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Project Summary Plan for HTGR Recycle Reference Facility

B. J. Baxter

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Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

HTGR FUEL RECYCLE DEVELOPMENT PROGRAM (189a OH045)
HTGR RECYCLE REFERENCE FACILITY (SUBTASK 930)

PROJECT SUMMARY PLAN FOR HTGR RECYCLE REFERENCE FACILITY

B. J. Baxter

with contributions by

Science Application, Inc.
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Date Published: November 1979

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FOREWORD

The HTGR Recycle Development Program is organized to research, develop, and demonstrate fuel recycle technology in support of efforts to commercialize HTGR reactor systems. The technology being advanced by this program is directed toward the conceptual definition of a reference recycle facility. A comprehensive discussion of the program is contained in the "National Program Plan for HTGR Fuel Recycle Development," GCR-78/19 (Revision 3), dated January 9, 1978.

This document introduces a summary plan for completing conceptual definition of an HTGR Recycle Reference Facility (HRRF). The plan describes a generic project management concept, often referred to as "the requirements approach to systems engineering." The plan begins with reference flow sheets and provides for the progressive evolution of HRRF requirements and definition through feasibility, preconceptual, and conceptual phases. The plan lays end-to-end all the important activities and elements to be treated during each phase of design. Identified activities and elements are further supported by technical guideline documents, which describe methodology, needed terminology, and where relevant a worked example.

Although the primary objective of this plan is to serve as a guide to activities and events needed to successfully complete conceptual design of the HTGR Recycle Reference Facility, the plan in part or its entirety may be applicable to other engineering efforts. Finally, it is hoped that this document will prove itself a benefit to the user in appropriate engineering applications.

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EXECUTIVE SUMMARY

The purpose of the Project Summary Plan for the HRRF Project is to provide a rationale by which the National Program for HTGR Recycle Development can effectively complete conceptual design of a reference fuel recycle facility. The HRRF Project is organized as Subtask 930 under the National Program. The scope of this HRRF Project Summary Plan is to provide a framework that will encourage participation and will promote communication between Subtask 930 and other task and subtask program elements, as well as external organizations such as GCRA, in the definition, specification development, and ultimate conceptual design of the HRRF physical plant and associated processes.

This Project Summary Plan is the necessary first step toward the development of an HRRF Project Plan and provides the basic structure for completing the Plan. Specifically, the Project Summary Plan and design analysis guidelines achieve the following three major objectives:

- ESTABLISHES THE UNDERLYING PRINCIPLES FOR AN EFFECTIVE DESIGN APPROACH (Section 3.0).
- RELATES THESE UNDERLYING PRINCIPLES TO A SUMMARY PROJECT SCHEDULE/DESIGN PLAN FOR THE HRRF (Section 4.0).
- SUPPORTS THE SUMMARY PROJECT SCHEDULE/DESIGN PLAN WITH A SERIES OF GENERAL GUIDELINES IN SEVERAL AREAS OF DESIGN ANALYSIS (Appendix).

To move from a Project Summary Plan to a Project Plan involves completing the details of the framework discussed in this document. A

complete HRRF Project Plan would include other elements not addressed in this document, as well as detailed elements that are in some cases considered only in summary form. These elements would include:

- An HRRF Project Management Plan for project control and monitoring. This Project Management Plan would be directly related to and a part of the existing management structure of the National Program for HTGR Recycle Development.
- A detailed design plan with task statements, budget estimates for both cost and manpower, and organizational responsibilities.
- A detailed Project Schedule relating work statements, manpower allocations, and budget estimates to calendar time.
- Supporting guidelines in all major areas of design analysis.
- A complete, documented set of design, operating, maintenance, and plant requirements.
- A guideline for initiating, maintaining, and controlling the interface between the National Program/HRRF Project and the Architect/Engineering firm engaged to complete the conceptual design effort.

The conclusion of this study is that the development of a detailed project plan within the framework of this Project Summary Plan will ensure the completion of the conceptual design for the HRRF by promoting effective coordination of internal program elements, by considering the external environment of the HRRF conceptual design effort, and by accomplishing the program charter within the constraints of a limited budget.

The major recommendations arising from the development of the Project Summary Plan include the following:

- CONTINUE HRRF PROJECT SUMMARY PLAN THROUGH THE COMPLETE DEVELOPMENT OF A PROJECT PLAN, INCLUDING MANAGEMENT PLAN, DESIGN PLAN, AND PROJECT SCHEDULE.
- DEVELOP A COMPLETE SET OF DOCUMENTED REQUIREMENTS.
- SUPPORT THE HRRF PROJECT PLAN WITH THE DEVELOPMENT OF GUIDELINES IN EACH MAJOR AREA OF DESIGN ANALYSIS.
- ESTABLISH A STANDING COMMITTEE COMPOSED OF PROGRAM TASK AND SUBTASK MANAGERS TO IDENTIFY PRINCIPAL PLANT FACTORS.

The major sections of this report include the design logic, the summary project schedule/design plan, and the design analysis guidelines. The design logic described in Section 3.0 provides the background for the summary project schedule/design plan in Section 4.0. The project schedule/design plan and supporting logic emphasize the development of a set of baseline requirements for the HRRF at three levels of design detail--plant (Level 0), facility (Level 1), and system (Level 2). The summary project schedule/design plan is supported by a series of guidelines in the Appendix that provide a general method that may be used to support the design analysis in a particular area, the types of documentation required to validate the method, the terminology used in the area, and an example where appropriate.

1.0 INTRODUCTION

The purpose of this Project Summary Plan is to provide a rationale by which the National Program for HTGR Recycle Development can effectively complete conceptual design of a reference fuel recycle facility. Conceptual design of this facility is the most complex task that will be undertaken under the program charter and is a principal objective of the National Program.

The purpose of this Project Summary Plan is to provide a rationale by which the National Program for HTGR Recycle Development can effectively complete conceptual design of a reference fuel recycle facility.

The National Program is organized by tasks and subtasks to advance fuel recycle technology through three principal phases. The phases broadly reflect an evolution in the development process and are termed laboratory, engineering, and prototype. Each phase has a compound structure distinguished by the use of irradiated (hot) or non-irradiated (cold) process materials.

Organized under the National Program as Subtask 930, the HTGR Recycle Reference Facility (HRRF) Project is a prototype design project intended to demonstrate the technical and economic viability of HTGR fuel recycle on a near-commercial scale. As such, it is the specific programmatic responsibility for Subtask 930 to participate actively with other

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tasks and subtasks in the definition, specification development, and ultimate conceptual design of the HRRF physical plant and processes.

At the present time, much of the development program has evolved through cold engineering status, and larger development activities, in terms of both cost and technical complexity, are being considered and sponsored. These development activities, when implemented, will require not only substantial portions of the resources of the National Program but also an expansion in program activities and budget. Therefore, the development of HRRF design requirements becomes a pivotal factor in the overall program since these requirements will provide continuity in current and future process development activities and will assure the conceptual integrity of the HRRF design effort.

The basic approach provided in this document involves the development of HRRF design requirements with the use of functional analysis.

The basic approach of the Project Summary Plan provided in this document involves the cooperative development of HRRF design requirements for the dual purpose of establishing clear guidelines for development activities and for completing a conceptual design during FY 1982-1983. The approach outlined in this document develops these requirements and analyzes them functionally, as described in Part A of the Appendix. The correct application of this functional approach to requirements' development and allocation permits trade-offs to be made in the design process without committing the facility designer to either a specific

process or piece of equipment before cost-effective options have been considered.

The summary project schedule/design plan is discussed in Section 4.0. This plan is supported by the design logic in Section 3.0 and a series of guidelines in the Appendix. These guidelines discuss the following relevant areas of design analysis: Requirements Documents, Principal Plant Factors, Unit Operations, Layout Analysis, Safeguards and Accountability, Physical Protection, Criticality, Environmental Analysis, Safety, Availability, Reliability, Maintainability, Logistic Support, and Licensing. These guidelines provide a general method that may be used to support the design analysis, the types of documentation required, the terminology used in each area, and a worked example.

A discussion of the design logic is presented in Section 3.0 of the Project Summary Plan. This design logic represents the basic approach to design used in this document for the HRRF project. As such, the logic provides the rationale for the relationships of the various elements of the summary project schedule/design plan.

Use of the approach outlined in this document is an extension of the existing program organization and will provide for a logical progression of task and subtask activities from the feasibility through the conceptual design phase of the HRRF.

2.0 PROGRAM/GCRA INTERFACE REQUIREMENTS

An important organizational interface exists between the National Program and the Gas-Cooled Reactor Associates (GCRA). This interface is important in determining the choice of the fuel cycle for HTGR commercialization since the recycle requirements and the development of needed technology will be the function of the National Program. A successful HTGR commercial program requires that HTGR Recycle enhance the position of the HTGR as a viable nuclear alternative. Thus, both GCRA and the National Program must be mutually supportive.

An important organizational interface exists between the National Program for HTGR Recycle Development and the Gas-Cooled Reactor Associates (GCRA). The two major interface areas are throughput/design and costs/design/pricing policy.

GCRA was established to provide the vehicle of participation for HTGR commercialization by utilities, suppliers, and the DOE. Currently, five utilities are members of the Association, with San Diego Gas and Electric (SDG&E) in the role of program coordinator.

In the GCRA Program Plan submitted by SDG&E to the DOE in March 1978, the Fuel Recycle Program is designated as Work Area 5 in the Work Breakdown Structure (WBS) and will provide fuel recycle technology and services to the GCRA Program. It is through this work area that the interface between the National Program and the GCRA will be maintained.

The common objective of the National Program and the GCRA is the commercialization of HTGR's. As noted in the RAMCO* report of December 1977 on the commercialization of gas-cooled reactors, the advent of a viable and economical recycle program for the HTGR substantially increases the financial benefits of HTGR operation. This conclusion is valid for both denatured uranium recycle with no highly enriched uranium (HEU) and full recycle with HEU.

Figure 2-1 depicts HTGR commercialization factors, emphasizing the HRRF plant design. Information concerning HRRF Plant Design flows from the National Program, GCRA, and the Federal Government. The National Program provides the results from on-going and anticipated development activities concerning HTGR Recycle, while GCRA is concerned with focusing the broader picture of HTGR commercialization, of which the recycle program is a vital portion.

Organizational interface requirements between GCRA and the National Program fall into three general categories: plant design, market factors, and financial factors. The inclusion of the latter two categories recognizes the importance of how and why market and financial factors influence plant design. Each of these three factors is considered in turn, and the general interface requirements between the National Program and GCRA are identified.

*Gas-Cooled Reactor Commercialization Study: Supplementary Report. Prepared by RAMCO for the U.S. Department of Energy, Contract EN-77-C-03-1358, December 31, 1977.

Figure 2-1 HTGR and HRRF Commercialization Factors.

2.1 Plant Design

The primary set of interface requirements deals with the HRRF plant design. The general summary of the HTGR commercialization factors is depicted in Figure 2-1, while specific interactions are shown in Figure 2-2. In the latter figure, dotted lines reflect National Program information flows, and solid lines represent GCRA information flows. The two major interface areas are throughput/design and costs/design/pricing policy. Any information outside of the lines labeled "scope line" is provided outside the National Program Charter.

The interface requirements for throughput/design evolve from government policy on recycle, the HTGR design concept, and the number of operating HTGR's. This information is utilized to develop total HTGR recycle requirements which, in conjunction with design considerations, will determine throughput for the HRRF. Factors that would be considered include the initial capacity and the timing of any desired plant scaling.

A second key set of interface requirements is the design/cost/pricing policy. In this case, the initial cost estimates, both operating and capital, will be determined by the plant design; however, to maximize the probability of success for HTGR's, certain cost goals for recycle will have to be met. Once the design/cost decision has been made, the pricing policy can be determined by examining the anticipated throughput in conjunction with costs.

A third set of interface requirements, not explicitly identified in the figure, involve the delineation of Principal Plant Factors as described in the Appendix, Part B. These plant factors represent a set

MARKET FACTORS

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AND HRRF COMMERCIALIZATION

Figure 2-2. HTGR and HRRF Commercialization.

of goals, constraints, and overall design requirements for the HRRF from which the preliminary set of plant requirements are extracted. The identification of the Principal Plant Factors will be a joint effort between National Program personnel, GCRA personnel, and various other groups involved in the field.

2.2 Market Factors

In Figure 2-2, the key market factors in the HTGR environment are shown on the left-hand side of the diagram. The interfaces between market factors and plant design occur at several points: the number of operating HTGR's, the HTGR design concept, and the costs of HTGR's relative to other nuclear options. Although there are no specific interfaces between the National Program and GCRA in this section as dealt with under plant design, the decisions made concerning HRRF throughput and the resulting costs will impact the number of operating HTGRs. It is therefore clear that the key interfaces identified in plant design are not isolated portions of the HRRF environment but are instead integral parts of the whole.

Decisions made concerning HTGR Recycle, especially the timing of the recycle option, can impact the plant design through the alteration of the position of HTGR's relative to other nuclear options in terms of cost and creditability. These latter two factors will in turn determine the market share attainable by the HTGR Fuel Cycle.

2.3 Financial Factors

An important element in the commercialization of HTGR Recycle is the profitability of the process. At this early stage, the final decision has not been made concerning the participation of private industry in the Recycle Program and all feasible options must therefore be kept open. Decisions must still be made concerning the degree of risk that will be borne by the interested parties--utilities, suppliers, and the government. Associated with the risk-sharing plan will be the shared costs. An initial cost-sharing breakdown for each of the three parties involved is provided in the GCRA Program Plan.

Figure 2-2 identifies the key financial factors in the HTGR environment on the right-hand side of the diagram. The interfaces between the financial factors and market factors and plant design occur at two points: in the determination of the HRRF total revenue, and in the determination of the total costs of the facility. As with market factors, there are no specific interfaces between the national Program and GCRA in this section, although the identified interfaces between these two entities will impact the financial factors associated with the HRRF.

3.0 DESIGN LOGIC

3.1 Introduction

The successful and timely accomplishment of the conceptual design for the HRRF will require the integration of a wide range of functional efforts and disciplines. The logic guiding this design process and supporting the summary project schedule/design plan in Section 4.0 must recognize the unique requirements of the HRRF: first, it is a highly advanced concept requiring new process development and phasing-in of state-of-the-art equipment and technology; and second, the design and operational characteristics of the HRRF must reflect the needs of a commercially viable operation.

The unique requirements of the HRRF indicate that the development of solutions to the challenges of communications, coordination, direction, and control requires the implementation of a total design management effort.

Under these circumstances, the design must not evolve from separate, parallel, uncoordinated efforts, but rather must be approached as a systems problem. The successful systems integration of the HRRF conceptual design presents challenges in the areas of communications, coordination, direction, and control over a wide spectrum of functional specialties and among geographically separated organizations. Three critical areas have been identified:

1. Control of design interfaces: internal design interfaces among the HRRF systems, equipment, personnel, and facilities; external design interfaces among such agencies as GCRA (see Section 2.0), DOE, or NRC.
2. Use of trade-off analysis techniques in allocation of functional requirements, selection of optimal design approaches, and resolution of conflicting design objectives and constraints.
3. Assurance that the performance specifications, detailed designs, and facilities' functional criteria are consistent with the principal plant factors and the design requirements while at the same time they are balanced with the consideration of such functional factors as reliability, safety, logistics, security, and the economics of plant operation.

The development of solutions to the challenges of communications, coordination, direction, and control requires the implementation of a total design management effort, often termed the systems engineering management approach. This approach may be defined as the management of the design process to transform an operational need into a description of system performance parameters and a system configuration. The systems engineering management process as described is summarized in Figure 3-1.

The design process is iterative and encompasses systems analysis, definition and synthesis of requirements, preconceptual design, and conceptual design. Systems analysis involves the analysis and transformation of overall system requirements into a series of functional groupings with quantitative measures of design parameters. These functional groupings can be analyzed individually or in the form of a total system model.

Figure 3-1. The System Engineering Process.

The operation of this model to simulate the operating environment identifies design sensitivities. Definition and synthesis of requirements is the translation of performance requirements of a selected systems approach into a design criteria and equipment specifications for each individual element making up the system. Preconceptual design develops the design approach for the system and its elements based upon the criteria provided by the definition and synthesis of system requirements. Conceptual design translates the design approach into a configuration which can be produced and supported within the state of existing or economically achievable technology and support capabilities. The design logic described in this section supports the preconceptual design and provides sufficient information for an Architect/Engineering firm to complete the conceptual design.

The design logic described in this section reflects the total design viewpoint, supports the preconceptual design, and provides sufficient information for an Architect/Engineering firm to complete the conceptual design. The three design phases are feasibility, preconceptual, and conceptual.

The degree of efficiency with which the design process is accomplished depends upon the degree of discipline and planning that is incorporated into the process. The relations between the functional disciplines and requirements such as reliability, safety, and logistics and the selected design concepts will appear as the design evolves; however, if proper planning and discipline are not present to ensure the

timely determination of inputs and requirements, the design process will be unlikely to prove cost-effective or time-efficient.

The following paragraphs describe the details of the design logic for the HRRF. The HRRF is organized as Subtask 930 under the National Program for HTGR Recycle Development. The relationship of the various tasks of the National Program to the HRRF is defined in the National Program Plan and centers on the identification of functional requirements for the HRRF.

Subtask 930 has the overall responsibility for the coordination and inclusion of these functional requirements in the conceptual design of the HRRF. Other program tasks/subtasks have the responsibility for the application of expertise to specific areas of design and the subsequent identification of HRRF requirements for these areas. Therefore, the successful completion of Subtask 930 requires the efficient utilization of development data resulting from these other program tasks/subtasks.

3.2 Overview of the Approach

The design logic outlined in this section is based upon the concept of systems engineering management and provides for the logical progression of the HRRF design through the conceptual design phase. Figure 3-2 provides a systems engineering overview of the approach. This design logic is a prelude to the summary project schedule/design plan in Section 4.0.

Design analysis begins with the identification of the Principal Plant Factors (PPF) as described in the Appendix, Part B. The PPF's are

Figure 3-2. HRRF Design Logic.

defined as a set of goals, requirements, and guidelines established for the purpose of guiding the HRRF design process. These factors provide the initial input to the Level 0 (plant) Requirements Assessment, where the PPF's are subjected to a requirement criteria determination to screen for true design requirements. Each of the specialty engineering groups would be represented in this requirements assessment process. (These groups are identified in Section 3.3.)

Once the Level 0 requirements have been assessed, the unit operations analysis can define the HRRF plant in terms of the major sets of processes or activities such as reprocessing, refabrication, etc. The definition of the plant consists of delineating the plant into these relevant sets of processes. The definition of each entity in the HRRF plant is discussed in the Appendix, Part C. The results from the unit operations analysis are then used in the functional analysis, trade studies, and interface requirements assessment.

With a firm definition of the HRRF plant, the requirements developed at Level 0 (plant) will be analyzed functionally, with interface requirements and trade studies performed on these functional descriptions. The questions dealt with at this level will primarily consider the logic grouping of functions, i.e., whether two functions can be combined or one split into several elements, or whether there is an alternative functional configuration that will meet the stated requirements. These functional configurations will be determined by the alternative sets of processes identified from the unit operations analysis that can meet the requirements of the HRRF plant.

After the Level 0 requirements have been evaluated, the Level 1 (facility) requirements are developed from the allocated Level 0 requirements. The same evaluation process is repeated, but at a different level of functional detail. The design analysis begins with unit operations analysis defining the facility-level entities that will be used in the analysis. In this case, unit operations will be adding more detail to the HRRF plant delineation developed to support the Level 0 Requirements Assessment, since those areas with identifiable process or operations questions would have been examined in detail in the first analysis.

