 The U.S. Nuclear Waste Management System

As discussed in Section 1.0, OCRWM is responsible for developing a system for managing HLW and spent fuel in accordance with the 1982 NWPA and its amendments. Before enactment of NWPA, OCRWM had explored the use of RAM standards and analyses to help coordinate the development of system elements and to ensure the achievement of overall system performance objectives. A brief list of some key DOE and DOE-sponsored activities aimed at providing guidance for RAM analysis in the context of the waste management system follows:

- 1980: Development of a methodology to aid in preparing engineering design criteria for a nuclear waste repository. This investigation included developing a conceptual design for the repository and a preliminary flow diagram for repository equipment and processes
- 1981: Publication of guidance for performing RAM analyses on repository equipment (Orvis et al. 1981)
- 1983-1988: Publication of a series of DOE orders pertaining generally to various aspects of large system development, including consideration of the use of RAM standards and analyses
- 1988: Publication of additional RAM guidelines (Guthrie et al. 1988a,b).

Other DOE-sponsored activities have investigated specific RAM characteristics of the waste management system and its components (Eger and Zima 1979; Westick et al. 1979; Orvis et al. 1981; Sovers 1987, 1988; Clark and Myers 1989).

4.3 WEST VALLEY NUCLEAR SERVICES CORPORATION

In 1980 Congress passed the West Valley Demonstration Project Act, which directed DOE to conduct a HLW solidification demonstration at the Western New York Nuclear Service Center. Large volumes of liquid HLW are currently stored

in tanks from a former commercial nuclear fuel processing plant that operated at West Valley from 1966 to 1972. Under the terms of the Act, West Valley is to:

- solidify the HLW into a form suitable for transport and disposal
- develop suitable containers for the permanent disposal of the solidified waste
- transport the solidified waste to a federal repository for permanent disposal as soon as is feasible
- dispose of the low-level waste (LLW) and transuranic wastes it produces
- decontaminate and decommission the facility, equipment, and materials used in HLW solidification.

West Valley Nuclear Services Corporation (WVNSC), a subsidiary of the Westinghouse Electric Corporation, is designing the system to solidify (vitrify) the HLW at West Valley. The literature search found numerous technical reports on various aspects of the design of the vitrification system and its components, but none of the design reports dealt with RAM analysis.

Follow-up interviews with the WVNSC engineering staff revealed that there had been no formal RAM analysis performed as part of developing the vitrification process, nor had establishing RAM standards been considered. However, consideration was given to reliability and availability issues, which were investigated on an ad hoc basis as needed for specific features of the system.

To improve system and equipment availability, WVNSC has relied more on feedback from actual equipment tests and monitoring of system performance. For example, when recent tests of the waste glass melter system were completed, it was stated that "these tests confirmed equipment operability, control system reliability, and provided samples of waste glass for durability testing" (WVNSC 1989).

The vitrification system description is not yet complete. The current major focus of analytical activity in WVNSC's System Engineering and Support Department is preparing the preliminary safety analysis report. Certain

features of RAM analysis will likely be included in probabilistic risk assessments and failure mode analyses that will be performed as part of the overall safety analysis effort, but formal RAM analysis is not contemplated at this time.

A system-level RAM analysis, Failure Modes and Effects Analysis of the West Valley Nuclear Services Vitrification System (Westick et al. 1979), was performed in 1987 by PNL. The abstract of that report states:

"A failure modes and effects analysis (FMEA) was performed to identify design changes and other corrective actions to improve system integrity and operational performance of the West Valley Demonstration Project vitrification system. The FMEA includes descriptions of the failure modes and causes of those failures, possible effects of the failures, qualitative estimates of the probability and severity of the failures, and possible corrective actions. Nineteen items were identified as having a high failure frequency or a medium failure frequency with lengthy repair times. An additional thirty items were identified whose failures could be mitigated or eliminated by design modifications or additional monitoring. Recommendations for improving these items are provided. An effort was also made to quantify the failure rates and repair times to prioritize the important components and to estimate the vitrification system's availability."

4.4 GENERAL ELECTRIC CORPORATION MORRIS OPERATION

General Electric's (GE) Morris Operation is an independent spent fuel storage installation (ISFSI) near Morris, Illinois, adjacent to the Dresden Nuclear Power Station. It has spent fuel pools with a total licensed capacity of 750 MTU (GE 1990). It has been operating with this capacity since 1976 and has in recent years been operating virtually in a steady-state, storage-only mode, since spent fuel shipments have been curtailed. The facility's operations and maintenance programs are probably typical of those that would be encountered at future wet-storage ISFSIs.

At the time Morris was designed and built, RAM standards were not considered critical to ensuring successful plant operations, and RAM considerations are not included in Morris Operation's consolidated Safety Analysis Report (GE 1990). Due to external constraints, the schedule of operations at

Morris currently has considerable excess capacity and RAM standards are, for all practical purposes, moot.

In 1979 the NRC commissioned a study of spent fuel storage operations at the Morris Operation (Eger and Zima 1979). The study was to provide a description of spent fuel handling activities and systems and to analyze the system's performance over its (then) seven-year operational history. Although the analysis focused not on throughput but on safety-related performance measures (e.g., containing radioactive materials, shielding against radiation, preventing criticality), it did have RAM implications.

4.5 U.S. NUCLEAR REGULATORY COMMISSION

An extensive literature search of NRC reports revealed very little in the way of RAM studies, RAM guidance, or the promulgation of RAM standards in regulations or orders. The few examples of RAM requirements set by the NRC derive from safety standards (Tzanos and Bezella 1984). The NRC does participate in the collection of RAM data for use within the nuclear industry; for example, it publishes NUREG reports containing nuclear-specific RAM data from the Nuclear Plant Reliability Data System (NPRDS), a source of reliability and failure information on safety-related systems and components (SWI 1980). The NRC also contracted a retrospective RAM-type study of the Morris Operation's spent fuel storage facility as part of its oversight responsibility with respect to ISFSIs (Eger and Zima 1979).