Once the facilities have been defined, the analysis proceeds as described, except for the fact that the functional requirements will be allocated to each facility, and the interface assessments and trade studies will be performed at this greater level of detail. The questions are generally the same, but the level of detail is greater, i.e., the design group still has to consider whether functions should be combined or if there are alternative functional flows that meet the requirements. The logic groupings of the functional flows at this level of the design analysis will be derived first from alternative processes and second, at Level 2, from alternative unit operations. Each of the specialty engineering groups (reliability, maintainability, logistics support, etc.) will evaluate the requirements allocated to the facility and the requirements allocated to the functional flow comprising the activities of the facility.

To provide the necessary design information to an Architect/Engineering firm, a baseline set of requirements must be developed. The assessment of requirements and the development of these baseline requirements is an iterative process.

The assessment of requirements is an iterative process. It is important to establish the requirements baseline and to control changes in this baseline at each level of the design analysis, but it is also important to incorporate important design information that emerges as the design process proceeds. Therefore, the design team must first evaluate the Level 0 (plant) requirements, then evaluate the combined Level 1 (facility) and Level 0 (plant) requirements, and, in the case of the HRRF, finally evaluate the combined Level 2 (system), Level 1 (facility), and Level 0 (plant) requirements. In this way, the requirements baseline will be a consistent package.

This process of allocation and evaluation continues until the required level of design detail has been achieved in the functional requirements assessment during the preconceptual design phase. This Project Summary Plan provides for the assessment to continue through Level 2, or systems which are defined as a set of unit operations supporting a particular process. At this level, design options for the system-level functional flows are developed. For each identified function, at least one design option, which may be a specific hardware item or simply a design concept, is identified. These options will be developed throughout the design process through the coordinated efforts of a

central design group, a development group, and several specialty engineering groups.

The purpose of the feasibility and preconceptual design phases is to provide the design options that are evaluated in the conceptual design phase.

The purpose of feasibility and preconceptual design phases is to provide the design options that are evaluated in the conceptual design phase. The specialty engineering teams will analyze each of the design options that have been identified for each function. Therefore, the specialty engineering groups will assist in both the requirements evaluation and the optimal design option selection. In the conceptual design phase, these groups are responsible for assisting in the identification of that particular combination of design options which meet the system requirements and provide the lowest or highest value for the trade criteria chosen for use in the trade studies.

Once this step has been completed, the Program Manager will have developed enough information to engage an Architect/Engineering firm to complete the conceptual design. The A/E firm will have available the design option specifications, facility design criteria, preconceptual design, technology requirements, and a cost estimate of the physical plant and processes based on the preconceptual design.

The documentation of this process is described in the Appendix, Part A under the Requirements Documents. In addition, complete guidelines are provided for Principal Plant Factor identification and Unit

Operations Analysis as well as for the specialty engineering disciplines of Availability, Reliability, Maintainability, Logistics Support Analysis, and Licensing.

3.3 Organizational Requirements

The completion of the conceptual design of an HRRF requires the existence of three functional groups: design, specialty engineering, and development. The design group would be organized under Subtask 930 and would have the basic responsibility of coordinating and incorporating inputs from the other two groups into the preconceptual design of an HRRF. The specialty engineering group, composed of several subgroups representing each of the disciplines, would provide input potentially based on substantial analysis in the requirements assessment, would function as review boards for the preconceptual design as it is developed, and would aid in the choice of optimal design options for the conceptual design. The development group would guide work on problems uncovered by specialty engineers, designers, and development engineers.

Areas of expertise that should be represented in the design group include criticality, process design, and process control. Other areas would be added on the basis of HRRF Program Management decisions.

The specialty engineering disciplines identified in this study are reliability, maintainability, logistics support, environment, safety, licensing, physical protection, layout, criticality, and safeguards/accountability.

3.4 Application

The following sections describe the application of the design logic in each of the three design phases being considered--feasibility, pre-conceptual, and conceptual. Several development tasks in the National Program for HTGR Recycle Development have progressed to the point that particular equipment items and design options have been well-defined. In these cases, the identified equipment and/or design options will be assessed on the basis of the requirements and will be utilized for the preconceptual design. Only in those areas where limited development work has been done will it be necessary for the complete design logic to be applied.

Only in those areas where limited development work has been done will it be necessary for the complete design logic to be applied.

Three elements of the design logic which are of considerable importance occur at each level of detail in the design process. These are functional analysis, trade studies, and interface control, each of which will be considered prior to the discussion of the design phases. The first to be considered is the functional analysis (FA). The flow of activities for the functional analysis as it applies to each level of requirements is shown in Figure 3-3. A complete discussion of functional analysis is provided in the Appendix, Part A. Functional analysis is a subset of the systems requirements analysis and is the second step in the system engineering process. It is used to analyze the operational

Figure 3-3. Functional Analysis.

aspects of a system by identifying and sequencing the system element functions that must be accomplished to achieve system objectives/requirements.

Functional analysis is composed of three interrelated activities: 1) functional identification, 2) functional performance requirements analysis, and 3) time requirements analysis. Functional identification is analysis of system objectives to identify functions that must be performed to satisfy the objectives of each functional cycle. The unit operations analysis will identify the primary functional activities, with the complete functional flows developed by connecting these activities with the necessary interface functions. As the design process continues through the design phases, functions should be indented from the highest level so that subfunctions are recognized as part of a higher order function, and they should be arranged in a logical sequence so that any specified operational use of the system can be traced in an end-to-end or closed loop path. All functional blocks at any level must be stated in action-oriented terminology and not in terms of its design or synthesized solution. A good goal is to limit the terminology to a two-word set, one verb and one noun. For example, transfer fuel is functionally oriented, while provide a fuel pump is a design solution.

As discussed in the Unit Operations Guideline in the Appendix, Part C, the alternative functional flows would be described when defining the unit operations baseline, since unit operations are normally functional activity descriptions. The final functional flows developed at each level of the design analysis would include the functional descriptions from

the unit operations analysis along with other functions that would be required to interface the primary process or unit operations activities.

For the Level 0 Requirements Assessment, the functional analysis concentrates solely on the overall HRRF plant functions, ignoring facility and system delineations within the plant in this first step. As the design process continues, the functional analysis will concentrate next on facilities and finally on systems.

The unit operations analysis will identify the primary functions at each level considered in the design analysis (see Appendix C.). The final functional flow sequence would be the responsibility of the design group, incorporating comments from other members of the HRRF design team.

A second element of the design process is the trade-off studies, which are performed at each level of the design analysis. Once the functional flow has been defined by the design group for each design entity (i.e., plant, facility, or system), which in turn is defined by the unit operations analysis, various design options will be identified for each function. The design detail increases as the functional descriptions become more process or operations specific; however, even at the plant level there may be two or more sets of processes that can achieve the plant requirements.

During the feasibility and preconceptual design phases, the trade-off analysis is concerned primarily with the logic grouping of functions. These functions will be derived from alternative sets of processes or unit operations. Where several design operations are available, trades should be made to limit the number of design options considered for a particular function.

In the conceptual design phase, the trade-off analysis is used to identify the optimal design option for each function. Figure 3-4 depicts the logic sequence for the trade-off analysis performed in the conceptual design phase. As shown in the figure, both the design and specialty engineering groups would be involved in this process. To rank the options being considered, figures-of-merit can be used as trade criteria. For example, systems-level figures-of-merit would include the ratios of system effectiveness to life-cycle cost or system availability to life-cycle cost. At a lower level of design detail, a ratio such as maintenance man-hour to operating-hour can be used. The figure-of-merit chosen for the trade criteria should reflect the degree of achievement for the requirements.

A third key element in the design logic is the interface control. In the feasibility phase of HRRF design, the interfaces will be between functions; in the preconceptual design phase, the interface is at first between functions, but at the final level of design analysis, the interface is between design options; and in the conceptual design phase the interface is between design options. Interface control involves the matching of output and input requirements between two or more functions and/or design options. The primary concern of interface control deals with identifying compatible design options that can be considered for evaluation in the conceptual design stage. This interface control assessment of design options and functions would be the responsibility of the design group. A discussion of interface control is provided in the Appendix, Part M under Transportation, Handling, and Storage of Materials.

Figure 3-4. Trade-Off Studies.

3.4.1 Feasibility Design Phase

The feasibility design phase consists of the Level 0 Requirements Assessment, supported by functional analysis, interface requirements assessments, and trade-off studies. The output from the feasibility design phase includes the Level 0 Requirements Baseline and functional flow and the general technology requirements for the HRRF identified in the design analysis.

The output from the feasibility design phase includes the Level 0 Requirements Baseline and functional flow and the general technology requirements for the HRRF identified in the design analysis.

Figure 3-5 displays the steps for the Level 0 Requirements Assessment. These requirements deal with the HRRF plant and would most likely include such factors as design capacity, throughput, operational availability criteria, operating efficiency, and cost constraints. Each requirement would be expressed in quantitative terms and would reflect the input of the various elements on the design team--development engineers, design engineers, and specialty engineers.

The initial input for the requirements assessment comes from the Principal Plant Factors, a set of goals, constraints, and guidelines that have been identified as having potential significant impacts on both the design process and the final conceptual design for the HRRF. The derivation of these Principal Plant Factors is described in the Appendix, Part B.

Figure 3-5. Level 0 Requirements Assessment.

Once the Level 0 Requirement Baseline Document is developed, the unit operations analysis may proceed with the definition of the HRRF plant. This process is described in the Appendix, Part C. Once alternatives have been identified (sets of processes) for the HRRF Plant, the functional analysis, trade-off studies, and interface control assessments will proceed.

3.4.2 Preconceptual Design Phase

As indicated in Figure 3-2, the same sequence of steps would be followed in the preconceptual analysis as in the feasibility analysis, with the difference that the plant level requirements (Level 0) would be allocated to facilities (Level 1) comprising the HRRF plant. The output from the preconceptual design phase includes the Requirements Baseline for the lowest level of detail considered in the HRRF systems engineering process (Level 2) and the technology requirements necessary to provide viable unit operations alternatives.

The output from the preconceptual design phase includes the Requirements Baseline for the lowest level of detail considered in the HRRF systems engineering process (Level 2) and the technology requirements necessary to provide viable unit operations alternatives.

Although the actual level of analysis will vary from project to project, it is appropriate to analyze all allocated requirements below Level 0 in the preconceptual design stage, allowing the system synthesis

and the development of design specifications to be accomplished in the conceptual phase of the design effort.

The final objective of the preconceptual phase is to identify design option alternatives for the Level 2 (system) functions that can be examined in the conceptual phase through the use of specialty engineering skills. The results of this integrated approach will be an optimal set of design options and/or equipment that will accomplish the requirements of the HRRF plant.

In the preconceptual phase, the Unit Operations Analysis consists of providing more detail to the original delineation developed in the feasibility design phase. The analysis will continue through process identification to unit operations. At each stage, the optimal alternatives will be chosen through a series of trade-off studies.

The Level 1 Requirements Assessment is shown in Figure 3-6. In many cases, the equipment descriptions, developed for the optimal unit operation configuration, will simply represent a design option. Sometimes the data are not available to support the various trade studies that will be necessary. In these instances, the evaluation process must proceed on the basis of assumed conditions, or until information is obtained from prototypes, or alternatives are found that can accomplish the same function. Potential research activities should be justified on the basis of risk reduction, potential for cost reduction, and/or safety, security, etc. The Level 2 Requirements Assessment proceeds along the same lines as shown in Figure 2-6.

Figure 3-6. Level 1 Requirements Analysis.

The final outputs of the preconceptual design phase are the Level 2 Requirements Baseline, technology requirements, and functional cost estimates for the facility. As part of the baseline, design options will be identified for each of the functions for the systems. These design options will be developed by the design team (design, development, and specialty engineering groups), with the design group evaluating their compatibility or interface requirements. The optimal design option for each function is chosen in the conceptual design phase.

3.4.3 Conceptual Design Phase

The conceptual analysis represents the last stage before an Architect/Engineering firm is required to begin the HRRF conceptual design.

The conceptual analysis represents the last stage before an Architect/Engineering firm would begin the facility conceptual design. The outputs from this stage in the design process include the equipment specifications, facility design criteria, technology requirements, and several plans including the Integrated Logistics Support Plan, Safety Plan, Security Plan, and Quality and Reliability Assurance Plan.

The basic flow of activities for the conceptual design phase is shown in Figure 3-7. Through feasibility and preconceptual design, especially in the latter phase, the focus of the research is on the development of alternatives and the demonstration of technologies. Although these functions will continue in the conceptual design effort,

Figure 3-7. System Synthesis.

the primary focus at this stage is to bring the specialty engineering disciplines together in an integrated fashion to judge equipment and design options according to a set of predetermined criteria. The amount of prototype testing that is performed is dependent upon several factors. First, the program budget provides an independent constraint on development efforts. Second, the program schedule constrains development efforts that may take long periods of time. And third, the manpower and facility resources available to the Program Manager may constrain development activities. There are obvious trade-offs that have to be made, but the more coordinated development that is performed during the three design phases being considered, the more detailed will be the design specifications that result from the conceptual design effort.

The key interfaces between the various specialty engineering analyses that have to be performed are delineated in the guidelines in the Appendix. Although specialty engineering considerations have been incorporated in the feasibility and preconceptual design phases, the primary analysis occurs when all units of a complete set of unit operations have been identified, and design options have been specified. At this stage, these engineering groups aid in the choice of the optimal set of design options.

The design group will update the preconceptual design with the results of the analyses performed by the specialty engineering task forces. In this way, the preconceptual design will progress from a set of drawings depicting several design options for each function to a set of drawings depicting the optimum design option.

With the output from the conceptual analysis, the Program Manager has the requisite criteria and definitions to guide the completion of the detailed conceptual design with appropriate A/E resources.

4.0 SUMMARY PROJECT SCHEDULE/DESIGN PLAN

The HRRF Summary Project Schedule/Design Plan reflects the underlying principles of design discussed in Section 3.0 and in the Appendix. The emphasis is on the use of a systems approach to develop a set of requirements documents at each level of design detail. In this Project Summary Plan, the final level of design analysis is Level 2 (system); however, in actual practice the level of analysis may vary depending on the information required to support the conceptual design.

Figure 4-1 presents the Summary Plan in precedence format.* In the precedence planning approach, each of the written descriptions represents a work package. In the figure, these work packages have been defined at a general level to provide a framework for the complete HRRF conceptual design effort. The three basic relationships used in the precedence network are shown below:

1.
Start of B depends on the start of A.
2.
Finishing B depends on finishing A.
3.
Start of B depends on finishing A.

*O'Brien, James J. Scheduling Handbook. McGraw-Hill Book Company, 1969. pp. 99-143.

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FIGURE 4-1. SUMMARY PRECEDENCE PLAN FOR HRRF CONCEPTUAL DESIGN.

Each phase of the Summary Plan is supported by a series of flow diagrams in Figures 4-2 through 4-4. These flow diagrams indicate the logical progression of activities, from consideration of plant requirements (Level 0) to system requirements (Level 2). For each design phase, the specific interactions between functional activities are indicated by arrows.

The feasibility design phase begins with the identification of Principal Plant Factors for the HRRF. A process for identifying these factors is discussed in the Appendix, Part B. The preliminary requirements would be identified by examining the Principal Plant Factors and by involving the specialty engineering groups. The design process reflects a continual updating and modification of these requirements to reflect technology and budget constraints. Unit operations analysis, functional analysis, interface analysis, and trade studies are essentially simultaneous activities, although the unit operations analysis will begin before the other tasks. The entire process would iterate until management felt the level of information justified an increase in design detail, at which point the Level 0 Baseline Requirements would be documented, and the preconceptual design phase would begin.

The preconceptual design phase represents an increase in the level of detail and will result in the definition and documentation of the Level 2 Baseline Requirements and the identification of design options for the Level 2 Functional Flow Block Diagrams (FFBD). Figure 4-3 indicates the flow diagrams for the preconceptual design phase and is presented in four parts, A-D.

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FIGURE 4-2. FEASIBILITY DESIGN PHASE.

FIGURE 4-3. PRECONCEPTUAL DESIGN PHASE - PART A.

IN PHASE - PART A,

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INTERFACE ANALYSIS LEVEL 1

ANALYZE SELECTED LOGIC
GROUPING TO DEFINE INTERFACE
REQUIREMENTS AT LEVEL 1

MAINTAIN INTERFACE
CONTROL DOCUMENT

TRADE STUDIES

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FIGURE 4-3. CONTINUED - PART B.

FIGURE 4-3. CONTINUED - PART C.

SEE FIGURE 4-3 PART B

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FIGURE 4-3. CONTINUED - PART D.

*SEE FIGURE 4-3. PART D. TRADE STUDIES

FIGURE 4-4. CONCEPTUAL DESIGN PHASE.

Figure 4-4 presents the flow diagram for the conceptual design phase. The conceptual design will be completed by an Architect/Engineering firm. Also, the A/E will be involved in the pre-criteria review in the preconceptual design phase and the criteria review in the conceptual design phase. This early involvement will help minimize any potential communication problems between the A/E and elements of the National Program.

The summary project schedule/design plan presented in flowchart format provides to the National Program a systematic approach to the conceptual design of an HRRF. Development, design, and specialty engineering functions will be working toward a common goal, with a baseline set of requirements which will be the result of a coordinated design analysis effort.

5.0 CONCLUSION AND RECOMMENDATIONS

The conclusion of this study is that the development of a detailed project plan within the framework of this Project Summary Plan will ensure the completion of the conceptual design for the HRRF by promoting effective coordination of internal program elements, by considering the external environment of the HRRF conceptual design effort, and by accomplishing the program charter within the constraints of a limited budget.

To support the conclusion of this study, the major recommendations are the following:

1. Adopt the proposed systems approach described in this document.
2. Establish a Standing Committee composed of Program Task and Subtask Managers and other individuals active in the field.
3. Identify the Principal Plant Factors for the HRRF.
4. Develop a set of preliminary requirements for the HRRF.
5. Continue the development of the HRRF Project Summary Plan in the following areas:
 - An HRRF Project Management Plan for project control and monitoring. This Project Management Plan would be directly related to and a part of the existing management structure of the National Program for HTGR Recycle Development.
 - A detailed design plan with task statements, budget estimates for both cost and manpower, and organizational responsibilities.

- A detailed Project Schedule relating work statements, manpower allocations, and budget estimates to calendar time.
- Supporting guidelines in all major areas of design analysis.
- A guideline for initiating, maintaining, and controlling the interface between the National Program/HRRF Project and the Architect/Engineering firm engaged to complete the conceptual design effort.

APPENDIX - PART A
REQUIREMENTS DOCUMENTS GUIDELINE

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A1.0 INTRODUCTION

The use of a Systems Engineering approach to process plant development, design, operation, and maintenance offers a planned and systematic way to assure achievement of realistic goals. Systems Engineering has been proven through decades of application of many different types of projects to be a very effective means of providing a disciplined approach to controlling costs, schedules, and allocations of available resources. Plant weaknesses can be identified early and improvement alternatives evaluated, including improvement influences on other plant parameters and costs and schedules. It provides the means for assuring that all participants are working toward common process objectives in a disciplined and controlled manner. Application to projects quite similar to the HRRF project has proven the efficacy of this approach to the HRRF.

Systems Engineering has been proven through decades of application of many different types of projects to be a very effective means of providing a disciplined approach to controlling costs, schedules, and allocation of available resources.

The Systems Engineering Process is generally understood to mean a logical sequence of activities and decisions transforming a plant need into a description of system performance parameters and a preferred system configuration. The elements of this Systems Engineering Process include:

- Plant Requirements Analysis
- FUNCTIONAL ANALYSIS*
- Allocation
- Synthesis
- Logistics Engineering
 - Maintenance Engineering Analysis
 - Repair Level Analysis
 - Logistic Support Modeling
- Life Cycle Cost Analysis
- Optimization
 - Trade-Off Studies
 - Cost Effectiveness Analysis
 - Effectiveness Analysis Modeling
- Production Engineering Analysis
- Generation of Criteria and Specifications

*Element covered by this guideline. It is not within the immediate scope of this work to cover all elements but it is ultimately desirable to consider all elements in HRRF planning.

Although the Systems Engineering Process involves several elements, this guideline is concerned with Functional Analysis.