The NRC performs (or contracts to have performed) RAM analyses where they are required to address specific nuclear safety issues. For instance, in the investigation of Generic (safety) Issue 99, "Loss of Residual Heat Removal (RHR) Capability in PWRs," the NRC performed a RAM analysis and set RAM standards to ensure that the RHR system could be relied upon to provide backup reactor cooling in certain emergency situations (Tzanos and Bezella 1984; Chu et al. 1988; Spano 1989).

4.6 NUCLEAR INDUSTRY ORGANIZATIONS

Nuclear plant and equipment reliability, availability, and maintainability has been an ongoing issue for the industry, motivated by both economic

and safety considerations. However, there is apparently little work by industry on RAM issues for large-scale systems. Several organizations sponsored by the nuclear industry conduct generic research for the benefit of the industry as a whole (e.g., the Electric Power Research Institute [EPRI], the Edison Electric Institute, the Institute for Nuclear Power Operations, and the Nuclear Safety Analysis Center). However, their studies typically focus more on specific, high-visibility issues or current problems, intending to maintain or improve nuclear plant performance at existing facilities. While various generic industry studies include some RAM-type information or RAM-type analysis, formal RAM analysis at the system level has not been emphasized. Other analysts (those closer to specific facilities, systems, and equipment design tasks) more frequently perform RAM analyses as they need them.

Though nuclear industry organizations have not emphasized establishing RAM standards or performing RAM analyses themselves, they have organized systems to compile, store, and disseminate RAM data for the benefit of other RAM analysts. The NPRDS, sponsored by the American Public Power Association, the Edison Electric Institute, the Tennessee Valley Authority, and the NRC, is an example of a nuclear-specific database of RAM information and experience. The NPRDS was designed to "serve as a source of reliability and failure information for operators, designers, manufacturers, architect-engineers, constructors, and regulators of safety-related systems and components" (SWI 1980). Its primary purposes are "to provide operating statistics of safety-related systems within a unit which may be used to compare and evaluate reliability performance and to provide failure mode and failure rate statistics on components to be used in failure mode effects analysis, fault hazard analysis, and probabilistic reliability analysis" (SWI 1980).

The nature of the nuclear industry's efforts in the RAM field can be summarized as being "descriptive" rather than "prescriptive," that is, they describe the RAM parameters of system components and are used to maximize system availability from the bottom up. They are not yet being used to set RAM requirements for lower-level system components to meet a preset overall system RAM standard.

4.7 WESTINGHOUSE ELECTRIC CORPORATION

Westinghouse is a major worldwide vendor of nuclear steam supply systems (NSSS), as well as a provider of advanced analysis services for a great variety of clients. Virtually all of their analytical work in the area of systems analysis [e.g., RAM analysis, failure mode analysis, probabilistic risk assessment (PRA), and human factors analysis] are for private clients. The two main thrusts of the company's work in this area are related to improving nuclear plant efficiency (i.e., profitability) and safety (driven by both business and regulatory imperatives).

Westinghouse regularly performs RAM analyses on small- and medium-scale systems such as specific safety systems at nuclear power plants. To the extent that power plant systems interact in complex ways, such system interactions are frequently incorporated into the analyses. PRAs concentrate on failure modes of safety systems and their consequences and are used more often than RAM analyses for large-scale systems (e.g., an entire nuclear power plant).

RAM standards have not been used as part of fundamental nuclear plant design criteria. No mention is made of formal RAM analysis or standards in plant design or plant licensing guidelines. RAM analysis is not included in Westinghouse's basic plant licensing report, the Reference Safety Analysis Report (RESAR) (Westinghouse 1975). RESARs are submitted to the NRC in accordance with 10 CFR 50, "Standardization of Design Staff Review of Standard Designs." Westinghouse first issued a RESAR in 1970 as part of its efforts toward design and licensing standardization of its NSSS.

4.8 MITRE CORPORATION

The MITRE Corporation was contracted to assist the U.S. Army destroy its stockpile of obsolete chemical agents and munitions. MITRE has participated in various aspects of the program, including facility and process conceptual design, performance testing and analysis, system modeling, and RAM analysis. Most of the program's reports, including those relevant to RAM standards and analyses, are not approved for public release; however, MITRE representatives agreed to discuss their RAM studies.

4.8.1 The U.S. Army Chemical Stockpile Disposal Program (CSDP)

The chemical stockpiles at eight Army storage facilities are to be destroyed. In each case the entire process will be conducted on the base; no offsite transportation of chemical munitions is planned. The munitions will be removed from their concrete storage "igloos," loaded into transport containers, transported onsite, unloaded into a container handling building (CHB) for temporary storage and possible thawing, and moved to the adjacent main demilitarization building (MDB) for disassembly and incineration. Figure 4.1 shows the basic process (Rod and Klingener 1989).

Two facilities have already been built to demonstrate the destruction process. The first operating facility, the Chemical Agent Munitions Disposal System (CAMDS), is a pilot plant in Tooele, Utah, used to test various processes and gather operational data, including large amounts of RAM data. The Johnston Atoll Chemical Agent Disposal System (JACADS) is a full-scale processing facility that is presently gearing up to demonstrate the complete destruction process as it will be carried out at the eight future chemical weapons destruction facilities.

MITRE has performed numerous RAM analyses on the CAMDS and JACADS facilities and sub-elements of these facilities, including individual machines (Wusterbarth et al. 1988, 1989, 1990). The results of RAM analyses at each stage of program development were used as input into subsequent development and design stages. RAM data collected at CAMDS, along with RAM analyses of early JACADS designs, were used to refine the final JACADS design. JACADS RAM data and additional conceptual MDB RAM analyses are being used to refine MDB designs.

The RAM analyses performed as part of the chemical stockpile disposal program (CSDP) describe the RAM parameters of system components and are used to maximize system availability from the bottom up. They are not yet being used to set RAM requirements for lower-level system components to meet a pre-set overall system RAM standard.