Application of these Systems Engineering Process elements varies depending upon the project development phase, type of project, and extent of information available. Usual practice is to take the elements of this approach and tailor each to meet the needs of a particular project. Absolute rigor is never required, nor is application required

to the extent that it becomes self serving--it must support meaningful and realistic project objectives and goals to the level of available information. As a project evolves, the depth of application and the extent of application of each element will increase toward more detail, with a number of iterations expected as more detailed information is generated and is made available. The above list of Systems Engineering process elements represents a general approach to any project, with certain elements requiring more emphasis in early project phases, while others become more important in later project phases. Thus a plan of application usually involves allowing project needs to dictate the point of, degree, and extent of application of these elements.

The Functional Analysis element follows a systematic series of steps where plant functions and subfunctions are progressively identified and analyzed as the basis for identifying alternatives for meeting plant performance and design requirements.

The Functional Analysis element follows a systematic series of steps where plant functions and subfunctions are progressively identified and analyzed as the basis for identifying alternatives for meeting plant performance and design requirements. These functions include the overall plant characteristics, development, testing, prototype development, production, and support needs. Plant functions and subfunctions will be developed in an iterative process based on the results of the Principal Plant Factors Analysis, the derived system performance requirements, and synthesis of lower-level system elements. Performance

requirements will be established for each function and subfunction identified. Where time is a critical or important element to a performance requirement, a time line or operating profile analysis will be made.

Once these functions and subfunctions have been developed, usually in the form of a tiered flow diagram, then a set of performance and design requirements are allocated to each function and subfunction. These requirements are normally derived concurrently with development of the function and subfunction flows from time line or operating profile analyses, syntheses of plant systems design, and evaluation performed through trade-off studies and plant system(s)/cost effectiveness analyses.

During the Feasibility, Pre-Conceptual, and Conceptual phases, the depth to which Functional Analysis is applied is usually the System Level, where the levels are defined here as:

<u>LEVEL*</u>		<u>DEFINITIONS</u>
0		Plant
1		Facility (Operational Facility)
2		System
3		Subsystem
4	Equipment	Assembly
5		Subassembly
6		Module
7	Component	Part

*See References.

Below Level 2, the functional analyses, suballocations, and trade-offs are usually left to the discretion of the individual responsible for particular system design. Where appropriate, assistance can be given

to the individual designer in developing his particular analyses. This assistance is usually important in the beginning phases of a project, since requirement allocations at the higher level (0, 1, and 2) need to be refined based on an attempt to meet them at the lower levels of allocations and analysis. For example, an allocated value of availability may be quite difficult to meet by one particular subsystem, yet another subsystem could meet its goal quite readily. At this point, a re-allocation of the goals for each of these two subsystems would be appropriate. It may be, however, that the overall plant goal for availability may be too high and require a downward adjustment following a review to determine the resources required to meet the higher goal. This illustrates a rather simplistic trade-off that is made during the Functional Analysis and Allocation processes.

Additional factors which can develop out of the conduct of a Functional Analysis include:

- Definition of Interface Requirements.
- The need and extent of Configuration Management required.
- Identification of and Planning for Support Technology (Requirements).

Although not all inclusive, these illustrate the kinds of things that can develop from systematically breaking down the plant operation and overall objectives into specific requirements to be met by successively smaller functions and pieces of hardware, to the part level.

A2.0 PURPOSE OF REQUIREMENTS DOCUMENTS GUIDELINE

The High Temperature Gas-Cooled Reactor Recycle Reference Facility (HRRF) Project has the task of developing a conceptual definition of the HRRF physical plant, processes, and operation. The HRRF Project Summary Plan is intended to cover the method by which current feasibility studies can evolve to conceptual design status and to serve as a planning base for project activities and interfaces. This appendix to the Project Summary Plan introduces a functional analysis design technique to the conceptual design of the HRRF physical plant.

A3.0 APPROACH

The HRRF conceptual definition will be developed by an integrated systems engineering and design activity that will identify major equipment/facility items and requirements for each item. The systems engineering tool selected to accomplish this definition is the functional analysis described in this appendix. This analysis is used as an integrating framework for "trades" and "analysis." Figure A3.0-1 shows the relationship of various project activities in the development of HRRF system requirements. These relationships are discussed below.

A3.1 Operating Requirements (Principal Plant Factors)

There are certain requirements which apply to the HRRF as a whole. These requirements are independent of the design choices to be exercised during project development but are dependent upon external factors interfacing with the HRRF. Examples of requirements of this type are:

- Quality, type, and rate of arrival of spent fuel to be reprocessed.
- Process nature, i.e., batch or continuous operation.
- Limitations on storage of incoming spent fuel, reprocessed fuel, and waste.
- Nuclear safety requirements, which are promulgated by independent agencies whose task is to assure that neither the public, operating personnel, or the environment is endangered by proposed nuclear-chemical activities.

FIGURE A3.0-1 RELATIONSHIP OF HRRF PROJECT ACTIVITIES TO DEVELOP REQUIREMENTS DOCUMENTS.

- Required capacity of the HRRF facility, which is dependent upon the above and many other factors.

These requirements are determined by review and assessment of HRRF environmental interfaces and by associated analyses to optimize the system.

A3.2 Functional Analysis

The functional analysis is the basic structure by which the systems engineering/feasibility design activity is organized.

The functional analysis is the basic structure by which the systems engineering/feasibility design activity is organized. Using this analysis, an orderly, from-the-top-down traceable system basis is developed as follows:

1. Operating requirements (A3.1 above) present the top level system problem statement.
2. This top level problem is partially solved by the definition of all activities or functions required within the HRRF plant to meet the operating requirements. Second level activities will be identified as systems.
3. Each system identified is functionally analyzed, and functional requirements are stated. These requirements define how well the function must be performed, the environment in which it is performed, inputs that must be provided, and required outputs.

4. The functional requirements present lower level problem statements for which design solutions must be developed. These solutions come from the experienced HRRF project team and will be supported by formal trade studies and analyses.
5. Requirements are then stated for parts of the system as applied to each system function.
6. Selection of appropriate design solutions for the problem statements of 4. will present still lower level problem statements, which are to be solved by definition of new functions and of new system parts and associated requirements. The process is iterative and is repeated until the requirements base is sufficiently detailed to allow preparation of a plant specification.

A3.3 HRRF System Analyses

The functional analysis describes the system and identifies problems which must be solved by the system.

There are many disciplines which must be applied during the development of the HRRF feasibility design. Several of these disciplines are identified in Figure A3.0-1. In applying these disciplines, analyses are conducted which result in requirements which are levied against elements of the HRRF system. The functional analysis describes the system and identifies problems which must be solved by the system. The discipline

analyses must be based upon the functional definition, and the requirements generated by the disciplines must be integrated into the functional analysis to develop the total requirements base. As an example, the HRRF operating requirements could include an operational availability requirement of 80% for the total system. The functional analysis would identify top level functions as:

- Reprocessing
- Refabrication
- Waste
- General Support
- Process Support

An availability analysis would be conducted and an availability allocation made to each of the top functions which would be documented with the functional requirements. Subsequently, additional levels of analyses and design activity would determine lower level functions and the required equipment. These functions and equipment would also be subject to evaluation by an availability analysis which could result in additional requirements being levied. These requirements would also be documented as part of the requirements base of the functional analysis. While the example above illustrates application of the availability disciplines, each of the disciplines would be integrated into the functional analysis in the same manner.

A3.4 HRRF Trade Studies

The problem presented by specific requirements as defined by the functional analysis can usually be solved in more than one way.

The problem presented by specific requirements as defined by the functional analysis can usually be solved in more than one way. For example, a function to transfer spent fuel assemblies from storage to the reprocessing area might be accomplished by one of these means:

- A crane device operating overhead in a hot bay.
- A wheeled dolly operating in a water bay.

The trade study would postulate the methods of solving the transfer problem, complete sufficient design to determine the major characteristics of candidate solutions, compare the candidates, and select a method. Not all design decisions can or should be vigorously documented by trade studies, due primarily to the number of decisions required. Consequently, major decisions are documented by formal trade study reports, intermediate decisions are documented by less formal, single page decision records, and a multitude of lower level decisions are made by the designers and may not be documented at all.

A3.5 HRRF Feasibility Design

Facility layouts, plot plans, and selected design details are provided as necessary to define the selected HRRF configuration. These

designs are developed such that all functions identified in the functional analyses may be performed in accord with the stated requirements. Selected design characteristics "feed-back" into the functional analysis activity and allow development of lower level requirements. This establishes Level 0 and 1 baseline requirements.

A3.6 HRRF Preconceptual Design

Further refinement of the requirements developed during the feasibility design activity is conducted during this phase of activity. At this point, the first broad iteration of the functional analysis is normally completed.

A3.7 HRRF Conceptual Design

With completion of the first broad iteration of the functional analysis activity, a plant level specification can be prepared that would guide subsequent development. This specification would use the functional analysis results, including data from system analyses, trade studies, feasibility, and preconceptual design.

A4.0 ELEMENTS OF FUNCTIONAL ANALYSIS

Five elements have been selected for accomplishment and documentation of functional analysis activity for the HRRF. These are shown in Figure A4.0-1, along with the basic purposes of each element and their interrelation.

Upon completion of all five functional analysis elements, a requirements package can be put together at the Plant, Facility, and System levels, each supporting the other.

Upon completion of all five functional analysis elements, a requirements package can be put together at the Plant, Facility, and System levels, each supporting the other. As the analysis work is completed at each level, a requirements package can be put together for that level. Figure A4.0-2 shows the total Project Requirements Package, composed of the five functional analysis elements for all three levels. By arranging the analysis elements in document form in the order shown, ready access is provided to varying levels of analysis within an element, as well as ready access to requirements support material at each level.

When used in conjunction with the Trade Study Report, this arrangement provides overview at all levels of the requirements support material.

Guidelines for preparation and documentation of each functional analysis element are provided in subsequent paragraphs.

FIGURE A4.0-1 SELECTED FUNCTIONAL ANALYSIS ELEMENTS.

ITERATIVE PROCESS - COMPLETION OF ONE ITERATION POSES NEW PROBLEMS AT A LOWER LEVEL TO BE ANALYZED AND SOLVED IN THE NEXT ITERATION.

FIGURE A4.0-2 REQUIRED PACKAGE PLANT/FACILITY/SYSTEM.
(TYPICAL)

A4.1 Functional Flow Diagrams

A4.1.1 Purpose

The Functional Flow Diagrams define the functions which the plant must perform in order to meet its operating requirements. These diagrams will be used in order to:

- Provide an orderly means of analyzing total plant requirements.
- Determine the functional requirements that meet the total plant requirements.
- Determine relationships between functions.
- Determine which functions are to be analyzed.
- Eliminate functions which are not required.
- Reduce the possibility of omitting essential elements.
- Organize the system analysis into work packages which can be related to specific skills.
- Provide documentation of results which are easily understood and facilitate communication between personnel.

A4.1.2 Guidelines

1. Functional Flow Diagrams will identify the functions involved in the operation of the HRRF in sequential terms. These diagrams will be prepared through successively lower levels or tiers of functional breakdown as the HRRF system development progresses. The top diagram will serve as a starting point which will shape the course of and serve as an index for the system functional analysis. Lower level Functional Flow Diagrams will represent a progressive breakdown of the top level flow to increasing detail in a systematic manner. Progression from one level to the next lower level may be performed for all functions

or restricted to selected functions as the needs of the HRRF project dictate. In either case, the next lower level will be developed by preparing a separate diagram for each function under consideration, showing its breakdown into a set of subfunctions.

2. Functional Flow Diagrams will be prepared to that level necessary for identification of major HRRF facilities, required systems, and establishment of key requirements for each equipment item.
3. During the course of preparing the Functional Flow Diagrams, situations will occur in which more than one flow path is possible, and no decision as to which path will be used in the HRRF will have been made. In these situations, alternate Functional Flow Diagrams will be prepared. Consideration of alternatives will be limited to those which offer significant payoffs in time, cost, or performance. Alternative flows will be maintained in parallel until decision points are reached. The decision must be made at the earliest possible time to minimize the effort involved in maintaining parallel sets of analyses. Alternative flows will be maintained either by separate Functional Flow Diagrams or be clearly indicated as alternative paths on the same diagram; the choice will depend on the extent of the different functions in the flow paths.

A4.1.3 Format

1. For the HRRF Project, Functional Flow Diagrams will be published as part of the project requirements documentation to be done in conjunction with other program task/subtask activities.

2. Figure A4.1-1 illustrates the selected Format. Specific procedures for preparation of Functional Flow Diagrams are discussed below:

General--Functional Flow Diagrams will be laid out so that the functional flow is from left to right, and the reverse flow (or feed-back loop) is from right to left. Primary input lines will enter from the left side, while the primary output lines will leave from the right.

- a. SCOPE NOTE. On top level Functional Flow Diagrams, this area shall contain the formal name of the system and its objectives, a brief description of the scope of the project, and comments, such as the limitations of the analysis. On lower level Functional Flow Diagrams, the scope note will be used to describe the relationship to data covered in other diagrams. It should briefly summarize the condition that exists at the starting point of the diagram and the general purpose and scope of the functions covered in the diagrams.
- b. ABBREVIATIONS AND NOTES. Abbreviations shall be used in flow blocks to reduce the space required. Generally, these abbreviations should be restricted to those commonly understood. All abbreviations and any notes used on the diagram to simplify or clarify the meaning shall be listed in this area of the drawing. Definitions and descriptions shall be complete and accurate. Standard program abbreviations may be listed in an appendix of the requirements documentation. In this case, a reference to this list should be made here.

FIGURE AA.1-1 FORMAT FOR HRRF FUNCTIONAL FLOW DIAGRAM.

- c. **STANDARD BLOCK.** The standard functional block will be a solid heavy lined block. No specific or standard size will be required. However, wherever possible all blocks on a given diagram should be of the same size.
- d. **FUNCTIONAL REFERENCE BLOCKS.** Each Functional Flow Diagram will contain a reference to the function on the next higher Functional Flow Diagram through the use of a reference block and reference drawing number. For example, function 5.1 should be shown as a reference block in a diagram where the functions 5.1.1, 5.1.2, 5.1.3, etc. are being used to expand function 5.1. Reference blocks will also be used to indicate interfacing functions as appropriate or functions which will not be further analyzed at lower levels. Reference blocks will be indicated as partially enclosed boxes. Where reference blocks are used to indicate functions which will not be analyzed, flag notes will be used to indicate this fact.
- e. **TENTATIVE FUNCTIONS.** Questionable or tentative functions will be shown on the Functional Flow Diagram by enclosing the function in a dashed block. Eventually, appropriate trades will be completed, and the tentative function will be either removed or elevated to normal status, with a fully enclosed functional block.
- f. **FUNCTIONAL DESCRIPTION**
 - (1) The functional blocks contain the words which describe the functions in the form of a separate statement of the action that is to occur. All functional statements

must contain an active verb form and a noun. The verb indicates the action, the noun the object of the action. Statements such as "combustible off-gas," "atmospheric protection," or "liquid waste concentrator" are incomplete or ambiguous. For example, for a function labeled "combustible off-gas," it is not clear whether gas is being produced, transported, or burned. A statement like "process combustible off-gas" is an acceptable description.

- (2) Each separate functional block on the diagram represents only a single action. However, on rare occasions it may be necessary that two or more verbs be used to describe a single action.
- (3) Each function description may be as gross or detailed as required by the level of diagram on which it appears. It must, however, adequately describe an action to be accomplished by equipment, personnel, facilities, or any combination.
- (4) The analyst should form functional descriptions in such a manner that a specific solution is not required. Philosophically, the difference between "requirements" and "solutions" is largely a matter of time. That is, as the HRRF project continues, "problems" will be posed and "requirements" stated. From these "requirements" the project activity will form "solutions." Once selected, these "solutions" become

part of the "requirements" environment for statement of new "problems." By way of an example, consider the following situations:

- (a) The project has been underway for some period of time.
- (b) During this time, a system function has been defined requiring storage of spent fuel received from the reactors.
- (c) Suitable project activity has been done to determine that the fuel elements would be stored in a water basin.
- (d) It is known that the fuel will be received in casks.
- (e) A function of unloading fuel from the casks has been identified, and it has been determined that the unloading would be done in a small pool in the receiving area.
- (f) A functional analysis is being done of the unloading activity.
- (g) The analyst recognizes that the cask must be lowered into the receiving pool and visualizes a crane attached to the cask and lowering it into the pool. While the analyst visualizes the use of a crane, it would not be proper to describe the function as "lower cask with crane," nor would it be proper to identify lower level functions such as "attach sling to cask and crane." The decision is yet to be made whether the cask will be lowered by crane or another possible solution, such as an elevator. Thus, a more proper functional description would be "Lower Cask into Receiving Pool." Note that it is proper to make reference to the receiving pool as at the time of the analysis a decision has been made to use the receiving pool (Item (e) above), and its use may impose requirements on the lowering device.

As the HRRF project continues, more decisions will be made, and lower levels of analysis will be entered. This will result in the analysis levels having different kinds of functional descriptions. The upper levels will appear very general (functional) in nature, but the lower levels will appear quite specific (solutional) in nature. However, at all levels the particular function being described should not lead to the requirement of a specific solution to that function.

- g. **FLOW LEADERS.** Lines connecting functions will be lighter than the lines enclosing the functions. Crossovers will be kept to a minimum and will use a broken line pass through; e.g.:

Lines connecting functions will indicate only the functional flow and will not represent a lapse in time or any intermediate activity. In indicating the flow, horizontal and vertical lines between

blocks will indicate that all functions so interrelated must be performed in either a parallel or series sequence.

- h. **SUMMING GATES.** Summing gate symbols will be used on Functional Flow Diagrams to indicate the convergence or divergence of parallel or alternate functional paths. As used in Functional Flow Diagrams, the gate is indicated by a circle at the junction of parallel or alternate flow paths. The circle contains the word "AND" and "OR." The term "AND" is used to indicate that all parallel functions leading into the gate must be accomplished before proceeding into the next function or that all paths emerging from the "AND" gate must be accomplished after the preceding function(s). The term "OR" is used to indicate that the function(s) immediately preceding the "OR" gate are a prerequisite for any of several alternates following the gate.
- i. **LEADER NOTES.** Leader notes will be entered adjacent to the lines entering a particular function when additional clarification is necessary. In particular, leader notes are used with "OR" gates to provide criteria by which each of the parallel paths is selected. As an example, following a function in which final assemblies are removed from a transport cask, it is necessary to begin functional paths for both the fuel and the cask. In this case, the leader on one path would indicate "cask," while the other path would include the leader note "fuel." Another example would be found following a function to test a transport cask for contaminants. If contaminants are found, one activity follows. If not, a different activity follows. In this situation, one of

the functions might be preceded by this leader note "contaminant detected."

- j. REFERENCE TO INDENTURED FUNCTIONAL FLOW DIAGRAMS. Each functional block which is to be expanded to a lower level should have an indicator placed at the bottom of the block.
- k. FUNCTION NUMBER. Functions identified on the Functional Flow Diagrams at each level will be numbered in a manner which preserves the continuity of functions and provides information with respect to function origin throughout the system. Functions on the top level Functional Flow Diagram will be numbered 1.0, 2.0, 3.0, and so on as necessary. On lower level diagrams, each of these top level functions will be broken down into indentured functions (the level of indenture corresponding to the level of the diagram). Each of these indentured functions will be assigned a number containing the next decimal place for each level of indenture; e.g., the first level indentured function of function 2.0 would be 2.1, the second level 2.1.1, the third level 2.1.1.1. In expanding a higher level function within a particular level of indenture, a numerical sequence will be used to preserve the continuity of function; e.g., if more than one function is required to amplify the function 2.0 at the first level of indenture, the sequence will be 2.1, 2.2, 2.3, and on. In expanding function 2.3 at the second level, the numbering will be 2.3.1, 2.3.2, and on.

In general, show only one level of indenture on a single Functional Flow Diagram. This can be accomplished by the careful structuring of functions.

In some cases, however, it may be desirable to include more than one level on the same diagram. These may involve: 1) functional flows where lower level functions must be identified to clarify relationships or feedbacks between the higher level functions, and 2) reduction of the total number of diagrams required to define the system functionally. The general criteria for the number of functions and level of indentures appearing on any particular flow shall be accuracy and clarity of presentation. Where several levels of indenture appear on a single Functional Flow Diagram, the numbering pattern described above will be maintained.

When changes are required, use the following numbering method: Additions or functions to existing data will be accomplished by locating the new function in its correct position without regard to sequence of numbering. The new function will be numbered using the first unused number at the level of indenture appropriate for the new function. Example:

When previously established functions must be redelegated to a different functional series, the function to be moved will be retired, and the new

location of that function shall be a new addition to the acquiring series and will be treated as follows:

NOTE: On the final documentation, it may be desirable to revise and completely renumber the Functional Flow Diagrams and the associated analysis sheets.

1. **DIAGRAM TITLE.** As the Functional Flow Diagrams are being prepared for incorporation into the Requirements Documents, the diagrams should be titled as document figures. The title should include the description and number of the function being analyzed. For example:

FIGURE 4.6. REPROCESS SPENT FUEL (Function 6.0)

- m. **SERIES/PARALLEL FUNCTIONS.** Functions are either series, parallel, or alternate. Series function follow in sequence such that, in the direction of flow, each function is a prerequisite to accomplishment of the following function. Parallel functions follow from a common prerequisite function and provide parallel flow paths to a downstream function. Parallel functions are not necessarily accomplished

simultaneously; however, completion of the function(s) in each parallel path is a prerequisite for accomplishment of the downstream function. Alternate functions also follow from a common prerequisite function (through an "OR" gate), but only one of the alternate flow paths is required for the downstream function.

A4.2 Analysis Summaries

A4.2.1 Purpose

Analysis Summaries relate the functions shown on functional flow diagrams to functional requirements, equipment, and facilities required to meet functional requirements, design requirements for equipment and facilities, and time to perform functions.

1. Analysis Summaries relate the functions shown on functional flow diagrams to functional requirements, equipment, and facilities required to meet functional requirements, design requirements for equipment and facilities, and time to perform functions.
2. The Analysis Summaries provide a means:
 - a. For analyzing the HRRF functions as defined by Functional Flow Diagrams and translating them into requirements.
 - b. To allocate the defined requirements to specific HRRF facility or equipment items.

- c. To verify that all functions have been analyzed and thereby to aid in assuring that no major requirements have inadvertently been overlooked.
 - d. To trace the development of HRRF requirements and the resulting design.
- 3. In translating project functions into requirements, major emphasis will be placed on performance terms. These terms express the following:
 - a. Purpose of the function,
 - b. Parameters of design, e.g., input, output,
 - c. Requirements which constrain design, such as environments and physical interfaces,
 - d. Requirements which derive from application of design disciplines, such as availability, safeguards, criticality, maintainability, and licensing.
- 4. The analysis summaries are prepared in conjunction with the conduct of trade studies (A3.4). Whereas the trade study report reflects the various options considered in arriving at a particular conclusion, the analysis summary shows the results of these trade-offs in the form of requirements. In addition, it provides the means for relating a specific design requirement to the plant function it supports. When the trade study report is prepared, it should identify the particular function/task(s) for each trade-off that is conducted. The trade study process and development of these analysis summaries are mutually iterative. As the trade-off process is conducted through each phase of the project development, the analysis summaries must be continuously revised to

reflect the trade-off results in the form of new or modified design requirements.

A4.2.2 Guidelines

The Analysis Summaries, as do all elements of the functional analysis, grow as the project develops. Early analyses may be somewhat sketchy and serve only to provide a functional skeleton of the HRRF system. Later, additional requirements and equipment and facility items will be added to provide a reasonable general description of the HRRF plant. Even later, very detailed requirements and equipment items may be added. The text to follow describes the preparation of the final Analysis Summaries. It should be noted, therefore, that summaries prepared early in the project will contain considerably less than noted, but will be expanded through the iteration process.

A4.2.3 Format

1. Figure A4.2-1 shows the format of the Analyses Summaries selected for the HRRF project. These summaries will be published as part of the Requirements Documents and will be prepared on 11 x 17 size forms which will be reduced to 8½ x 11 for publication.
2. Specific procedures for preparation of the summaries are provided below.
 - a. TITLE--Each Analysis Summary will include the function number and title of the basic function being analyzed. If the Analysis Summary analyzes functions 1.1, 1.2, 1.3, etc., the basic function is 1.0.

FIGURE A4.2-1 FORMAT FOR HRRF ANALYSIS SUMMARIES.

ANALYSIS SUMMARY BASIC FUNCTION: ① TITLE			
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
② FUNCTION	④ FACILITY ITEM REQUIRED ⑤ EQUIPMENT ITEMS REQUIRED	③ FUNCTIONAL REQUIREMENTS ⑥ FACILITY DESIGN REQUIREMENTS ⑦ EQUIPMENT DESIGN REQUIREMENTS	⑧ TIME
ANALYST: ⑨ _____ PROJECT APPROVAL ⑩ _____ REV DATE ⑪ _____			

- b. **FUNCTION--Each Analysis Summary will include analysis of one or more functions. The number and title of each function being analyzed will be entered in the "function/task" column of the summary.**
- c. **FUNCTIONAL REQUIREMENTS**
 - (1) Functional Requirements will be entered in sufficient detail to provide a firm basis for recommending and evaluating alternate methods of performing each function. The requirements presented in the "FUNCTIONAL AND DESIGN REQUIREMENTS" column will provide the basis for future equipment identification. Care will be taken when writing requirements to use the minimum work count consistent with providing the necessary requirements. Complete sentence structure is not required. Repetitive statements should not be made in a number of functions. To avoid this, material which applies to a large number of functions may be removed and placed in separate documentation, which is referenced on the Analysis Summary. Reference will not be made to external documents not generally available to the HRRF project. Contractual or Program information, such as delivery dates or equipment quantities, are not appropriate to the Analysis Summary.
 - (2) The functional requirement describes the "what," "why," and "how good" of the function. As an example, a function "Crush

HTGR spent fuel" will be considered. This function could be a preparatory subfunction for the basic function "Reprocess HTGR spent fuel." For this subfunction, typical functional requirements could include:

- (a) Inputs--physical characteristics of the HTGR spent fuel, including weight, physical dimensions, chemical corrosiveness, physical hardness, and radiative levels.
- (b) Outputs--Size of particles exiting the crushing function and throughput rates.
- (c) Environments and requirements from the disciplines--An allocation of the systems availability quota to the crushing function, maintainability requirements, personnel protection requirements, and requirements for avoidance of nuclear criticality.

Note that the crushing function will be performed by several items of facilities and equipment. The functional requirements may not apply directly to any of the items but do apply to the function itself. Note also that there may be several possible equipment and facility solutions for the function; however, the functional requirements must be satisfied by the solution eventually selected.

- (3) With the example noted in 2. above, where several solutions are possible to meet the function requirements, a trade study or design decision will be required to select the solution. In this event, a Decision Record (see paragraph A3.3 below) may be

desirable to provide traceability of the design development. A reference to the Decision Record should be made in the functional requirements. Initially, this reference will indicate that a decision is required and thereby help in organizing the projects decision activity.

d. and e.

FACILITY AND EQUIPMENT ITEMS REQUIRED--Following the trade study or design decision associated with the function, the required system or equipment and facility items will be known. Their identifying nomenclature and item numbers can be entered in the Analysis Summary. In the crushing example used above, the required items might include a hot cell, a shear, and handling equipment. These items would be identified.

f. and g. **FACILITY AND EQUIPMENT DESIGN REQUIREMENTS**

- (1) Each item identified as being required to perform the function will be analyzed to determine its design requirements for the function. Design requirements will contain the following types of information.
 - (a) Requirements which constrain the design of the specific item, such as power, physical space available, environment.
 - (b) Design parameters including input, output performance.
 - (c) Requirements from the HRRF disciplines, such as maintainability and nuclear safety.
- (2) Design requirements will be prepared so that a specific solution is not dictated.

When the analyst writes a design requirement, he normally visualizes some item that would do the job. Care will be exercised to avoid using this preconceived hardware to prematurely tie down the design. In the crushing example used above, a trade study of ways to meet the functional requirement resulted in selection of a crusher. The analyst may visualize a device with rollers crushing the fuel segments. However, there may be other devices which also could do the job, such as machines using balls, or drop hammers, or perhaps more exotic processes involving sudden temperature changes to disintegrate the fuel. The design requirements stated for the crusher will apply whatever crusher mechanism is selected.

- (3) Facility requirements are similar to equipment requirements, but some differences arise. Typical facilities requirements include:
 - (a) Controlled environments the facility must maintain, including temperatures, humidity, illumination, noise levels, and radiation protection.
 - (b) Special civil, structural, or architectural requirements.
 - (c) Any special site preparation, such as waste disposal or utility services.
 - (d) Road and rail support requirements, including wheel loads, turn radius, and maximum grades.
 - (e) Separation distances between facilities.

- (f) Safety and security requirements.
 - (g) Requirements for special facility equipment not otherwise covered in the analysis, including cranes, elevators, moving platforms, mobile structures, and hazardous storage.
- (4) In developing requirements, it will be found that some apply to many functions or to many items of equipment. Continued repetition of the same requirements is of little value and will be avoided. The method used to document these requirements will be a series of Design Criteria Documents. As an example: Many HRRF Environmental Control Design Criteria Documents will be prepared. This document, or applicable portions of it, will be referenced in the design requirements section of the Analysis Summary. Similar situations occur with the use of design standards. Government or commercial standards and specifications are often applied to system design. These documents will also be referenced in the requirements column.
- (5) The requirements statements portrayed above apply to the total body of functional analysis and not to each and every Analysis Summary. The Analysis Summaries vary with time and with their level in the flow structure. Requirements for upper level functions define Facility or system, while the lowest levels lead to the design of a specific component. As the HRRF project continues, lower level analyses

will be added, thus providing a change in analysis character with time. Additional changes with time are brought about by iterations of the analysis. Early Analysis Summaries will contain only key requirements associated with the functions and identified hardware and facility items and therefore may not contain all of the characteristics noted above. The analysis will grow as the project data base grows, and the Analysis Summaries will be iterated. The key is that at any given time the Analysis Summaries will reflect the data available on the project and will grow at a rate commensurate with project resources.

- h. TIME--Some of the functions analyzed will be time critical. As an example, the HRRF principal plant factors call for a plant of 1500 MTU per year capacity, with fuel being received 20% by road and 80% by rail; thus the number of receiving bays need to be determined. This determination will be assisted by analysis of each of the functions of the receiving bay and estimating the time required for each function. For the functions where this is required, the estimate will be included in the time column.

i. and j. ANALYST AND PROJECT APPROVAL

The preparation of the functional analysis must be an integrated effort of the total HRRF project organization to be effective. Generally, a given function will be assigned to an analyst, who will be responsible for preparing the

functional analysis. However, much of the material documented will be obtained from others who have other responsibilities. It is necessary that all of the affected parties, or HRRF project organizations, be cognizant of and participate in the preparation of the analysis. For this reason, the Analysis Summaries include locations for signatures (on controls) of those participating in the analysis.

- k. REVISION DATE--As the HRRF functional analysis is iterative, many changes will occur as the project progresses. For this reason, each Analysis Summary page will include the date on which the last revision was made.

A4.3 Decision Records

A4.3.1 Purpose

The Decision Records will provide the documentation of the analytical work performed by the HRRF project to select between alternative methods of meeting requirements.

1. The Decision Records will provide the documentation of the analytical work performed by the HRRF project to select between alternative methods of meeting requirements. For this purpose the following must be provided:
 - a. A statement of the problem to be solved, i.e., the requirements to be met.
 - b. A description of the alternatives considered.
 - c. A statement of the factors considered in making the decision.

- d. A statement as to which alternative was selected.
2. The Decision Record has two purposes:
- a. To initiate the HRRF decision process. During the functional analysis, it will become clear that options exist and a decision is required. The portion of the Decision Record will be prepared which states the problem. The appropriate HRRF project organization can then assign, schedule, and monitor the progress of the decision process.
 - b. Record HRRF project decisions and provide traceability from the decision back to the requirements.

A4.3.2 Guidelines

HRRF project decision will have varying impact on the program. Consequently, the various decisions will have differing levels of resources spent on them. Some decisions may require extensive test programs in order to gather enough data to allow a decision. Other decisions will require extensive trade studies supported by considerable analysis and feasibility designs. Still other decisions will be made judgmentally, with only a Decision Record to document the decision. Other decisions will be made as a part of the design process, and the only documentation will be their presence in the design. The functional analysis will indicate where decisions are required, and by use of the partially completed Decision Record the HRRF management team can assess

decision requirements and determine the level of resource and documentation to be provided for each decision. Each decision selected for documentation will be summarized on the single page Decision Record. Decisions supported by test reports, trade studies, or other external documentation will reference the external documentation.

A4.3.3 Format

HRRF Decision Records will use the format presented in Figure A4.3-1 and will be filled out as follows:

1. **SOURCE OF REQUIREMENTS**--The requirements statements guiding the decision process will be extracted from the Analysis Summaries. The function number and title from which the requirements have been extracted will be indicated on the record.
2. The functional and/or design requirements will be listed as obtained from the Analysis Summaries. Editing will be accomplished as necessary to provide a stand-alone statement of the problem.
3. **ALTERNATIVES CONSIDERED**--The alternatives considered and identification of significant characteristics of each design approach will be listed. This list will be generated after analysis of the requirements to determine possible ways of meeting requirements. For each potential and alternative design approach listed, significant characteristics will be described. These characteristics will relate to those factors bearing most directly on the suitability of meeting the requirements. The significant characteristics shall reflect predicted impact on factors such as cost, plant availability, and personnel safety.

FIGURE A4.3-1 FORMAT FOR HRRF DECISION RECORD.

DECISION RECORD	SOURCE OF REQUIREMENT ①	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA
		ALTERNATIVES CONSIDERED	
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS			
②		③	④
			SELECTED APPROACH ⑤
ANALYST ⑥		APPROVAL	
APPROVAL		REV LTR	LAST REV DATE

4. **SELECTION CRITERIA**--The factors considered important and evaluated during the decision process will be listed. Some factors may weigh more heavily on the decision than others. In this case, some indication of the relative importance of the selection factors will be provided.
5. **SELECTED APPROACH**--A simple statement of the alternative selected will be provided.
6. The Decision Record will include signature spaces for the analyst stating the requirements and for the various HRRF organizations supporting the decision. A last revision date will also be provided.
7. The Decision Record will be a single 8½ x 11 page which will stand alone in recording a decision. However, some decisions may require supplemental information which can be attached. Attachments will be listed on the Decision Record.

A4.4 Operating Profile and Time Line Sheets

A4.4.1 Purpose

The Operating Profile and Time Line Sheets use Functional Flow Diagrams, Process Schematic Diagrams, and other analysis information available at the time of preparation.

The Operating Profile and Time Line Sheets use Functional Flow Diagrams, Process Schematic Diagrams, and other analysis information available at the time of preparation. One important category of "other" information is the maintenance philosophy and maintainability approach

developed for HRRF. Repair-in-place, remove and replace, repair on site, repair at the vendor facility, etc., all will have a significant influence on maintenance task time lines and the skills required.

This particular functional analysis element provides visibility for a number of items:

1. Summarizes and displays each operating segment.
2. Identifies operating and maintenance interfaces.
3. Is the display of an evaluation of operating and maintenance needs for each mode of plant operation.
4. Provides a basis for determining operating and maintenance personnel skills.
5. Provides some information toward identifying special tooling and maintenance equipment to be designed or procured.
6. When summed with other Other Profile and Time Line Sheets, gives an estimate of the numbers and skills of operating and maintenance personnel. This is a major factor in determining plant operating costs, as well as unique or special training requirements.

A4.4.2 Guidelines

The Operating Profile and Time Line analysis will be restricted to functions requiring verification of capability to meet plant capacity requirements, as well as critical time requirements to assure achievement of efficient plant operation. The depth of detail will vary depending on the significance of the function and the extent to which specific operations need to be defined and evaluated.

A4.4.3 Format

The Operating Profile and Time Line Sheets will be developed as an extension of the Functional Analysis and Schematic Diagrams. Each sheet will represent the smallest repeatable cycle or time slot in each process campaign, or may cover a full campaign. Figure A4.4-1 shows the information to be included on each sheet. The top line of information (sheet #, function, system, and functional area) includes a sufficient number of identifiers to relate any given sheet to a particular Functional Flow Diagram and Process Schematic. The second section down on the sheet displays the Operating Profile of the smallest repeatable cycle. Included are the appropriate operating modes the function must go through against a progressive time scale. The next section down lists the source of the function, task to be performed (operating and/or maintenance), and the estimated time required. The times (in a bar or line form) for these tasks are shown against the Operating Profile time scale so the task times and profile modes are directly related.

A4.5 Equipment and Facilities Summaries

A4.5.1 Purpose

The Equipment and Facilities Summaries represent the summary of all information concerning each item analyzed in the HRRF conceptual design effort.

The functional analysis develops data on a function-by-function basis. There will be many HRRF project activities involving hardware or

FIGURE A4.4-1 FORMAT FOR OPERATING PROFILE AND TIME LINE SHEET.

OP & TL SHEET #	FUNCTION	FUNCTIONAL AREA	SYSTEM
<p>OPERATING PROFILE</p> <p>UP DOWN UP IDLE</p> <p>MAINT. ACTIVE ACCOUNT-ABILITY</p> <p>SMALLEST REPEATABLE CYCLE (PROCESS CAMPAIGN)</p> <p>TIME</p>			
SOURCE OF FUNCTION	TASK	TIME (CAMPAIGN)	
<p>FUNCT. ANAL. BLOCK #</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p>	<p>MAINTENANCE</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>_____</p> <p>STARTUP</p> <p>_____</p> <p>_____</p> <p>_____</p>		
<p>PREPARED BY _____ DATE _____ APPROVED BY _____ DATE _____</p>			

facilities on an item-by-item basis. Thus it is necessary to extract all the material concerning each item and to list it in a single location. This is accomplished by the Equipment and Facilities Summaries. A second purpose of these summaries is to provide an abbreviated specification for each required facility or equipment item.

A4.5.2 Guidelines

The Equipment and Facilities Summaries essentially do not result in new data being generated, as all the information is extracted from the Analysis Summaries. The Equipment and Facilities Summaries will grow as the analysis grows with the project data base. Early summaries will be little more than an equipment list. Later summaries may be mini-specifications.

A4.5.3 Format

Figure A4.5.1 shows the format that will be used for the HRRF functional analysis. The summaries will be prepared as follows:

1. ITEM NUMBER--Each equipment or facility item will be assigned a number. This will be done to avoid confusion between references to different equipment with similar nomenclature.
2. NOMENCLATURE--Each item will be assigned a nomenclature which will be used throughout the project. This will reduce confusion between various HRRF project documentation.
3. FUNCTIONS REQUIRING THE ITEM--Each function in which the item is used will be listed.

FIGURE A4.5-1 FORMAT FOR EQUIPMENT AND FACILITY SUMMARY

EQUIPMENT AND FACILITY SUMMARIES

LAST REVISION DATE ⑤

ITEM NUMBER	NOMENCLATURE	FUNCTIONS REQUIREMENTS ITEM	REQUIREMENTS
①	②	③	④

4. REQUIREMENTS--Requirements applicable to each item as contained in the Analysis Summaries will be listed. Some items may be used in several functions, and the requirements for each function may vary. For this reason, some editing of the requirements will be required to develop an integrated requirements statement.
5. LAST REVISION DATE--Each summary sheet shall be dated.

A5.0 EXAMPLE DESIGN ANALYSIS

A.5.1 Introduction

Sections A1.0 through A4.0 define a Systems Engineering approach to the systematic development of plant design, operation, and maintenance. This analysis will identify the necessary operations that define the methodology used in a systems requirements analysis.