The only system-level studies that resemble RAM-type studies performed to date on the CSDP system are a "logistical analysis in support of

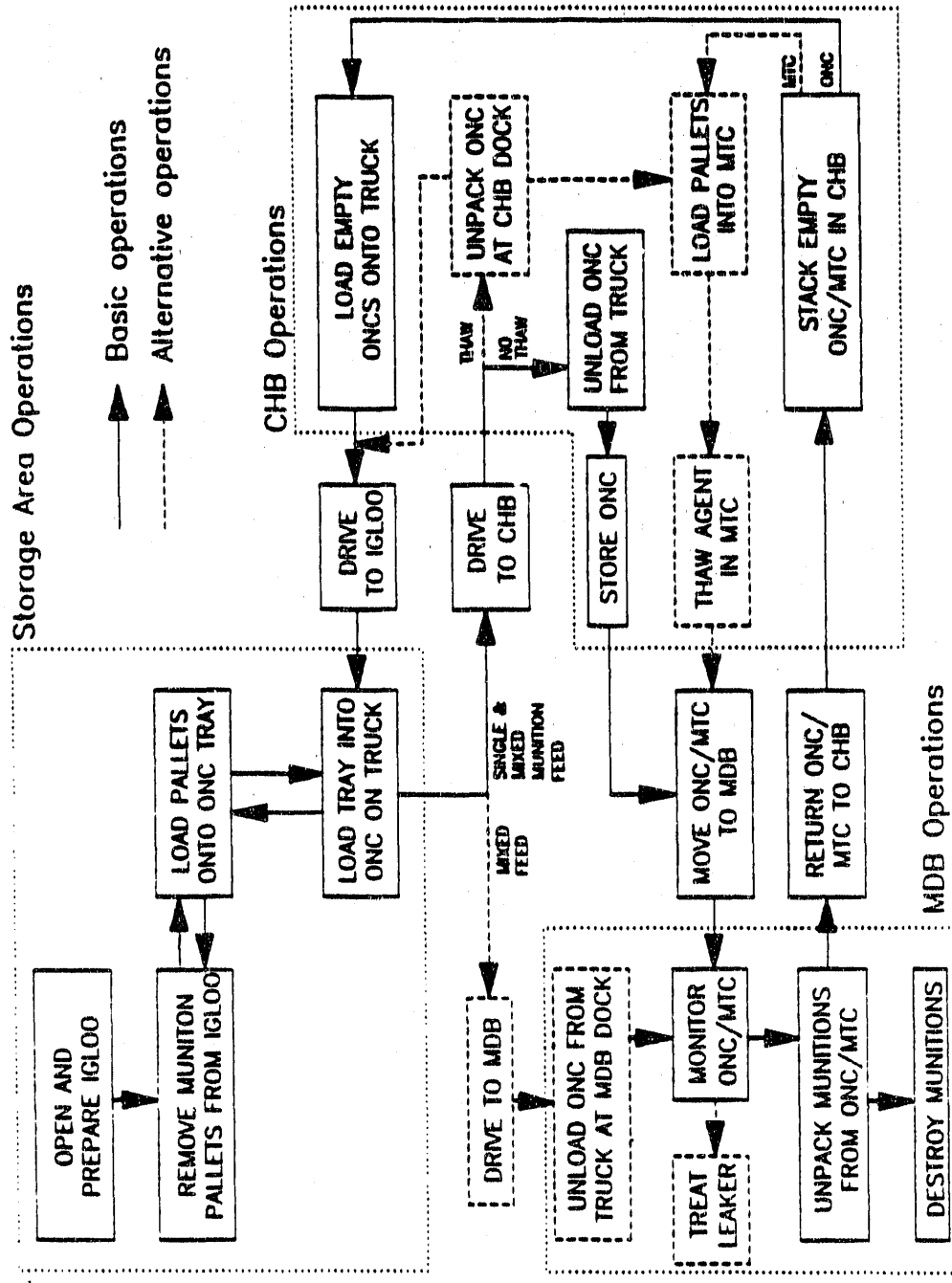


FIGURE 4.1. Flowchart of the U.S. Army's Chemical Munitions Demilitarization Operations

demilitarization operations" (Rod and Klingener 1989) and a similar follow-on study currently under way at Ralph M. Parsons Company. These studies assess the performance of the conceptual system shown in Figure 4.1 under various logistical assumptions and adverse external conditions. They are being used to determine building and buffer sizes and equipment requirements.

MITRE has recommended to the Army that a comprehensive formal RAM analysis be performed for the conceptual onsite demilitarization system; the Army is agreeable to conducting such an analysis while the eight onsite facilities are still in the early design stages.

4.9 RALPH M. PARSONS COMPANY

The Ralph M. Parsons Company provides a wide range of engineering, architectural, and project management services to government and private industry. Its services include systems analysis work such as RAM analysis, PRA, and risk/benefit analysis (RMP 1990b).

Confidentiality constraints prevented Parsons representatives from discussing or releasing details of specific clients' applications of system-level RAM analysis. They did, however, describe Parsons' typical use of RAM standards and analyses.

Parsons routinely performs formal RAM analysis for engineered systems at many levels of complexity: machines, work cells, major components or operations within facilities, and entire industrial facilities. RAM analyses of multiple-facility systems are rare, mainly because such systems are rather rare. One example of a system-level quasi-RAM study, the U.S. Army's chemical stockpile disposal program (CSDP) is cited below.

System-level RAM analyses (whole-factory RAM analyses) would typically be conducted as an integral and ongoing part of the following facility design process:

- Fundamental objectives are developed in consultation with the client. Fundamental objectives may include schedule, throughput, cost, and safety goals.
- "Availability goals" for the overall system are derived from the mission objectives.