This section will develop, through the systems engineering approach, a piece or set of hardware which is to be used in the HRRF project. The analysis will not be rigorous nor extensive, but will show the major salient points in a systems requirement analysis.

A5.1.1 Scope

This example will be limited to the development of a systems analysis for a device which will reduce an HTGR fuel element block or pieces of elements to a condition where the graphite moderator can later be separated from the nuclear material.

A5.1.2 Purpose

The intent of this example is not to "re-engineer" any existing equipment items, but to use the HRRF crusher in an example of how a systematic Systems Engineering approach could lead to the development of a similar piece of equipment. Further, the example is intended to show how the forms, as shown in the earlier sections, might be completed.

A5.2 Fuel Cycle

A systems analysis, or functional requirements analysis, begins with a reasonably well defined need. This need may be the result of a marketing analysis or survey which indicates that a product or service is required and that it is economically viable. In this example, we are generally assuming that some economic analysis has been performed and that a decision has been made to evaluate a reprocessing plant for gas-cooled reactor fuel elements.

The first step in the evaluation is the determination of where the reprocessing plant "fits" into the back end of the fuel cycle. Figure A5-1 shows a general function flow which indicates where and how the recovery plant fits into the recycle. As can be seen, the reprocessing plant must interface directly with the spent fuel transportation system for feed material and two product transportation systems; one for reusable nuclear materials and one for waste. The functional requirements at this Tier I, or top level, are basic and minimal.

SCOPE NOTE:
 THIS FUNCTIONAL FLOW DIAGRAM SHOWS THE 'HTGR'
 REPROCESSING FUEL CYCLE. THE SUBSEQUENT ANALYSIS
 WILL BE LIMITED TO ONLY CERTAIN FUNCTIONS
 PERFORMED IN THE REPROCESSING PLANT.

ABBREVIATIONS AND NOTES

HTGR-HIGH TEMP GAS COOLED REACTOR

FIGURE A5-1 - HTGR FUEL RECYCLE FUNCTIONAL FLOW.

TITLE RECOVER NUCLEAR MATERIAL			
ANALYSIS SUMMARY		BASIC FUNCTION: 2.0	
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.0 Recover Nuclear Material	Reprocessing Plant	Market analysis has shown that there is a need for a reprocessing plant which can recover nuclear material from spent fuel elements at a rate of 20,000 standard fuel elements per year.	
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A5.3 Reprocessing Plant

The top level functional flow, Figure A5-1, identified a function block 2.0, which is titled "Recover Nuclear Material;" this is the function performed by reprocessing plant. This example will deal with only one small, although very important, operation within the plant-removal of the fuel from the graphite. Figure A5-2 shows many of the other functions which occur within the plant; however, it is incomplete, and only sufficient functions were shown to indicate the nature and "fit" of the comminuting function, Block 2.3.

Each of the function blocks in the flow would, of course, have a set of functional requirements that must be met. In this example case, only the function which addresses the comminuting process is shown as a functional requirement. This example shows only very general requirements; however, these could be expanded in much more detail.

SCOPE NOTE:
 FURTHER ANALYSIS FOR THIS EXAMPLE WILL BE
 LIMITED TO THE DEVICE WHICH WILL PROCESS THE
 SPENT HTGR FUEL ELEMENTS TO A CONDITION WHERE
 THE FUEL PARTICLES CAN BE SEPARATED FROM THE
 GRAPHITE MATRIX MODERATING MATERIAL.

FIGURE A5-2 - RECOVER NUCLEAR MATERIAL (FUNCTION 20).

TITLE RECOVER NUCLEAR MATERIAL

ANALYSIS SUMMARY

BASIC FUNCTION: 2.0

FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3 Comminute Spent Fuel		<p>The comminution device(s) shall be capable of reducing graphite spent fuel elements and pieces to a size which will permit complete separation of the fuel particles from the graphite matrix. This shall be accomplished in a manner which will permit processing of 20,000 fuel elements and pieces per year.</p> <p>These device(s) shall be remotely maintainable.</p> <p>Dust and fines from the comminuting process shall be kept to a minimum.</p> <p>Off-gas control shall be provided.</p>	
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A5.4 Fuel Particle

The next sequence of analysis is to invent a functional flow which describes the operations to be performed. This was done and is shown as Figure A5-3. This takes function block 2.3, from Figure A5-2, and expands it into a logical sequencing of events. As can be seen, the fuel moves from a temporary storage system into a feed unit and into a device which somehow reduces the spent fuel element into pieces from which the fuel particles can be removed. It then goes into a device which separates the different materials. Each of the blocks shown on the flow would nominally have a set of function requirements which the hardware must satisfy. This example will be limited to block 2.3.3.

The system engineering analysis is now at a level of depth where very specific requirements can be levied. As can be seen, there are 20 different identifiable constraints. Each of these must be met or later revised, such that hardware and requirements are compatible.

SCOPE NOTE:
DETAILED ANALYSIS WILL BE FURTHER LIMITED TO THE
FUNCTION WHICH ACTUALLY REDUCES A SPENT FUEL
ELEMENT OR PIECES TO A PARTICULATE SIZE FROM WHICH
THE NUCLEAR MATERIAL CAN BE EFFECTIVELY SEPARATED.

1 NO FURTHER ANALYSIS WILL BE PERFORMED
FOR THESE FUNCTIONS

FIGURE A5-3 -- COMMINUTE SPENT FUEL (FUNCTION 2.3).

TITLE COMMUNUTE SPENT FUEL

ANALYSIS SUMMARY

BASIC FUNCTION: 2.3

FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
<p>2.3.1 Transfer Spent Fuel from Storage 1</p> <p>2.3.2 Place Fuel into Feed and Withdrawal Unit 1</p> <p>2.3.3 Commute Spent Fuel</p>		<p>1 Analyses are not being carried forth for these functions</p> <p>2.3.3 The following requirements shall be met by the spent fuel comminution unit(s):</p> <ul style="list-style-type: none"> a. Process 20,000 spent fuel elements per year b. Reduce spent fuel element(s) into sizes which will pass through a 3/16 inch ring sizing device. c. A 10-year basic unit service life. d. Remotely maintainable. e. Provide ventilation flow from the least contaminated area to area of most contamination 	
<p>ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____</p>			

TITLE COMMUNUTE SPENT FUEL			
ANALYSIS SUMMARY		BASIC FUNCTION: 2.3	
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3 Commute Spent Fuel (cont'd)		f. Comply with the Category III seismic requirements of RDT standard F9-2T g. Allow no lubricants to be entrained with the fragmented material. h. Operate in a radiation environment of 4.9 (10 ³) R/HR. i. Material hold-up shall be limited to less than 0.5% of customer lot through-put. j. Contain all dust and radioactive product. k. Operate in temperature range of room temperature to 400°F. l. Operate in a nitrogen, carbon dioxide atmosphere, or inert atmosphere. m. Operate with an internal pressure of 14.7 + 0 - 6 psia	
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TITLE COMMUNUTE SPENT FUEL			
ANALYSIS SUMMARY		BASIC FUNCTION: 2.3	
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3 Commute Spent Fuel (cont'd)		n. Operate with an external pressure of 14.7 psia nominal. o. Interface with the feed subsystem (function 2.3.2) p. Interface with the comminuted fuel transfer device (function 2.3.4) q. Break less than 0.8% of the fertile (BISO) particles and less than 2.6% of the fissile (TRISO) particles (cold fuel - unirradiated) r. Accept fuel elements and pieces which weigh approximately 300 lbs. s. Accept fuel elements which are hexagon shaped in cross section (14 inches across the flats) and are less than 32 inches in length.	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE COMMINUTE SPENT FUEL ANALYSIS SUMMARY BASIC FUNCTION: 2.3			
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3 Commminute Spent Fuel (cont'd) 2.3.4 Transfer Comminuted Material to Fuel/ Graphite Separ- ator		t. Capable of starting and operating either empty, partially loaded, and fully loaded conditions.	
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There are, of course, many possible ways to satisfy the functional requirements of block 2.3.3. The next series of operations will be the development of a decision record matrix. This matrix reiterates the general functional requirements and then defines or delineates a number of possible solutions. It should be pointed out that most, if not all, of the alternatives considered will require some extensive analyses and, in some few instances, actually fabricating feasibility hardware. Novel or new approaches, too, are often identified; in this case, thermal shock and hydraulic fracturing. The brief analysis discussion would often be filled in some time later in a revision.

Some of the options considered would need little or no analyses to characterize their full applicability; others would require testing. In this example, we have assumed that only two viable alternatives exist-- the hammer-mill crusher and a jaw type crusher. Two new functional flow sheets were made. Since the functional requirements are the same as previously described, there is no need to repeat them. However, a brief discussion on the merits of each system and flow is warranted.

DECISION RECORD	SOURCE OF REQUIREMENT BLOCK NUMBER 2.3.3	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA	
		ALTERNATIVES CONSIDERED		
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS		"COMMUNUTE SPENT FUEL"		
<p>A requirement exists to reduce the spent fuel element into sizes which will allow the separation of the nuclear materials from the graphite block matrix material.</p> <p>Service Life - 10 years Capacity - 10,000 elements/year Fragment Size - TBD</p> <p>Maintenance - Remote and/or modular design for parts replacement Seismic - Category III; RDT STD. F9-2T Radiation Environment - $4.9 (10^3)$ R/hr. Temperature - 100°F max Blanket Gas - Nitrogen, carbon dioxide, or inert atmosphere. Pressure - 14.7 + 0, -6 psia internal - 14.7 psia nominal external</p>		<p>A. Hammer Mill</p> <p>Rotating device with articulated "arms" hinged at the center hub. The outer surface is configured such that crushing can take place when the material is caught between the wall and the hammer. Analysis: See Option Functional Flow 2.3.3A</p> <p>This approach will reduce the fuel block to fragment size but does so in an uncontrolled manner. The unit would be large because of the size of the fuel block. Test and experience indicated that a higher than acceptable particle breakage percentage exists. The unit could be modularized and remote operation could be achieved. Maintenance of the hammers and anvils would be difficult. Withdrawal of spent fuel elements for maintenance purposes would be extremely difficult.</p>	<p>1) Efficiency 2) Maint. 3) Remotability 4) Modularity 5) Size</p>	
			<p>SELECTED APPROACH</p> <p>See Option B Functional flow revised (jaw crusher)</p>	
<p>APPROVAL _____</p> <p>ANALYST <u>L. E. Mayfield</u> APPROVAL _____ REV LTR _____ LAST REV DATE _____</p>				

DECISION RECORD	SOURCE OF REQUIREMENT	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA
	BLOCK NUMBER 2.3.3	ALTERNATIVES CONSIDERED	
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS		"COMMUNUTE SPENT FUEL"	
<p>Lubrication - Radiation Resistant</p> <p>Construction - Modular, Abrasion resistant</p> <p>Controls - Remote operation</p> <p>Breakage - 0.8% Biso particles 2.6% Triso particles</p> <p>Charge size - 30J lb block, hexagon cross section 14 inches across flats, 32 inches long + pieces.</p> <p>Operation - Start and operate under any load condition</p> <p>Accountability - Material holdup 0.5%</p> <p>Ventilation - Air flow from high pressure to low pressure areas</p> <p>Contamination - Lubricant contamination of the product shall be minimized.</p> <p>- Metal fines from wear and abrasion shall be kept to a minimum</p>		<p>B. Gyrating Cone Crusher</p> <p>Crushing device which uses an oscillating, orbiting conical roll crusher. The device would be set up such that the axis would be vertical.</p> <p>Analysis:</p> <p>This approach will reduce the fuel block to fragment size but does so in an uncontrolled manner. The unit would be large because of size of opening required for fuel element feeding. The unit could be modularized and could be operated remotely. Maintenance of this unit would be extremely difficult. The drive motors would be buried within the orbiting roller. The entire assembly would require removal to gain access to the drive. The drive might be susceptible to radiation damage. Withdrawal of partially crushed fuel elements would be difficult, if not impossible.</p>	<p>SELECTED APPROACH</p>
<p>APPROVAL _____</p> <p>ANALYST <u>L. E. Mayfield</u> APPROVAL _____ REV LTR _____ LAST REV DATE _____</p>			

DECISION RECORD	SOURCE OF REQUIREMENT	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA	
	BLOCK NUMBER 2.3.3	ALTERNATIVES CONSIDERED		
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS		"COMMINUTE SPENT FUEL"		
		<p>C. Jaw Crusher</p> <p>A device which would crush the fuel element between a fixed and moving jaw.</p> <p>Analysis: See Option Functional Flow 2.3.38</p> <p>This approach will reduce the fuel block to fragment size. Size can generally be controlled by the gap at the juncture of the two jaws. This device would be a vertical device with gravity feed. Crushing speed can be controlled. The unit is readily modularized. Remote operation can be accomplished. Shaft drives can be located outside the hot cell. Drive motor maintenance is routine, hands on. Crusher jaws could be designed for removal for maintenance. Feed material input could be either horizontal or vertical. Withdrawal of feed material in the event of a broken machine element which required tear down for</p>		
			SELECTED APPROACH	
APPROVAL _____				
ANALYST <u>L. E. Mayfield</u> APPROVAL _____ REV LTR _____ LAST REV DATE _____				

DECISION RECORD	SOURCE OF REQUIREMENT BLOCK NUMBER 2.3.3	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA	
		ALTERNATIVES CONSIDERED		
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS		"COMMUNUTE SPENT FUEL"		
		<p>repair would be hard but not impossible.</p> <p>D. Core Drilling</p> <p>This technique would utilize a hollow drill, or cutter. The drill would be centered over the fuel core and when activated would "core" out a column containing the nuclear material.</p> <p>Analysis:</p> <p>This method removes the material in an efficient manner but it does not reduce the material to fragment sizes. This would be a high maintenance item. This would be a time consuming operation because the drill would have to be positioned for each coring operation.</p> <p>E. Whole Element Burning</p> <p>This method would consist of placing the fuel element or pieces in a burner and burning the graphite matrix away.</p>		
			SELECTED APPROACH	
APPROVAL _____				
ANALYST <u>L. E. Mayfield</u> APPROVAL _____ REV LTR _____ LAST REV DATE _____				

DECISION RECORD	SOURCE OF REQUIREMENT BLOCK NUMBER 2.3.3	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA	
		ALTERNATIVES CONSIDERED		
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS		"COMMUNUTE SPENT FUEL"		
		<p>Analysis:</p> <p>This device effectively removes the graphite from the nuclear material. The graphite is completely oxidized into CO and CO₂. It is a time consuming operation, however. The burner must be opened, the block placed in and then the oven resealed. The block must then be brought to combustion temperature. Remote operation could be satisfactorily achieved. Modular construction would be possible.</p> <p>Thermal Shock</p> <p>This technique would consist of cooling the fuel block to cryogenic temperatures and then shattering it into fragments.</p> <p>Analysis:</p> <p>This method will require large amounts of a cryogenic fluid, probably N₂. Although the technology</p>	SELECTED APPROACH	
APPROVAL _____				
ANALYST <u>L. E. Mayfield</u>		APPROVAL _____	REV LTR _____ LAST REV DATE _____	

DECISION RECORD	SOURCE OF REQUIREMENT	DECISION RECORD NUMBER AND TITLE	SELECTION CRITERIA
	BLOCK NUMBER 2.3.3	ALTERNATIVES CONSIDERED	
FUNCTIONAL AND TECHNICAL DESIGN REQUIREMENTS		"COMMUNUTE SPENT FUEL"	
		<p>for production of N₂ is satisfactory, the handling of large amounts of gaseous N₂ from boil off on contact with fuel elements may be difficult. When the block is shattered it will not break in a controlled manner. Remote operation could be achieved as well as modular construction. It would require a secondary comminuting device, however.</p>	
			SELECTED APPROACH
<p style="text-align: right;">APPROVAL _____</p> <p>ANALYST <u>L. E. Mayfield</u> APPROVAL _____ REV LTR _____ LAST REV DATE _____</p>			

SCOPE NOTE:
THIS FLOW IS FOR A HAMMER-MILL TYPE CRUSHER. NOTE
THAT A SIZING UNIT (SCREEN) AND CRUSHED MATERIAL
HANDLING UNIT HAVE BEEN ADDED.

FIGURE A5-4 - COMMINUTE SPENT FUEL (OPTION FUNCTION 2.3.3A).

A5.4.1 Option A--Discussion

The hammer-mill type crusher initially appeared to meet the requirements of crushing the fuel element assemblies in a single pass. It would reduce the block to fragments which meet the size requirements; however, it would also damage an unacceptable number of fuel particles. The hammers are located inside a drum, which makes the unit rather difficult to maintain, and maintenance would probably be necessary at the hammer pin joints frequently. A large amount of fines and dust would be produced, which would mean that large HEPA filtration systems would be needed, although a cyclone dust removal system could be installed which would reduce the HEPA filtration needed.

The fact that a large number of fuel particles would be broken and high maintenance are reasons enough to discard this idea. No further action is required.

SCOPE NOTE:

THIS FLOW IS FOR A JAW TYPE CRUSHER. A SIZING FUNCTION HAS BEEN ADDED TO PREVENT LARGE 'CHUNKS' FROM PASSING THROUGH.

1 THIS UNIT WILL GENERALLY COMMINUTE IN A CONTROLLED MANNER. HOWEVER, A SINGLE UNIT MAY NOT BE FULLY CAPABLE OF MEETING THE SIZE REQUIREMENT IN A SINGLE PASS.

FIGURE A5-5 - COMMUNITE SPENT FUEL (OPTION FUNCTION 2.3.3B).

A5.4.2 Option B--Discussion

The jaw crusher has several advantages when used in the postulated application. The device consists of only three major components, less drive mechanisms. These are: the stationary jaw or anvil, the driven jaw, and the driving mechanism. The stationary jaw is rigidly mounted to reaction structure, while the driven jaw is a link in a four bar mechanism. The driving mechanism can be of several types; one could be a reciprocating shaft arrangement, which pushes and pulls the jaw open and closed, and the other could be an eccentric shaft arrangement.

This latter system is commercially available and could be modified to meet the system requirements. The driving motors and control system can be placed outside the crushing cell, which will greatly enhance the maintenance of those components. Drive shafting would be passed through the hot cell wall with stepped and shielded passageways. Modularization of the components within the hot cell could also be accomplished readily. The stationary jaw can be attached to the frame using simple clamps. The driven jaw is somewhat more complex, but if the driving mechanism can be removed simultaneously, then those components can be easily removed by disconnecting the shaft bearing supports and the lower reaction link.

There are disadvantages to this system. The driving system requires a significant amount of lubrication to insure that the driving eccentric shaft system is not damaged under the severe loads imparted in the crushing mode. The shaft bearings will experience the same requirements. This means that contamination of the crushed material, by lubricating oils, is highly possible. Special seals and sealing techniques

may be required. Generally, this system will not be capable of reducing a fuel element to the required size in a single operation. It is possible that large pieces, which are of the correct nominal thickness, but larger in the other dimensions, could fall through. These would then require additional processing, but if they were transferred back to the whole element crusher, then these oversize pieces would again fall through. It would appear that another in-line crusher would be required.

The second in-line crusher could, like the primary crusher, be selected from any one of the previously mentioned devices, but these would generally be rejected for the same reasons. This again leaves a jaw type crusher as the next in-line unit. Since the fragments are smaller than the feed material to the primary crusher, then this secondary unit could be smaller. Unfortunately, the exact problems exist with this secondary crusher as exist with the first device. However, the fragments can be made much nearer the required size. The need for a third crusher is evident.

Very nearly the same argument exists for this third unit, except that it is obvious that the jaw type crusher no longer satisfies the need to reduce the fragments to smaller sizes. There are any number of commercial crushers which can attain the desired result. One of the simplest is a double roller crusher. The output from the secondary crusher could become the feed for this unit. There are the same possibilities of material falling through as exists in the other crushers; however, the basic particle size is correct. It would be beneficial to "size" the material now.