- Preliminary system designs ("0% designs" - functional block diagrams, equipment general arrangement, etc.) are created, based on mission goals.
- Various system performance analyses are performed, possibly including elements of RAM analysis, at a level of detail consistent with the extent of facility design and the availability of RAM data.
- More detailed design is undertaken, incorporating the results of the previous system analyses and numerous other inputs, both quantitative and qualitative.
- Formal RAM analysis is typically performed, incorporating the additional information developed during the design process at about 35% design completion. Results of the analysis are compared with availability goals, and modifications to the system may result.
- Formal RAM analysis is again performed at about 90% completion, incorporating the new design data. Results of the analysis are compared with availability goals.
- A final system design will be created based on these analyses, other analyses, and various other considerations.

This general approach has been applied to several projects, including the Strategic Petroleum Reserve, other oil and gas facilities (RMP 1990b), Idaho National Engineering Laboratory's (INEL) Remote Analytical Laboratory (RMP 1982), INEL's Fuel Processing Restoration Facility (RMP 1985, 1987b), the U.S. Army's Multiple Launch Rocket System Binary Chemical Warhead Production Facility (RMP 1989), and the Army's CSDP in a study done by Ralph M. Parsons Company in 1990. RAM analysis was not used and no RAM requirements were considered when Parsons developed a preconceptual design for an MRS transfer facility within the U.S. nuclear waste management system (RMP 1990a; Wood et al. 1991).

4.9.1 The U.S. Army Chemical Stockpile Disposal Program (CSDP)

Like MITRE, Parsons has been contracted to assist the U.S. Army in destroying its stockpile of obsolete chemical agents and munitions. Parsons has been involved in various aspects of the program, including both conceptual and detailed design of facilities, system modeling, and RAM analysis. None of the existing Parsons reports on the program, including those relevant to RAM stan-

dards and analyses, are approved for public release; however, Parsons representatives discussed their RAM studies for the CSDP.

Parsons performed numerous formal RAM analyses on the CAMDS and JACADS facilities (RMP 1987a). The results at each stage of program development were used as input into subsequent development and design stages. However, like the MITRE studies previously discussed, Parsons' reports are descriptive. They are not yet being used to set RAM requirements for lower-level system components to meet a preset overall system RAM standard.

The only system-level studies that resemble RAM-type studies performed to-date on the CSDP system are more detailed follow-up studies to the MITRE logistical analysis (Rod and Klingener 1989). These studies are being used to determine building sizes, buffer sizes, equipment requirements, and other design criteria.

4.10 BECHTEL GROUP INCORPORATED

Bechtel provides a wide range of services to both government and private clients, including virtually all industrial sectors. Under the broad heading of "Systems Engineering," the company provides services covering all phases in developing major industrial projects, including RAM analysis, system analysis, PRA, and risk/benefit analysis. Bechtel conducts its system engineering activities through three major business lines: "Power," "Refinery and Chemical," and "Manufacturing."

For reasons of confidentiality, Bechtel provided no documentation describing the company's experience with or applications of system-level RAM analysis. However, PNL received approval from Bechtel's president to interview the manager of Engineering Technology, Special Operations, Bechtel Group. A summary of the interview follows.

4.10.1 Power, Refinery, and Manufacturing Systems

Analyses are always conducted at the earliest stages of major engineering projects (e.g., power plants, refineries, factories) to identify critical aspects of the system under design and ensure that it meets the client's

objectives. This analysis may or may not be called RAM analysis, but features of RAM-type analysis are part of the system analysis.

The initial system analysis is tailored to the characteristics of the particular system under development. For electric power plants, system reliability, availability, and maintainability are affected by complex interactions among many plant systems. Therefore, Bechtel performs "interactions analysis" to understand how component or system failures propagate to shut down the power station (as plant designs progress, this type of analysis evolves into formal PRA). Refineries and chemical processing plants are characterized by the throughput of bulk materials. For these types of facilities, input/output analysis is performed to identify critical nodes (or choke points) and the consequent need for buffers or queues in the process path. For manufacturing plants, the need for efficient parts delivery and inventory management systems calls for "just-in-time" studies, which are an extension of input/output analyses.

For all industrial design and development projects, Bechtel's aim is to determine (and optimize) the resilience of the system (how rapidly backup processes and/or procedures can restart the system after a failure). Also, in the early stages of all projects, system-level RAM-type standards are derived from the client's preliminary objectives (e.g., throughput, cost, productivity, and safety goals). Early standards are frequently stated qualitatively and are made more quantitative through several iterations of system analysis and facility design. As system design progresses, more specific RAM standards are determined by the higher-level requirements (i.e., system requirements determine facility requirements, which determine work station requirements, which determine machine requirements, etc.). The development process, however, remains a mixture of quantitative analysis and heuristic design improvements.

5.0 SYSTEM LEVEL RAM MODEL AND ANALYSIS OF THE U.S. NUCLEAR WASTE MANAGEMENT SYSTEM

PNL created a system-level RAM computational model using the existing commercial software SIMAN to perform the system-level RAM analysis for the U.S. waste management system (Pegden 1985). Its purpose was to explore the usefulness of RAM analysis for gaining insights into the operational relationships among major waste system facilities.

For this initial exploration, the model was kept as simple as possible, including only a "Level 0" description of the basic system as described in System Description of the Basic MRS System for the FY 1990 Systems Integration Program Studies (McKee et al. 1991). The RAM model includes six major elements: waste generators, waste-generator-to-MRS transportation, waste-generator-to-repository transportation, the MRS, MRS-to-repository transportation, and the repository.

The analysis yielded results consistent with those of earlier RAM studies of alternative system configurations (e.g., MRS, multiple MRS, and repository-only systems). Though the analysis at the level of detail used in this study produced rather straightforward results, it is clear that system-level RAM analysis can yield valuable insights on the kinds of issues that are critical to the waste management program (e.g., queue and interim storage sizes, average and peak inventories).

Sample results of the calculations performed for this study are presented in Appendix B.

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APPENDIX A

MISCELLANEOUS BACKGROUND INFORMATION

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MISCELLANEOUS BACKGROUND INFORMATION

A.1 RAM GUIDANCE PUBLICATIONS AND RAM TOOLS

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APPENDIX B

RAM CALCULATION SAMPLE RESULTS

APPENDIX B

RAM CALCULATION SAMPLE RESULTS

System-level RAM calculations were performed, using an existing low-complexity computer model to study the effects of differing facility reliability levels on other facilities that must perform in series in the waste management system.

PNL created a system-level RAM computational model using existing commercial software, SIMAN (Pegden 1985), to perform the system level RAM analysis. The model was kept as simple as possible, including only a "Level 0" description of the basic system, as described in System Description of the Basic MRS System for the FY 1990 Systems Integration Program Studies (McKee et al. 1990). The basic monitored retrievable storage (MRS) system is shown in Figure B.1, and the derived model used in the present analysis is shown in Figure B.2.

The model system's major elements include waste generators, waste generator-to-MRS transportation [PWR (pressurized water reactor) rail, BWR (boiling water reactor) rail, PWR truck, and BWR truck options], waste-generator-to-repository transportation (MRS bypass), the MRS, MRS-to-repository transportation (rail transport only), and the repository.

The basic MRS and non-MRS (repository only) systems have previously been modeled and analyzed with spent fuel throughput rates ranging from 3,000 to 6,000 MTU per year (Clark and Myers 1989). For this study, a nominal shipping rate of 2,200 MTU per year from waste generators was used. This value was derived from the 10-year average annual acceptance allocations for all waste generators from OCRWM's Annual Capacity Report (DOE 1990).

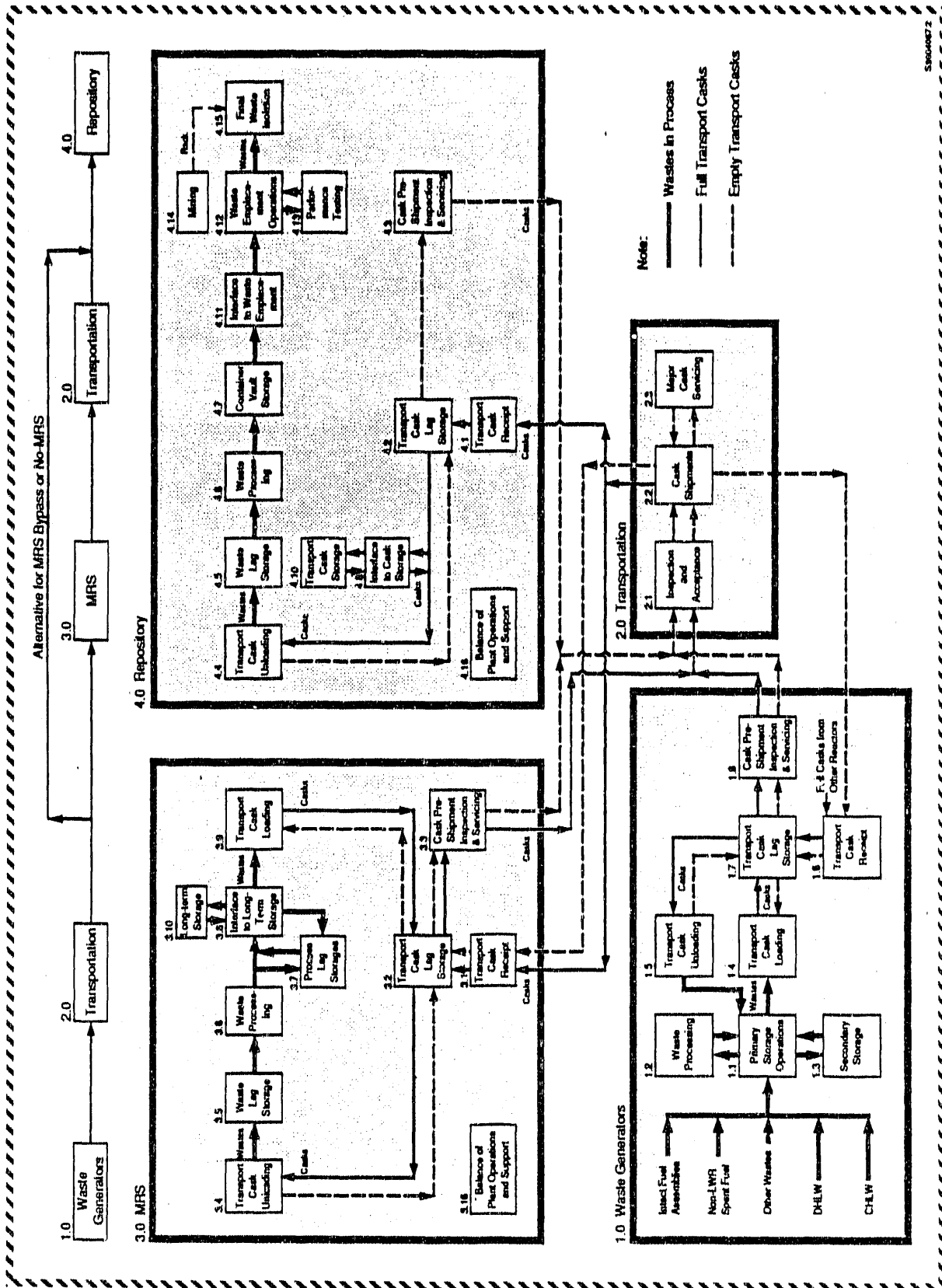
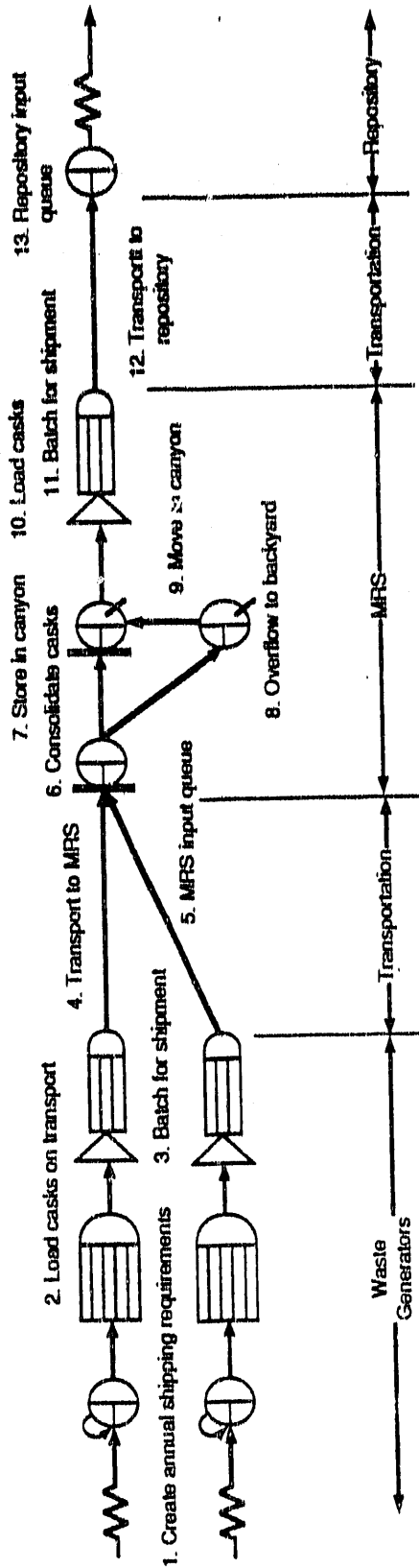
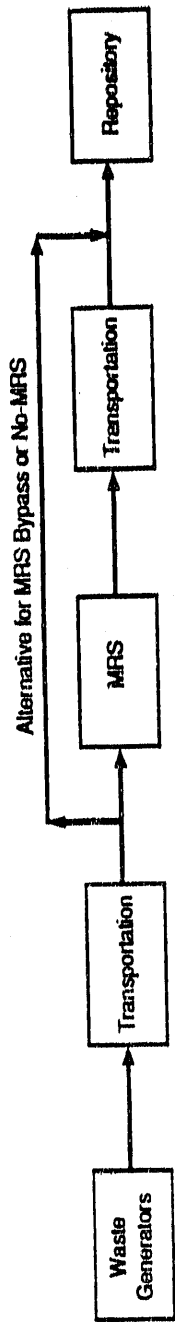