Any number of screening devices could be used to size the material. The two most common units are a rotating drum and a vibrating screen; both have their advantages. The rotating drum unit can be made so that the drive system is accessible for maintenance. It does, however, require shaft support bearings which will require lubrication and protection. The bearings provide a potential contamination source if lube oil or grease migrates into the product material. A vibrating screen type can be driven from a totally enclosed system which permits little or no contamination by lubricants. The screen itself can be suspended on springs. Care must be taken to insure that the natural frequency of the suspension springs is not near the driving or vibrating frequency. The screen will separate the fragments into two size categories: correct and oversize. The oversize material will require further processing. Again, a crusher is the most likely answer. But, it is estimated that only about 5% of the original material will be oversize and will require any reworking. This crusher, then, can be quite small in comparison to the other units, which must process the complete fuel element assembly. The same type of analysis for crusher selection could be performed, but in this case let's assume that we know a simple unit which would be satisfactory. Its small size would tend to be acceptable to modular construction--the entire unit could be removed and replaced. The crusher would be remotely operable and would be activated at the same time as the final large crusher.

To Summarize:

There are three crushers: a) two in-line jaw or pincher type devices, b) a large double roller crusher, c) a vibrating screen sizing device, d) an oversize fragment crusher. There is one outstanding feature of all of these units--input and output are vertical. This means that gravity can be used as the motive force to move the crushed fragments through the system. This means that a vertical stackup could be designed. Each unit in the stackup could be designed so that the remotability and maintainability are achieved.

The above discussion items are evidence that the initial Option B functional flow is inadequate. A new option flow sheet was prepared and reflects the considerations delineated. A functional requirements sheet for the revised Option B has been prepared.

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FIGURE A5-6 - COMMUNUTE SPENT FUEL (REVISED OPTION FUNCTION 2.33B).

TITLE COMMUNITE SPENT FUEL ANALYSIS SUMMARY BASIC FUNCTION: 2.0 (FUNCTION 2.3.3B Revised)			
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.1 B Perform Control System Checkout	Console control panel	<p>The control panel shall be equipped with automatic controls for each crusher.</p> <p>Each system shall have an automatic self test initiated by the operator.</p>	
2.3.3.2 B Activate Device and Checkout Operation	Console control panel	<p>The control console panel shall be equipped with operator initiated start-up functions. The panel shall be equipped with indicators which indicate the operational status of the various crushers, motors, drive systems and screens.</p>	
2.3.3.3 B Perform Maintenance	Miscellaneous remote handling equipment and tools	<p>The maintenance response function is keyed to many repair operations. As such, they would be the subject of an exhaustive analysis which would be interactive with the machine design functions. This analysis will not be attempted here, but it is shown for completeness.</p>	
2.3.3.4 B Load Feed Material into Device	Gravity operated loading chute	<p>A fuel element or element piece loading/transfer hoisting mechanism is required. This unit shall be remotely operable. A closed circuit television system or optics is required for operator visual control in placement. A window through the hot cell wall shall be provided for direct vision.</p>	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE COMMUNUTE SPENT FUEL (CONTINUED)

ANALYSIS SUMMARY

BASIC FUNCTION: 2.0 (FUNCTION 2.3.3 B Revised)

FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.4 B (cont'd) 2.3.3.5 B Crush Fuel Elements in Primary Unit	Jaw Type Crusher	<p>A hopper which can handle multiple elements and broken pieces is required. This unit shall be capable of releasing one complete element, or part thereof, at the operator's command.</p> <p>This unit shall meet the following requirements:</p> <ol style="list-style-type: none"> Accept a single complete fuel element or piece thereof, from the feed subsystem identified in 2.3.3.4 B. Reduce, by crushing, a fuel element, or any piece thereof, to a 6" ring size. A basic 10-year operational life. Be remotely maintainable. Meet CAT III seismic requirements of RDT Std. F9-2T. Permit a minimum of product contamination by bearing lubricants. Operate in a radiation environment of approximately 4.9 (10³) RAD/hr. Limit material hold-up to less than 0.5% of customer lot through-put. Contain all dust and radioactive product. Operate at a maximum temperature of 400°F. Operate in an N₂, CO₂ or inert atmosphere. 	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE COMMUNIT SPENT FUEL			
ANALYSIS SUMMARY		BASIC FUNCTION: 2.0 (FUNCTION 2.3.3 B Revised)	
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.5 B (Cont'd)	Jaw Crusher	1. Operate with an internal pressure of 14.7 + 0 - 6 psia. m. Operate with an external pressure of 14.7 psia nominal. n. Break less than 0.8% of biso particles and less than 2.6% of the triso particles. o. Start and operate either empty, partially loaded, or fully loaded conditions. p. Interface with the secondary crushing unit by a gravity chute/feed block 2.3.3.6 B.	
2.3.3.6 B Crush Fuel Element Fragments in Secondary Unit	Jaw Type Crusher	This unit shall meet the following requirements: a. All requirements of 2.3.3.5 B except a, b, and p. b. Accept crushed 6" ring size broken elements from primary crushing unit. c. Reduce by crushing, all fuel element pieces, received from the primary crusher to a 3/4" ring size. d. Interface with the gravity feed chute from the primary crusher. (Block 2.3.3.5 B) e. Interface with the gravity feed chute to the tertiary crusher. (Block 2.3.3.7 B)	
ANALYST <u>L. C. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE COMMINUTE SPENT FUEL ANALYSIS SUMMARY BASIC FUNCTION: 2.0 (FUNCTION 2.3.3 B Revised)			
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.7 B Crush Fuel Element Fragments in Tertiary Unit	Roll Type Crusher	This unit shall meet the following requirements: a. All requirements of 2.3.3.5 B except a, b, and p. b. Accept 3/4" ring size broken elements from secondary crushing unit. c. Reduce, by roll crushing, all fuel element pieces, received from the secondary crusher to a 3/16" ring size. d. Interface with the gravity feed chute from the secondary crusher. (Block 2.3.3.6 B) e. Interface with the gravity feed chute to the screening unit. (Block 2.3.3.8 R)	
2.3.3.8 B Screen Fragments	Vibratory Screen	This unit shall meet the following requirements: a. Accept all fragments from the tertiary roll crusher. (Block 2.3.3.7 B) b. Pass all fragments which pass through a 3/16" ring size screen. c. Transfer all oversize fragment to a final crushing device. (Block 2.3.3.9 B) d. Screen supported by springs detuned to the vibrating frequency.	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE COMMUNUTE SPENT FUEL			
ANALYSIS SUMMARY		BASIC FUNCTION: 2.0 (FUNCTION 2.3.3 B Revised)	
FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.8 B (Cont'd)	Vibratory Screen	e. 10-year operational life. f. Meet CAT III seismic requirements of RDD F9-2T. g. Permit a minimum of product contamination by bearing lubricants. h. Operate in a radiation environment of approximately $4.9 (10^3)$ RAD/hr. i. Limit material hold up to less than 0.5% of customer through-put. j. Contain all dust and radioactive product. k. Operate in maximum 400°F environment. l. Operate in an N ₂ , CO ₂ or inert atmosphere. m. Operate with an internal pressure of 14.7 + 0 - 6 psia. n. Operate with a nominal 14.7 psia external pressure. o. Interface with oversize crushing device. (Block 2.3.3.9 B) p. Interface with material handling system. (Block 2.3.3.10 B)	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE COMMUNITE SPENT FUEL

ANALYSIS SUMMARY

BASIC FUNCTION: 2.0 (FUNCTION 2.3.3 B Revised)

FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.9 B Crush Oversize Fragments	Roll Type Crusher	<p>This unit shall meet the following requirements:</p> <ul style="list-style-type: none">a. All requirements of 2.3.3.5 B except a, b, and p.b. Accept all fragments of 3/4" to 3/16" ring size and reduce to less than 3/16" ring size.c. Interface with the vibratory screen. (Block 2.3.3.8 B)d. Interface with the material handling system. (Block 2.3.3.10 B)	
2.3.3.10 B Transfer Crusher Material to Storage	Gravity Transfer Chute or Air Transport System	<p>The gravity transport system feed directly into a surge storage hopper and shall interface with the vibratory screen and the oversize crusher.</p> <p>The air transport system may be used if a gravity feed stack-up system cannot be efficiently used. It shall meet the following constraints:</p> <ul style="list-style-type: none">a. Utilize the internal ventilation air flow as transport fluid.b. Pipe size to hand 3/4" ring size or larger fragments.c. Be abrasion resistant.	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

TITLE **COMMUNITE SPENT FUEL**

ANALYSIS SUMMARY

BASIC FUNCTION: 2.0 (FUNCTION 2.3.3 B Revised)

FUNCTION/TASK	REQUIRED EQUIPMENT AND FACILITY ITEM	FUNCTIONAL AND DESIGN REQUIREMENTS	TIME
2.3.3.10 B (Cont'd)	Gravity Transfer Chute or Air Transport System	d. Interface with the oversize crusher. (Block 2.3.3.9 B) e. Interface with vibratory screen. (Block 2.3.3.8 B) f. Interface with surge storage hopper.	
2.3.3.11 B Deactivate System	Console Control Panel	The control console panel shall be equipped with operator initiated shut-down functions.	
ANALYST <u>L. E. Mayfield</u> PROJECT APPROVAL _____ REV DATE _____			

A5.5 Timelines

Once a working system has been developed, then a timeline flow sheet must be generated. This sheet will provide visibility as to what time can be allowed for maintenance or down-time and how many units may be needed to accomplish the intended task.

In this example, one of the constraints was to operate for 233 days per year, 24 hours per day, at 90% efficiency. A 30-day accountability period was to be provided.

In this instance, we wish to know how fast the system must operate to attain the necessary throughput and then to determine the number of systems needed. This was done on the face of the timeline flow sheet. As can be seen, the recommended system has two crushing systems; each is operated for 52 consecutive days, then there are seven days for maintenance, seven days for material accountability. This cycle is repeated twice for each machine for a total of 264 days, meeting the 30-day accountability period (28 actual) and providing 28 days for maintenance. The machine operating speed would be one block/15 minutes.

OP & TL SHEET NO. LEM 1		FUNCTION 2.3.3.8	FUNCTIONAL AREA HEAD END	SYSTEM CRUSHER
<p>0 oper.</p> <p>DEVICE #1</p> <p>52 D oper. 7 D maint. 7 D idle 52 D oper. 7 D maint. 7 D idle</p> <p>DEVICE #2</p> <p>7 D maint. 7 D idle 52 D oper. 7 D maint.</p> <p>← 264 D →</p>			<p>As can be seen, this system requires two complete units. The time sequence shown could be arranged any number of ways other than the one shown.</p> <p>Each machine would have to process 10,000 whole equivalent elements per year.</p>	
SOURCE OF FUNCTION	TASK	TIME (CAMPAIGN)		
FUNCT. ANAL. BLOCK NO. 2.3.3.8 Revised	MAINTENANCE	<p>NOTES: It has been determined that the reprocessing plant shall be on-line 233 days/year, with a 30-day accountability period and efficiency of 90%.</p> <p>COMPUTATIONS:</p> $(\# \text{ of elements})(\text{time/element}) = (\text{days/year})(\text{hours/day})(\text{minutes/hour})$ $(\text{efficiency})(20,000)(T) = (24)(233)(60)(.9)$ $T = 15.1 \text{ minutes/element}$		
	STARTUP	<p>This is the actual rate of the crusher system. It does not allow for any maintenance down-time. The above flow shows how this might be arranged.</p>		
PREPARED BY L. E. Mayfield		DATE _____ APPROVED BY _____ DATE _____		

A5.6 Equipment and Facility Summaries

The concluding effort in the systems analysis is the preparation of a summary table which contains all of the requirements which have been levied against each function. In this example only, a single equipment system was identified, and so the requirements are generally a paraphrasing of the ones shown on the analysis summaries. If the entire system had been analyzed, then a set of summary sheets for every facility item and every major equipment system would have been prepared.

These sheets would be assigned to design organizations for ultimate solution. They would be revised when and if specific conditions could not be met in the designated manner or within some other constraint.

EQUIPMENT AND FACILITY SUMMARIES

LAST REVISION DATE

ITEM NUMBER	NOMENCLATURE	FUNCTIONS REQUIREMENTS ITEM	REQUIREMENTS
CEI *1	Crusher, Fuel, HTGR	2.3.3 B Revised	<p>This unit shall meet the following design and operating requirements:</p> <ol style="list-style-type: none"> Provide a material feed system capable of feed whole HTGR spent fuel elements, or pieces thereof, into the primary crushing unit. It shall feed the material upon operator command. Provide a primary jaw type crusher, operated by an eccentric shaft and Pitman arm, to crush HTGR fuel elements or any piece thereof, the maximum size which is 32 inches long by 14 inches width across a hexagonal shape flat and 300 pounds in weight, into fragments which will pass through a 6-inch screening ring. Provide a gravity flow funnel or chute with a transfer material from the primary crusher to the secondary crusher. Provide a secondary jaw type crusher, operated by an eccentric shaft and Pitman arm, to crush the 6-inch ring size fragments from the primary crusher into 3/4-inch ring size elements. Provide a gravity flow funnel or chute to transfer material from the secondary crusher to the tertiary crusher. Provide a roller type crusher to crush the 3/4 inch ring size fragments into 3/16 ring size fragments.
*Contract End Item			

EQUIPMENT AND FACILITY SUMMARIES

LAST REVISION DATE

ITEM NUMBER	NOMENCLATURE	FUNCTIONS REQUIREMENTS ITEM	REQUIREMENTS
CEI 1 (Cont'd)	Crusher, Fuel, HTGR	2.3.3 B Revised (Cont'd)	<p>g. Provide a gravity flow funnel or chute to transfer material from the tertiary crusher to the screening device.</p> <p>h. Provide an axi-symmetric vibrating screen separator which can receive the output from the tertiary crushing unit and separate the oversize fragments from the material flow. This device shall be suspended from tuned springs.</p> <p>i. Provide an oversize fragment crushing unit to reduce the fragments to an acceptable size of 3/16-inch ring size.</p> <p>j. Provide a gravity flow material transfer system or an air transport system to move crushed fragments to a surge storage hopper. The air transport system must be capable of moving 3/4 inch ring size fragments and shall be abrasion resistant.</p> <p>k. Provide a frame structure that will allow mounting of the items a-j in a manner which allows modular assembly and meets the gravity flow conditions.</p> <p>l. All equipments shall have a basic 10-year operating life.</p> <p>m. The system identified by items a-k shall be capable of comminuting a whole spent fuel element within 15 minutes.</p>

EQUIPMENT AND FACILITY SUMMARIES

LAST REVISION DATE

ITEM NUMBER	NOMENCLATURE	FUNCTIONS REQUIREMENTS ITEM	REQUIREMENTS
CEI 1 (Cont'd)	Crusher, Fuel, HTGR	2.3.3 B Revised (Cont'd)	<p>n. Each major component shall be modularized for ready removal in a remote maintenance mode.</p> <p>o. The frame structure and all equipment mounted thereon shall withstand Category III seismic events as defined by RDT Standard F9-2T.</p> <p>p. The system identified by items a-k shall process the equivalent of 10,000 elements per year defined as 233 days at 90% efficiency.</p> <p>q. Product contamination, by lubricants shall be minimized.</p> <p>r. All equipment items shall be fully operable in a continuous environment of $4.9(10^{-5})$ RAD/hr or less.</p> <p>s. Material hold up in the system shall be held to 0.5% or less of a customer's through-put lot.</p> <p>t. All dust and radioactive fines shall be confined within the system, items a-k.</p> <p>u. All systems shall be capable of operating in a temperature range of room ambient to 400°F.</p> <p>v. All systems shall be capable of operating in an atmosphere of N_2, CO_2 or other inert gas.</p> <p>w. Operate with an internal pressure of 14.7 to -6 psia.</p>

EQUIPMENT AND FACILITY SUMMARIES

LAST REVISION DATE

ITEM NUMBER	NOMENCLATURE	FUNCTIONS REQUIREMENTS ITEM	REQUIREMENTS
CEI 1 (Cont'd)	Crusher, Fuel, HTGR	2.3.3 B Revised (Cont'd)	<ul style="list-style-type: none">x. Operate with an external pressure of 14.7 psia nominal.y. Break less than 0.8% biso and 2.6 triso particles total.z. Each subsystem shall be capable of starting and operating under conditions of no load, partial load, or fully loaded.aa. Provide a drive subsystem for crusher components which are outside of the hot cell. The drive shafts shall be passed through the cell wall using stepped shafts and openings to reduce neutron particle streaming.ab. Provide a control subsystem which has self/operator test functions, start-up/shutdown features and remote viewing devices.

A6.0 DEFINITIONS

DISCIPLINE--A body of rules governing the orderly allocation of a specific class of requirements among the major functions of a plant, facility, or system.

FACILITY--This word is used with dual meanings in this Appendix, Part A:

1. An autonomous operational entity of a plant, dedicated to a single major function. When so used, this word will be capitalized.
2. A function contributing to the production of the plant output, but not generic to any of its processes. Examples are: rail service, power (electrical, pneumatic, steam), water supply, etc.

FUNCTION--The action for which a person or thing is especially fitted or used for, or for which an entity exists.

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APPENDIX - PART B
PRINCIPAL PLANT FACTORS GUIDELINE

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B1.0 INTRODUCTION

In the early design stage of any major industrial facility, a set of goals, requirements, and guidelines is established for the purpose of guiding the design process. These factors will be referred to as Principal Plant Factors (PPF's) and will be utilized as inputs in the requirements assessment. The method of arriving at this original set of PPF's is extremely important to the successful conclusion of the project. The purpose of this guideline is to establish a methodology for the selection of these factors and to show how these factors interact in the design function.

In the early design stage of any major industrial facility, a set of goals, requirements, and guidelines is established for the purpose of guiding the design process. These factors will be referred to as Principal Plant Factors (PPF's).

Four impact areas are presented to provide a reference from which the Principal Plant Factors can be derived. The delineation of these areas serves to structure the problem. By placing the development of the PPF's in this broader context, considerations deriving from each of the impact areas will be included in the design process. For instance, when considering plant throughput, considerations of the commercial viability of the project may provide definite upper and lower bounds. In conjunction with an evaluation of available technology, throughput requirements should reflect a realistic objective in light of the broad

environment within which the HRRF will operate. Other general PPF's such as capacity, stretch capacity, availability, etc. would be considered in the same vein when the requirements for the plant are developed.

To accomplish the goal of PPF identification and quantification, a committee is suggested that is composed of one subcommittee for each of the impact areas. These subcommittees will provide a list of all identifiable factors that should be considered in the design of the facility.

To provide a group perspective to the problem of identifying the PPF's, a Project Standing Committee, composed of program task and subtask managers and other individuals from the NRC, DOE, etc., would be utilized.

The use of a committee approach to this problem is suggested by the organization of the National Program into the functional areas of reprocessing, refabrication, waste treatment, and other support. Since it is necessary that the final set of PPF's reflect a group perspective on the problem, each of these groups must be represented in the decision-making process. Also, involvement of individuals from outside the National Program will provide viewpoints on the problem that reflect specific aspects of such issues as licensing, funding availability, etc.

During the process to identify Principal Plant Factors, significant interactions will occur between personnel from all phases of the HTGR Recycle Development Program as well as other informed parties from the Federal government and private industry. Unless a major design change

occurs during the later design phases (either external or internal to the project), the Principal Plant Factors will remain unaltered.

B1.1 Scope and Objective

This guideline specifies a methodology for identifying the initial list of Principal Plant factors for the HRRF. Suggestions are provided in two areas: (1) structure of the Standing Committee, and (2) organization of the efforts of the standing committee.

The objective of this guideline is to provide a general method that, if followed, will lead to the identification of the HRRF Principal Plant Factors and in turn will provide the first input to the design process.