FIGURE B.1. Level 1 Functional Flow Diagram for the Basic MRS Waste Management System



B.3

59110017.2

FIGURE B.2. Basic Waste System Level 0 RAM Model

RAM analyses were run for all of the system's facilities. The effects of facility availabilities of from 0 to 100% for each system element on all other elements were assessed. Sample results are shown in Figures B.3 through B.6.

In a system with an MRS, low availability at one facility need not affect the processing rate at other facilities for several years if the MRS inventory is maintained roughly midrange between 0 and its legal maximum of 15,000 MTU. For example, Figure B.3 shows that for MRS average annual availability down to 50%, overall system throughput can be maintained by using MRS bypass transportation. Figure B.4 shows quantitatively that low availability of shipping from waste generators does not necessarily reduce deliveries to the repository. Shortfalls from waste generators can be made up from MRS inventory until it is exhausted. Figure B.5 shows that, at a 2,200 MTU/year throughput rate throughout the system, total failure of shipping from waste generators leads to exhaustion of a 10,000 MTU inventory at the MRS in about 4.5 years (idling the MRS and the repository). Figure B.6 shows the effects of long-term unavailability of the MRS/repository transport link. Waste generators could continue to ship 2,200 MTU/year to the MRS for about 2.4 years before the MRS exceeded its legal maximum inventory. After that point, all shipments from waste generators would have to go directly to the repository.

The present analysis yielded results that are consistent with earlier RAM studies of alternative system configurations (e.g., MRS, multiple MRS, and repository-only systems). Though the analysis at the level of detail used in this study produced rather straightforward and intuitive results, it is clear that system-level RAM analysis can yield valuable insights on the kinds of issues that are critical to the waste management program (e.g., queue and interim storage sizes, average and peak inventories, and other considerations).

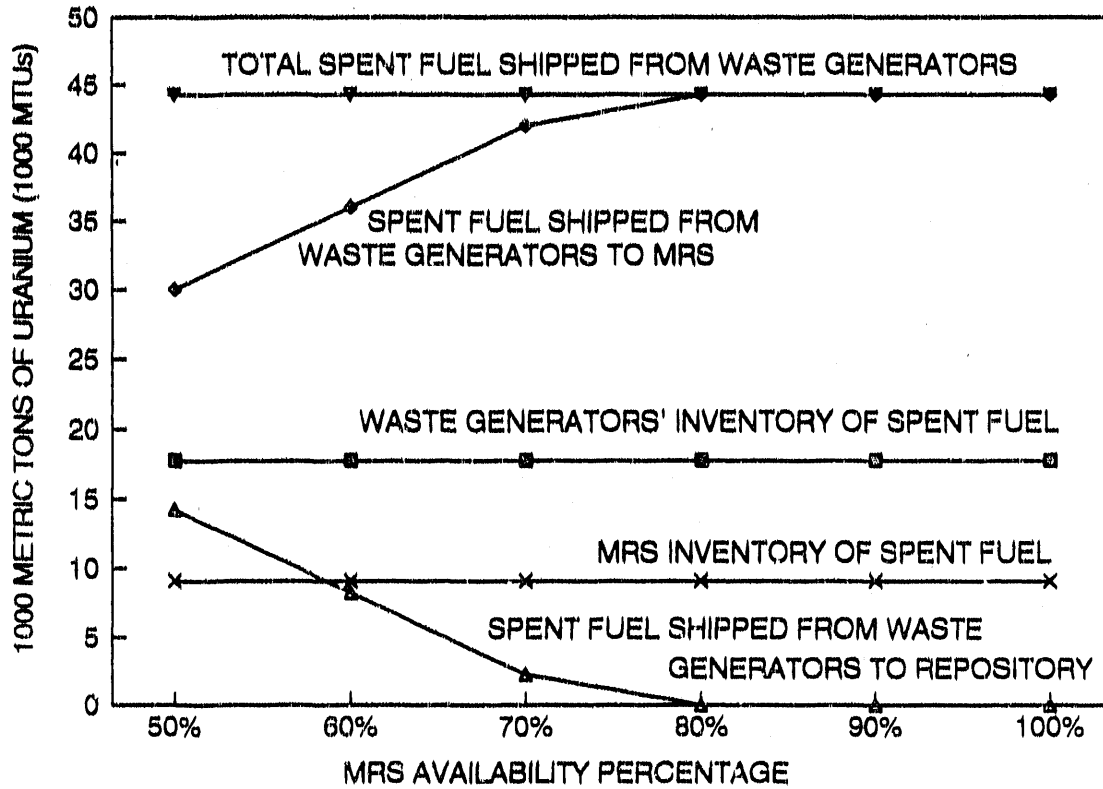


FIGURE DEPICTS SYSTEM STATUS IN 2030 (20 YEARS OF OPERATION)

FIGURE B.3. MRS Availability Analysis

ASSUMPTIONS:

- MRS opens in 1998 with a maximum capacity of 10,000 MTU
- MRS inventory in 2010 is just under 10,000 MTU
- Repository opens in 2010
- MRS maximum capacity after 2010 is 15,000 MTU
- 100% availability processing rate is 2,200 MTU/year
- MRS bypass (WG/repository transport) used as needed.

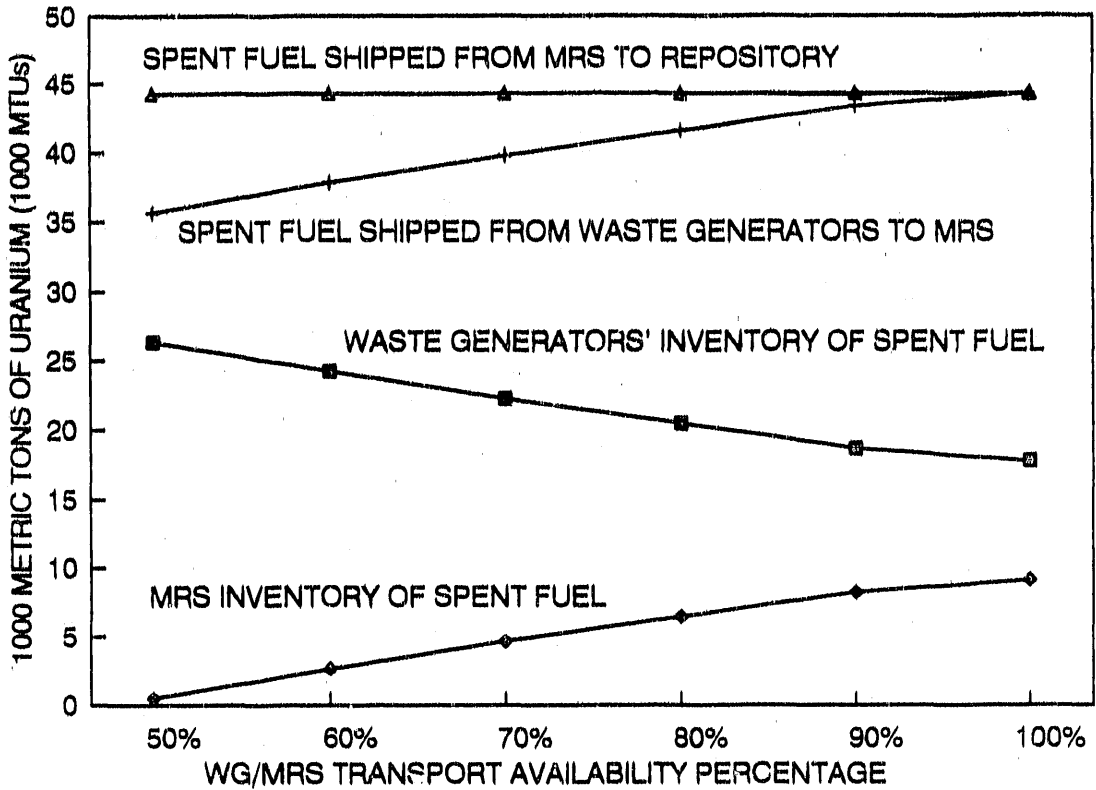
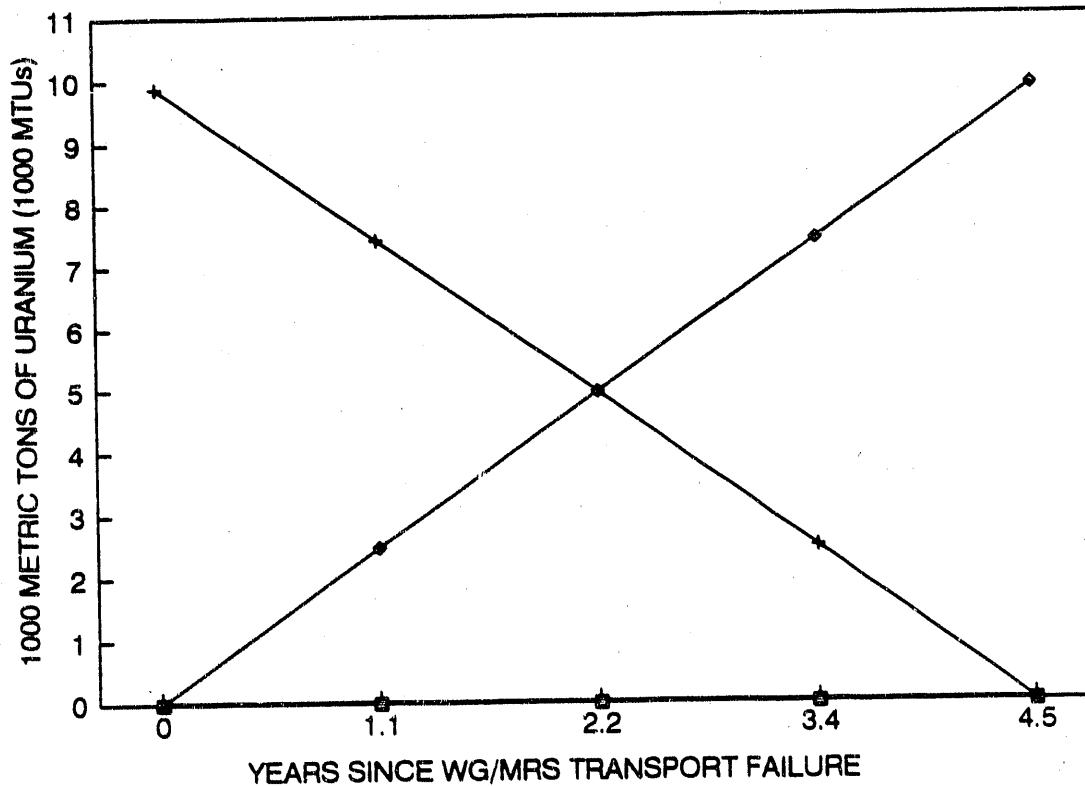