B1.2 Organizational Requirements

The identification of HRRF Principal Plant Factors will be accomplished through the use of a Standing Committee organized under the Program Manager. After the Principal Plant Factors have been identified, the Program Manager will have the committee members available for future consultation in case the factors have to be re-evaluated in light of the requirements assessment analysis. In order to reduce the time requirement of the Program Manager in coordinating the efforts of the committee, the Project Manager for Subtask 930 may be asked to share the responsibilities of this effort with the Program Manager.

B2.0 IMPACT AREAS

Principal Plant Factors can be categorized into four general impact areas: commercial viability, government regulations, sociopolitical factors, and technological capability. Although one area may prove more important for a particular plant, the initial identification of Principal Plant Factors should include all relevant impact categories. It is important that conclusions concerning relative importance are made after the initial identification of Principal Plant Factors in each impact area, for the flexibility of the process will not be exercised if decisions are made before the complete information has been analyzed.

B2.1 Commercial Viability

For facilities such as the HRRF which have a major portion of the development expenditures financed by the Federal government, the commercial viability of the final product should be considered in the design phase for several reasons. First, the Federal government may try to transfer the technology to private industry after the development stages. If the technology transfer is to be successful, private industry must be convinced that the required investment is sound. Second, since the Federal government commands limited resources to accomplish a variety of goals, the commercial viability of a project will provide an indication of the return the taxpayer is receiving for the dollars expended.

In cases where the Federal government is not involved, commercial viability is an obvious consideration. The commercial viability of an industrial facility depends upon three major factors: the time-phase of the development process, the market for the product, and the financial package that must be put together to construct and operate the plant. Briefly, the time-phase of the development process refers to the sequencing of development activities and the integration of development results into the final package. Certain research and development activities must provide a baseline product on a particular date or the entire project schedule will be impacted. The other elements of commercial viability, the market for the product and the necessary financial package, have obvious impacts.

These considerations mentioned above will have a direct impact on other general Principal Plant Factors such as throughput, capacity, availability, scalability, and adaptability.

B2.2 Government Regulations

In the past ten years government regulatory agencies have become a critical factor in the design of facilities, with a key government regulation involving licensing. Failure to include or partially anticipate licensing considerations in the initial design stage could lead to costly revisions later in the design procedure. Other regulatory criteria evolve from regulations designed to protect the environment and the safety of the operating personnel. Also, state and local agencies with jurisdiction over the site where the facility is to be located have to be considered.

B2.3 Sociopolitical Factors

The successful completion of the HRRF Project requires that sociopolitical factors be considered from the early design phases through final design, construction, and operations. In the early design phase the degree of program flexibility is the greatest and this should be utilized to maximum advantage. Also, when considering Principal Plant Factors in the area of sociopolitical impacts conclusions must be sensitive to the probable course of events over the life cycle of the project. For example, in a growing number of industries government funding is necessary since capital costs are significant, the technology is not sufficiently developed to assure commercial success, and/or the Federal government decides the national need outweighs commercial viability and desires participation in the project from private industry.

It is therefore imperative that the Principal Plant Factors take into account the type of government resources available, the amount of government resources needed, and the lead time necessary to obtain the resources from the government agency involved.

B2.4 Technological Capability

In the case of a facility that is being commercialized for the first time, one of the most important problems is the lack of definition of the technical process and/or products. The available technology capability becomes an important Principal Plant Factor consideration in those areas where the process is not clearly defined or where the process has not been demonstrated to offer a reasonable risk. Even in the

cases where pilot facilities have been successfully operated, the scaling factors may be such that the amount of useful information is limited. Other areas of technology which could become important involve waste disposal criteria, the yields and conversions for all steps in the particular process and the special hazards involved in the operation of the facility.

To disregard adaptability or override the construction schedule could cause delays or even insurmountable problems within the project design plan, requiring redefinition of the project.

B3.0 METHODOLOGY

The methodology is based on the premise that a Committee approach can best provide a pooling of minds to generate the HRRF Principal Plant Factors and supporting information required to drive the interactions of the Design Process. Each Impact Area Committee would be provided a concept baseline representing decisions that have already been made and other supporting information.

Group interaction to develop a group opinion can compensate for individual bias, reduce speculation, and provide involvement and communication within the effort, which tends to establish a higher commitment level for participants.

In order to accomplish this effort effectively there are three facets inherent in the method outlined to improve objectivity. First, the method includes the capability of providing an appropriate aggregation of responses from individuals; second, the method fosters iteration to improve ideas or concepts that may be feasible resolutions of the problem; and third, the method provides the opportunity for individuals to remain anonymous in their final response to the proposed questions. This group interaction to develop a group opinion can compensate for the bias of individuals, reduce speculation, and provide involvement and communication within the effort which tends to establish a higher commitment level for participants.

The methodology for determining the initial Principal Plant Factors is provided in the following subsections as a series of steps which lead the project into the requirements assessment. A summary flow chart of the methodology is shown in Figure B3-1.

B3.1 Standing Committee Structure

The first step is the establishment of a Standing Committee with four subcommittees representing the impact areas described in Section B2.0. Committee composition should include knowledgeable individuals in each of the impact areas. For example, the Technology Capability Subcommittee should include representative individuals with expertise in an appropriate technical discipline, governmental regulatory guidelines and/or resource knowledge, and specific information on commercial viability, as well as an appropriate mix of participating organizations.

The total committee structure should not exceed 24 persons and should minimally include:

1. Program Task Managers and Project Subtask Managers for Task 900 as identified in the National Program Plan;
2. GCRA member organization representatives;
3. DOE and NRC representatives.
4. Supplier representatives.

These individuals would be selected to participate in accord with the following criteria:

Figure B3-1. Development Of Principal Plant Factors (PPFs).

1. Achievement--refers to those persons who have acquired expertise in one of the impact areas through academic preparation, or are otherwise recognized as having expertise by their peers;
2. Recognition--indicates that the person has established expertise (nationally or internationally) through contributions of research or publications relative to one of the impact areas; and
3. Involvement--implies that the person is currently a practicing professional in his field, is interested in the HRRF project, and will be made available by his organization or agency to participate as a committee member.

The list of committee members should be finalized through consultation with other officials involved in the program such as those from GCRA, GA, ORNL, DOE, or NRC to determine suitability and availability of the individuals in question. When the list has been finalized, the committee members should be assigned to impact areas with emphasis on maintaining an interdisciplinary balance.

Each committee member should receive at least the following information:

- An agenda for the conference;
- An assignment of the individual to a particular impact area, as well as other persons assigned to the same committee to include addresses and telephone numbers;
- An information packet specifically related to the impact area. This packet should not exceed ten pages to include
 - (1) Introduction to briefly describe the impact area,
 - (2) Summary of baseline materials pertinent to the area,

and (3) Conclusions relative to purpose of effort and the Design Plan.

It will be advantageous for each member to arrive at the conference with the most current information and knowledge available about the National Program for the HTGR Recycle Development and the HRRF Project. Additionally, each committee member should be encouraged to communicate frequently with others in the same impact area prior to the formal conference. An example list of preliminary Principal Plant Factors should be provided which includes a sufficient number of factors in the particular impact area to provoke thought and promote extended discussions.

To maximize the advantage of collective input, the sequence of events at the group meeting must be well-planned.

An example outline of key subcommittee elements would include:

<u>Elements</u>	<u>Committee Output</u>
Principal Plant Factor	Capacity
Definition	Maximum design capability
Interface	Availability, efficiency, throughput, costs, safeguards, plant safety, design life, adaptability, expandability, etc.
Utilization Criteria	Design requirement is ____% of throughput

The next step in the process is the short conference. To maximize the advantage of collective input, the sequence of events at the conference must be well-planned. First, a short meeting should be held to allow all experts to get acquainted with each other and to obtain more detailed information about the process and product. Following this large group session, each impact area subcommittee will convene. Information generated from each subcommittee's session should minimally address:

1. The Principal Plant Factors essential to guarantee that each impact area requirement is all-inclusive;
2. The interfaces perceived by the representatives where problems can best be identified and/or resolved. It is important that the committee look for impact area blind spots in the qualitative analysis of interfaces; and
3. The utilization criteria to be quantified in terms of goals, objectives, ranges, etc. for each Principal Plant Factor.

The first action of the subcommittee should be to select a person to act as recorder. The recorder should document the proposed ideas generated during the Impact Area Committee meeting.

Basic responsibilities of the recorder are:

1. To keep the focus of the subcommittee on the assigned impact area topic;
2. To record all ideas generated as alternative initial Principal Plant Factors, a definition of the factor, interfaces of these factors, and the utilization criteria; and

3. To remain on location for one additional day and present the subcommittee ideas generated to the Program Manager.

Recorded results of the committee should be concise yet germane to the impact area. For example, each entry may be recorded on a form similar to that shown in Figure B3-2.

The product of the group meeting would be a compiled listing of the initial Principal Plant Factors to include a definition, interfaces, and utilization criteria.

The product would be a compiled listing of the initial Principal Plant Factors to include a definition, interfaces, and utilization criteria arrived at by each impact area committee. This listing, when validated, then becomes a key factor in the design process.

The HRRF Project Leader and the Program Manager for the HTGR Recycle Program should then formalize the compiled list of Principal Plant Factors with definitions and utilization criteria and design a simple matrix depicting the interfaces. The results of the final list and the matrix should be collated into a packet for verification as described in Section B3.2 below.

B3.2 Verification

The collated packets of the compiled list of Principal Plant Factors, definitions, criteria, and the resulting matrix should then be forwarded to each Committee member to obtain concurrence. Each committee

FIGURE B3-2.

PRINCIPAL PLANT FACTOR IDENTIFICATION SHEET,

Impact Area	
Principal Plant Factor	
Utilization Criteria	

Definition:

Interface Identification:

Interface Element

Explanation

Rationale for Choosing this as a Principal Plant Factor:

member should be requested to respond to each Principal Plant Factor in terms of both importance and feasibility. To quantify the responses, a rating scale should be utilized when soliciting these responses. Also, the committee members should be asked to suggest any revisions to the interface matrix.

Results from this process can be tabulated and a mean score for each item obtained in both categories (importance and feasibility). The mean score will then enable the Program Manager to establish a list of priorities in both categories. A prioritized list will provide some early iterations to occur between importance and feasibility to determine which Principal Plant Factors become the initial input for the requirements assessment.

B4.0 INTERACTION

The selection of the Principal Plant Factors is critical to the success of the total integrated design. These factors are used as input to the requirements assessment. The final design of the facility will be greatly affected by the required plant capacity that has been determined and the capital and operating costs that have been dictated by market factors and the available financing. Licensability and the control of hazardous material may govern the process that is chosen for the plant or may completely alter the plant layout. Other Principal Plant Factors that will impact the design process will be identified in the process previously described.

The initial list of Principal Plant Factors would be input to the Level 0 (facility) Requirements Assessment.

The list of initial Principal Plant Factors represent the crucial first element in the design process as discussed in Section 3.0. These factors are input to the Level 0 Requirements Assessment, an evaluation that results in the baseline requirements document for the HRRF. In this manner, the Principal Plant Factor identification initiates the entire design logic process discussed in Section 3.0.

B5.0 DEFINITIONS

PRINCIPAL PLANT FACTOR--A goal, design requirement, or design guideline established for the purpose of guiding the design process. These Principal Plant Factors are specified for the HRRF, not specific systems within a facility.

INTERFACE--The point of contact between two or more heterogeneous elements of the HRRF.

UTILIZATION OF CRITERIA--The numerical value associated with a particular Principal Plant Factor. For instance, the utilization criteria for availability may be 80%.

RECORDER--Individual chosen by the members of each subcommittee to document the ideas generated by that subcommittee. The basic responsibilities of the recorder are: (1) to keep the focus of the committee on the assigned impact area topic; (2) to record all ideas generated as alternative initial Principal Plant Factors, a definition of the factor, interfaces of these factors, and the utilization criteria; and (3) to remain on location for one additional day and present the subcommittee ideas to the Program Manager.

REQUIREMENTS--Mutually supportive design criteria established for the HRRF in the areas of unit operations, safety, criticality, licensing, physical protection, reliability, availability, maintainability, safeguards/accountability, environments, and layout.

REQUIREMENTS ANALYSIS--The process of studying the requirements developed at each level of the design process to determine if the requirements support the objective and if the requirements are supportive, not contradictory.

DESIGN LOGIC--The approach developed to guide the design process of the HRRF through feasibility to conceptual design. The design logic stresses the use of functional analysis and an integrated approach to requirement development and assessment.

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APPENDIX - PART C
UNIT OPERATIONS ANALYSIS GUIDELINE

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C1.0 INTRODUCTION

An industrial plant can be defined as a combination of all the processes, services, or activities which perform or facilitate the performance of a major function. Particular combinations of activities associated with any individual industrial process (either physical or chemical) are normally termed unit operations.

Unit operations are defined as particular combinations of functional activities associated with any individual industrial process (either physical or chemical).

The definition of a unit operations baseline for the HRRF plant would provide a basis for system delineations. The unit operations would be identified primarily in terms of systems with particular functions, e.g., crushing of solids, transportation of solids and liquids, transfer of heat, evaporation, etc. The functional areas defined by the unit operations analysis would form the basis for the integrated system synthesis in the conceptual phase of project design. For each unit operation, at least one equipment item or design option would be identified which can perform the function. The process of identifying specific unit operations would aid in explicitly defining the design criteria.

Unit operations analysis is defined as the analysis accompanying the identification of the primary sets of processes, the particular processes, and the supporting unit operations that compose the HRRF plant.

In addition, the unit operations analysis compliments the organization and definition of the project and the results would be needed in the development of an effective Work Breakdown Structure (WBS), where equipment alternatives, functional requirements, and organizational elements would be integrated. Effective project planning and control will require a well-conceived WBS as a communications medium.

C1.1 Scope and Objective

The scope of this guideline is to provide a general method for delineating the HRRF plant into facilities, and in turn delineating the various facilities into systems. The facility is a combination of processes, services, or activities which work toward a common function, while a system is a particular process, service, or activity. The guideline identifies design and information requirements that would be necessary to accomplish a successful delineation. From this information a project Work Breakdown Structure would be developed and updated. Requirements assessment would be performed at each level of plant detail defined by the unit operations analysis.

C1.2 Organizational Requirements

The integration of unit operations into the proposed design logic requires the existence of separate design and development groups. The design group would be organized under Subtask 930 and oversee the collection and validation of data leading to the construction of a design data base applicable to the HRRF Plant. The development group refers to those participants in the various development tasks now on-going under the National Program. The members of this group would collaborate with the design group in formulating experiments and would conduct the experiments and analyze the data produced. This group would also act in a technological support role in the design process.

C2.0 METHODOLOGY

C2.1 Introduction

The Unit Operations Analysis provides a basis for allocating Program and Level 0 (plant) requirements to Level 1 (facility) and Level 2 (system) requirements by providing a methodology to translate process information and flowsheets into systems engineering concepts. To accomplish this goal, development activities would be directed toward providing relevant physical, chemical, nuclear, and engineering data bases, while design activities would utilize this data in the synthesis of integrated plant, facility, or system designs or in the specification of particular unit operations.

The unit operations analysis provides a basis for allocating Program and Level 0 (plant) requirements to Level 1 (facility) and Level 2 (system) requirements by providing a methodology to translate process information and flowsheets into systems engineering concepts.

The design data base would consist of physical property, chemical property, nuclear property, and unit operation data relevant to the HRRF plant and processes. The development of this data base is currently the job of the development group and has been an on-going activity under the National Program. Data base development for areas such as reprocessing and refabrication has progressed to the point that unit operations can be defined, although the level of detail in the definition may vary. In

other areas such as off-gas and waste treatment, the data base has yet to be fully developed. At the beginning of the design study, information on requirements would be available from the Principal Plant Factors Analysis. However, plant, facility, system, and subsystem functions would not have been defined. Since functional analysis for each of these entities requires some basis (physical-chemical relationships or data) in function definition, an initial data set based on a priori assumptions would be necessary.

The preliminary data set can be derived from literature surveys and previously conducted basic research. Program and plant requirements would suggest the types of process information and physical, chemical, and nuclear data to be included.

As the design phase begins, functional analysis and trade studies may indicate that sufficient design information is not available and that the design data base should be upgraded. To upgrade the data base, information from two types of sources would be used, the literature and the experiment. Experimental validation and modeling would assure that the data are correct and in a form useful for design purposes.

A most vital part of this procedure would be the interaction of the design group with the appropriate development group in the selection and design of experiments. Such interaction serves two purposes: (1) the resources of the development effort are centered on the most important design problems, and (2) optimal design of experiments would insure the production of useful design data. The reduction of data to verified models could eliminate or reduce the need for pilot testing in some

applications, thus further streamlining the design process. Extensive development and pilot testing would still be necessary for operations where theoretical analysis cannot adequately model the process.

Once the data and models are produced and verified, they would be incorporated into the data base. The iterative process would continue until an adequate technology has been defined and the conceptual design effort would then proceed to completion. The data base developed at each stage of the design process may be used in generating and verifying facility and system delineations.

C2.2 Plant Delineation Method

The purpose of the HRRF Plant design group under Subtask 930 is to define a fuel recycle plant optimized within the bounds set by the requirements. The plant will also be defined on the basis of existing technology. To obtain an optimal configuration, a system for analyzing requirements, organizing the plant structure, and generating and evaluating alternatives is necessary. The design logic proposed in Section 3.0 of the Project Summary Plan is suitable for this purpose.

For the design process to proceed from HRRF plant considerations to greater levels of design detail, the delineations chosen to guide the analysis must be supported with the types of process information as previously described. Once the next level of detail has been identified through the Unit Operations Analysis, each of the functional engineering groups would proceed with requirements assessment as discussed in Section 3.0 of the Project Summary Plan. Since this delineation structures

the entire design analysis, it is imperative that adequate consideration be given the entity definition. A summary flow diagram for the Unit Operations Analysis is shown in Figure C2-1.

At each level of analysis, the design group would examine the available process information to determine its adequacy to support further system definition. This delineation would be conducted on the basis of the physical and chemical properties of the feed, product, and wastes, as described in the data base, and of generic processes or equipment which could be used to achieve the requirements of the plant. Other information that would have to be considered includes the fuel element characteristics and the product specifications for the output of the particular entity being analyzed.

The definition of a particular entity, i.e., plant, facility, system, must be preceded by an analysis of the sets of processes, process, or unit operations, respectively, that compose the entity being defined.

Figure C2-2 shows the general delineation for the HRRF Plant. The definition of a particular entity, i.e., plant, facility, system, must be preceded by an analysis of the sets of processes, process, or unit operations, respectively, that compose the entity being defined. Therefore, to define a reprocessing facility, the design and development groups must have available sufficient information to delineate the processes that would compose a facility of this type. To define a particular process, these groups must have information on the unit operations.

FIGURE C2-1. UNIT OPERATIONS ANALYSIS.

FIGURE C2-2. PROCESS-ORIENTED DELINEATION OF HRRF PLANT.

An approach of this type allows the designers to monitor and maintain adequate interface control between the entities being considered as well as providing a rationale for the HRRF plant delineation.

Generally, the delineation process would continue through both the feasibility and preconceptual design phases. However, during the feasibility phase it may be necessary to evaluate a particular process or set of processes through unit operations to insure technical feasibility of the function. In cases where alternatives exist, trade studies would be necessary to establish the unit operations baseline. At Level 0 (plant), the trade studies would be performed on sets of processes that could meet the HRRF plant requirements. Once the optimal sets of processes have been identified through the interaction of the design, development, and specialty engineering groups, the remainder of the Level 0 design analysis would proceed. This process would be repeated at each level of design detail. Trade-off studies are discussed in Section 3.0 of the Project Summary Plan.

The definition of an HRRF plant would result when the optimal combination of processes has been identified through the trade-off analysis. To define facilities, processes would be evaluated; to define systems, unit operations would be evaluated.

The Unit Operations Analysis would be basically an iterative process, with the system delineations developed during the feasibility design phase continually updated with new information from development activities. During the feasibility phase, the basic outline would be developed, including a preliminary definition of unit operations for

those areas where questions exist as to technical feasibility. In the preconceptual design phase, this basic framework would be developed in more detail and refined where appropriate.