FIGURE DEPICTS SYSTEM STATUS IN 2030 (20 YEARS OF OPERATION)

FIGURE B.4. Waste Generator/MRS Transport Availability Analysis

ASSUMPTIONS:

- MRS opens in 1998 with a maximum capacity of 10,000 MTU
- MRS inventory in 2010 is just under 10,000 MTU
- Repository opens in 2010
- MRS maximum capacity after 2010 is 15,000 MTU
- "100% availability" processing rate is 2,200 MTU/year



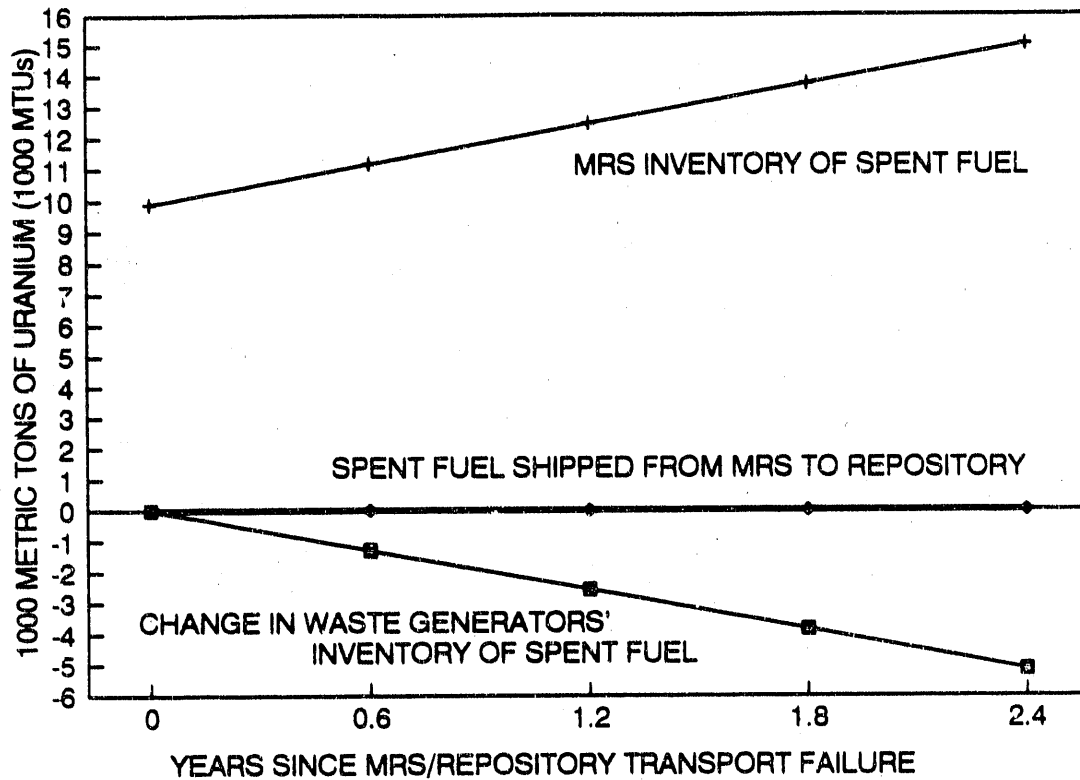
NO MRS BYPASS

- CHANGE IN WASTE GENERATORS' INVENTORY OF SPENT FUEL
- + MRS INVENTORY OF SPENT FUEL
- ◇ SPENT FUEL SHIPPED FROM MRS TO REPOSITORY

FIGURE B.5. Waste Generator/MRS Transport 0% Availability

ASSUMPTIONS:

- MRS opens in 1998 with a maximum capacity of 10,000 MTU
- MRS inventory in 2010 is just under 10,000 MTU
- Repository opens in 2010
- MRS maximum capacity after 2010 is 15,000 MTU
- "100% availability" processing rate is 2,200 MTU/year



NO MRS BYPASS

FIGURE B.6. MRS/Repository Transport 0% Availability

ASSUMPTIONS:

- MRS opens in 1998 with a maximum capacity of 10,000 MTU
- MRS inventory in 2010 is just under 10,000 MTU
- Repository opens in 2010
- MRS maximum capacity after 2010 is 15,000 MTU
- "100% availability" processing rate is 2,200 MTU/year

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