C3.0 INTERACTION

The output from the unit operations analysis is utilized at each stage of the design process by both the design group, with overall responsibility for plant design, and the support or specialty engineering groups. In the feasibility and preconceptual design phases, the delineation provided by Unit Operations Analysis forms the basis of the design logic and the Work Breakdown Structure. Unit operations activities will be essentially completed at the end of the preconceptual design phase, unless unexpected problems are encountered in the conceptual design phase.

Output from the design group will be the subject of analysis by the other groups. The resulting feedback initiates iterative design changes which lead to facilities, processes, and equipment criteria and specifications optimized from standpoints of safety, reliability, maintainability, and layout, as well as cost and normal operating profiles. These optimal design criteria, when reduced to equipment specifications, can serve as the design guidelines for the HRRF.

C4.0 EXAMPLE

The example discussed in this guideline is the fuel block size reduction unit. The Unit Operations Analysis proceeds by consideration of design requirements and Principal Plant Factors in the light of chemical and physical properties and technology constraints. This example is designed to show how process information would be utilized to support the definition of the HRRF plant, the various facilities in the plant, and the systems in each facility.

The HRRF plant is defined by examining the sets of processes, i.e., reprocessing, refabrication, etc., that compose the plant to establish the boundaries of the design analysis. However, the sets of processes have to be defined by examining individual processes and in turn individual unit operations. Although it would not be necessary to define all unit operations in great detail in the early stages of design analysis, it is necessary to consider the unit operations in enough detail to identify critical areas and to provide a clear delineation between what would be included and what would not be included in the HRRF plant. Also, viable alternatives would be identified for further analysis.

Once the HRRF plant has been defined and the requirements evaluated, the next level of design detail is the facility, consisting of a set of processes. To define the facilities, the analysis to define the HRRF plant would be continued, resulting in more detailed definition of the set of processes and the supporting unit operations. Assuming this has resulted in the definition of a Reprocessing Facility, the facility

would be characterized by fuel blocks as input and product and waste streams of given composition as output. The final numbers for the input and output would result from the requirements evaluation.

Analysis of the Reprocessing Facility may reveal that to obtain the desired products it would be necessary to separate first the graphite from the fuel, then the fertile and fissile products, and finally the product elements from the waste. Study of the physical and chemical properties of the fuel may suggest that these processes cannot be combined but must be treated as separate steps. Therefore, these three processes would define the Reprocessing Facility.

The processes would then be analyzed for the unit operations required for performance of the process. Examination of existing technology may reveal several alternatives applicable to the HRRF. Figure C4-1 shows three separate unit operations for the graphite-fuel separation process. If the definition and/or boundary of the system under consideration would be impacted by the choice of a particular unit operation, then a decision would have to be made by the design team (design, development, and specialty engineering groups) on the unit operations baseline through a series of trade studies. Given a set of requirements for the HRRF plant, the trade-offs may occur at any level of design detail, i.e., among sets of processes, processes, or unit operations. In this way, the set of unit operations that most effectively meets the allocated requirements would be utilized.

Once the unit operations baseline has been established through a series of trade-off studies, the definition of the HRRF plant,

FIGURE C4-1. EXAMPLE PROBLEM

facilities, and systems would be completed. The next step in the analysis would involve the equipment trade-offs as discussed in Section 3.0 of the Project Summary Plan.

C5.0 DEFINITIONS

PLANT--an integrated industrial operation consisting of a combination of all the processes, services, or activities which perform or facilitate the performance of a major function.

FACILITY--an integrated group of systems (processes) which perform a major task or function within a plant.

SYSTEM--a collection of subsystems (unit operations) organized to perform an intermediate level task or function.

UNIT OPERATION--

(1) a piece of equipment which performs a basic function, such as transfer of heat, separation of chemical compounds, etc.

(2) basic principles of operation, such as fluid flow, heat transfer, and mass transfer commonly encountered in equipment, systems, and facilities.

REQUIREMENTS--specified goals and limits to be met in design, i.e., design criteria.

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APPENDIX - PART D
LAYOUT ANALYSIS GUIDELINE

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D1.0 SCOPE AND OBJECTIVE

This guideline description is designed to indicate the types of information necessary to perform the layout design evaluation. The layout analysis would interact with unit operations and, using the functional descriptions of activities, would provide candidate layouts for evaluation by other design groups.

D2.0 METHODOLOGY

A reference functional flow diagram is provided in Figure D2-1 and indicates the basic functions involved in the layout design analysis. Layout analysis would begin after the requirements evaluation at Level 0 (see Section 3.0) and the Unit Operations Analysis (see Appendix, Part C) have been completed in the feasibility design phase. As the design analysis progresses to greater levels of detail, the candidate layouts would become more process and hardware specific. At the end of the pre-conceptual design phase, a candidate layout may be necessary for each set of design options that would be evaluated in the conceptual design stage. The optimal layout would then result when the optimal design option configuration is selected.

FIGURE D2-1. LAYOUT ANALYSIS.

LAYOUT ANALYSIS

APPENDIX - PART E
SAFEGUARDS/ACCOUNTABILITY GUIDELINE

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E1.0 SCOPE AND OBJECTIVE

This guideline description is designed to indicate the types of information necessary to perform the safeguards/accountability design analysis. To aid in this discussion, a reference flow sheet is provided that considers the major factors associated with safeguards/accountability. This guideline has not been developed completely and therefore cannot serve as more than a brief description of the analysis area.

E2.0 METHODOLOGY

There are three primary means of safeguarding a nuclear facility such as the High Temperature Gas-Cooled Reactor Recycle Reference Facility (HRRF). These are (See Figure E2-1.):

1. Resident Inspection,
2. Containment and Surveillance, and
3. Material Balance Accounting.

In the early design stage of the HRRF, these safeguard methods should be considered. For example, an office and small laboratory facility may be needed for the resident inspector, and this would need to be placed in the facility such that industrial proprietary information would not be compromised. Visitation by international inspection teams should be designed for the least intrusion upon the process. Containment and Surveillance should be considered in the design of the

FIGURE E2-1. SAFEGUARDS/ACCOUNTABILITY.

perimeter fence surrounding the facility and in the areas surrounding a sensitive portion of the facility. Cameras and radiation detectors may need to be placed in several locations.

The most important design consideration in safeguard techniques is the Material Balance Accounting (MBA). Key measurement points must be established, and in a facility such as the HRRF the various operations may need to be individually considered with the material inventories that are contained in each process building, or set of buildings. It is very important to provide for MBA in the early design stage of the HRRF because some process equipment design may be impacted by the need to obtain a material balance.

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PHYSICAL PROTECTION GUIDELINE

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F1.0 SCOPE AND OBJECTIVE

This guideline description is designed to indicate the type of information necessary to perform the physical protection design analysis. This guideline has not been developed completely and therefore cannot serve as more than a brief description of the analysis area.

F2.0 METHODOLOGY

In the feasibility and preconceptual design phases, the physical protection design analysis group would participate in the requirements assessment process as discussed in Section 3.0 of the Project Summary Plan. The general method for the physical protection design analysis for the design analysis is shown in Figure F2-1. A partial list of information required as input would include the flowsheet diversion points, a description of the facility and processes, the integrated logistics plan, and the site location. With this information, the physical protection design analysis group would provide input on the acceptance of response policies developed for various scenarios and possible design changes that may enhance physical protection.

FIGURE F2-1. HRRF PHYSICAL PROTECTION DESIGN ANALYSIS.

SECTION DESIGN ANALYSIS

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CRITICALITY ANALYSIS GUIDELINE

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G1.0 SCOPE AND OBJECTIVE

This guideline description is designed to indicate the types of information necessary to perform the criticality design evaluation. The criticality analysis would interact with the unit operations analysis and the layout analysis to provide input for the safety, maintenance, and operations plans.

G2.0 METHODOLOGY

A reference functional flow diagram is provided in Figure G2-1 that indicates the basic functions involved in the criticality design analysis. The criticality analysis would provide input to three plans--safety, maintenance, and operations. In the feasibility and preconceptual design phase, the criticality analysis would aid in the requirements evaluation process (see Section 3.0 and Appendix, Part A) and in general design review during the determination of an optimal set of unit operations. When considering alternative design options to perform the unit operations, the criticality analysis would be involved to a greater degree in determining both the viable alternatives that would be considered for further analysis and the optimal design options.

FIGURE G-2-1. CRITICALITY ANALYSIS.

CRITICALITY ANALYSIS

APPENDIX - PART H
ENVIRONMENTAL ANALYSIS GUIDELINE

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H1.0 SCOPE AND OBJECTIVE

The objective of this guideline is to provide a brief description of the environmental considerations which can impact the design analysis for the HRRF. The scope of the environmental analysis includes participation in the requirements assessment process as described in Section 3.0 of the Project Summary Plan. In addition, the environmental analysis includes participation in the selection of the optimal design options in the conceptual design phase.

H2.0 METHODOLOGY

The general method for the environmental assessment is shown in Figure H2-1. Through each design phase, the depth of the analysis would vary with the quality and quantity of information available. The basic inputs to the process include the baseline environmental data; the engineering data on effluents, both routine and accident², occupational exposure, and design characteristics; and resource data including land and water use, a biotic inventory, and socioeconomic and demographic data. This information is used in the five analysis steps identified in the figure: dispersion and siting, exposure assessment, impact assessment, synthesis, and the NEPA procedure. In the synthesis step, the question "Is it potentially licensable?" will be answered by several groups of specialty engineers, including licensing and safety; however,

FIGURE H2-1. HRRF ENVIRONMENTAL ASSESSMENT PROCEDURE.

ASSESSMENT PROCEDURE

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the answer will determine the relative rank of the particular set of factors (processes or design options) being considered.

For the assessment of exposure to the human population and other biota, the analysis would first consider three effluent collectors: air, soil, and water. Each of the collectors would have associated with it various accumulators such as animals, crops, and fish. From these accumulators, the pathways to human and other biota would be analyzed. These pathways would include inhalation, ingestion, immersion, land surface contamination, or submersion. Once the appropriate pathways are identified, the type of exposure, either internal or external, would be identified.

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SAFETY ANALYSIS GUIDELINE

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11.0 SCOPE AND OBJECTIVE

This guideline description is designed to indicate the types of information necessary to perform the safety design evaluation. The safety analysis would interact with physical protection, environment, and licensing design evaluation. In the Appendix, Part N, more detail is provided on this interaction when considering licensing analysis.

12.0 METHODOLOGY

A reference functional flow diagram is provided in Figure I2-1 that indicates the basic functions involved in the safety design evaluation. In the feasibility and preconceptual design stages, the evaluation would be designed to rank order the particular set of processes, process, and unit operations that have been identified and fulfill the requirements at each level of the design analysis. Therefore, the choices will be between various functional activities all accomplishing the same goal. In the conceptual design phase, the safety evaluation will concentrate on design options that have been developed for the optimal functional flow of activities. In this stage, the task is to rank order the sets of design options. The final evaluation and determination of the optimal set of functions and design options is described in Section 3.0.

Also, safety considerations would be represented in the design criteria by involving a member of the safety evaluation group in the

FIGURE 12-1. SAFETY ANALYSIS

requirements assessment process as described in Section 3.0 and in the Appendix, Part A.

APPENDIX - PART J
AVAILABILITY ENGINEERING GUIDELINE

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J1.0 INTRODUCTION

Availability engineering is that part of the design effort that is directed toward minimizing system downtime through limiting the failures of individual components and improving the maintainability of these components. This document is a guideline that provides:

1. Information concerning various availability engineering techniques.
2. A basis for incorporating availability engineering requirements into the design of the HTGR Recycle Reference Facility (HRRF).¹

The methods may be directed toward operating availability, safety related reliability, or maintainability.^{2,3,4} This document contains material to aid communication among designers regarding the application of systems availability engineering analysis techniques during the design of the HRRF and associated hardware under development.

Availability engineering is that part of the design effort that is directed toward minimizing system downtime through limiting the failures of individual components and improving the maintainability of these components.

J.1 Scope and Objective

This guideline specifies requirements for a comprehensive Availability Engineering Program (AEP) for the HTGR Recycle Reference Facility (HRRF) that involves both general considerations of overall plant design

and specific assessments of component failure and repair characteristics. This guideline suggests elements to be employed in the HRRF Availability Engineering Program, but does not specify specific analysis methods.

The main objective of this guideline is to present a series of steps for systematically incorporating availability engineering techniques throughout the HRRF design process. Specifically, the Availability Engineering Guideline (AEG):

1. Sets requirements for the Reliability Engineering Program (REP) and the Maintainability Engineering Program (MEP).
2. Combines the results from the REP and MEP.

Following the availability guideline will contribute to safe and reliable plant operation. Also, the life cycle costs of the plant will be reduced by appropriate application of these Guidelines.

The main objective of this guideline is to present a series of steps for systematically incorporating availability engineering techniques throughout the HRRF design process.

The procedures and techniques addressed are applicable during feasibility studies, preconceptual, conceptual, and final design phases, and throughout the operational life of the plant. This guideline applies to those systems and components whose satisfactory performance is required for safe, reliable operational life of the plant, as well as to those systems which provide for the prevention of accidents and mitigation of consequences of accidents.

This Guideline can be applied at any level and in any functional area of the plant design, as well as to the whole project. However, all of the technical and managerial elements in the Guideline will not be applicable to all portions of the project.

J1.2 Required Inputs

The inputs to the AEP Include:

1. Principal plant factors
2. Safety regulations
3. The proposed plant design layout and environmental conditions
4. Delineation of facility/system descriptions from the unit operations
5. Feedback from the Reliability and Maintainability Engineering Programs (component failure and repair characteristics).

These inputs will be updated as the design progresses through the conceptual design stage.

Component failure and repair characteristics include failure rates and mean downtimes for the various component failure modes. These parameters are allocated to the various system constituents based on the plant availability goal and are verified or modified by the Reliability and Maintainability Engineering Programs. Safety regulations influence plant availability through the REP (Appendix, Part K). The proposed plant design layout, layout analysis, and logistics support analysis are input through the MEP (Appendix, Part L).

Availability requirements are supported by quality assurance and logistics support planning.

J1.3 Relation to Quality Assurance

Availability is defined as the probability that a system is in a specified working state at a specified time. Quality assurance⁵ efforts are primarily concerned with verifying achievement of some level of system capability or conformance of the system to specifications. Quality assurance programs influence availability by improving component reliability because detectable faulty components are rejected.

Product quality is not, mathematically at least, linked to time as is availability. Product quality may best be defined as the quality of conformance of the product to the applicable specifications, standards, and workmanship criteria.

Another aspect of quality assurance is quality of performance. While reliability, thus availability, does not address directly the capability of the product, it can be used as a measure of the product's ability to perform. Quality of performance is thus a function of availability and capability.

J1.4 Relation to Logistics Support

Integrated Logistics Support (ILS)⁵ blends together the ingredients needed to support a product or a system over its expected life. ILS is concerned with repair, maintenance and test procedures, personnel, parts, supplies, and the interaction of these factors with maintainability.

There must be constant interaction provided via the availability subprogram between the AEP and the ILS program. Various stages of the AEP specify requirements for the ILS. These requirements are continuously revised based on results of the AEP, as well as other elements of the HRRF design process. ILS in turn provides information for the AEP in the form of what support will or will not be available. Logistics support analysis is discussed in more detail in the Appendix, Part M.

J1.5 Organizational Requirements

Availability engineering activities will be planned, implemented, and managed as an integral part of the HRRF design effort by availability subprogram management.

The availability program management regularly reviews and evaluates the status and adequacy of the availability engineering activities and coordinates the Reliability and Maintainability Engineering Programs. The availability management must also interface with all technical activities, design reviews, and quality assurance work performed by various development tasks. Decisions concerning design changes based on considerations of availability will be made by the members of the Standing Committee (Appendix, Part B) under Subtask 930 of the National Program.

J2.0 AVAILABILITY ENGINEERING PROGRAM ELEMENTS

The technical elements of the Availability Engineering Program for the HRRF design project are discussed in this section. The AEP elements illustrated in Figure J2-1 consist of:

1. System definition and requirements specification
2. Availability allocation
3. System and plant availability verification
4. Detailed allocation and relaxation of system and plant availability goals.

Sections J2.1 through J2.4 provide details of these elements.

Availability is defined as the probability that an entity is in a specified working state at time t .

Availability is defined as the probability that an entity is in a specified working state at time t . Availability, $A(t)$, is a time dependent quantity, and if the failure and repairs are exponentially distributed, can be expressed as,²

$$A(t) = \frac{1 + \lambda\tau\{\exp(-(\lambda + 1/\tau)t)\}}{1 + \lambda\tau} \quad J.1$$

where λ = failure rate, hrs.⁻¹

and τ = mean down-time, hrs.

Figure J2-1. HRRF Availability Engineering Program.

Asymptotically, for any distribution type,

$$A_{\text{sym}} = \frac{1}{1 + \lambda\tau} \quad \text{J.2}$$

where λ = average failure rate (MTTF^{-1}), hrs.^{-1}
and τ = mean down-time (MDT), hrs.

The type of availability given by Equation J.2 depends upon the formulation of the mean downtime. Inherent availability,⁵ a quantity determined from development program tasks, includes downtime due exclusively to repair of the system or component and is independent of layout and logistics support. Inherent availability, A_i , can be expressed as,

$$A_i = \frac{\text{MTTF}}{\text{MTTF} + \text{MDT}} \quad \text{J.3}$$

where MTTF = mean time to failure, λ^{-1}
MDT = mean time to repair, MTTR.

Operational availability involves downtime due to preventive maintenance, logistic support delays, and administrative actions.

Operational availability⁵ involves (in addition to the actual repair time) downtime due to:

1. Preventive maintenance
2. Logistic support delays
3. Administrative actions (accountability, etc.).

Operation availability, A_o , can be expressed as,

$$A_o = \frac{MTTF}{MTTF + MDT} \quad J.4$$

where $MDT = MTTR + PM + LS + AD$

PM = preventive maintenance downtime

LS = logistic support downtime

AD = administrative delays.

The significance of various contributions to mean downtime is discussed in greater detail in the Appendix, Part L.

J2.1 System Definition and Requirements Specification

This section describes the process of establishing the physical and analytical bounds of the plant.⁶ This information is obtained from the Unit Operation analysis (Appendix, Part C). Establishing physical bounds is defining what system hardware is to be included in a specified tier of the analysis. The analytical bounds include defining the system failures of interest, initial and boundary conditions, and qualifying assumptions. System failures of interest reflect the loss of HRRF availability, such as less than adequate output from the reprocessing facility.

Initial or boundary conditions include:

1. All component operating states of the working system.
2. The proposed plant operating profile.
3. Functional relationships between facilities and components within the systems.

Other required information includes:

1. Design capacity of components and systems
2. Possible storage requirements of inter- and intra-facility feed and product
3. Maintenance policy
4. Spare parts availability
5. Nuclear criticality
6. Material accountability.

During the availability allocation effort, much of this information will be tentatively set based on best estimates.

The limits of resolution for this analysis, that is, what is a system and what is a component, are established during system definition (from the Appendix, Part C). Because of the ability to tier the analysis, components in initial analyses can become systems in subsequent analyses. Failure to establish the system's physical and analytical bounds will result in a diverging analysis.

J2.2 Availability Allocation

Availability allocation, a portion of requirements assessment (Appendix, Part A), is specifying component or system availability requirements so that the plant availability goal is met. This section also describes the interface between the component reliability and maintainability analyses and the iterative process that results in component failure rate and mean downtime allocations.

Allocation of availability requirements is accomplished through system definition and development of a system logic model.

Inputs to the availability allocation step include the plant requirements and the preliminary system logic model. One portion of the Level 3 Requirements Assessment involves developing an overall plant availability goal. System and component availability profiles are synthesized from the overall plant goal using standard availability analysis techniques, such as fault tree analysis^{7,8,9} and associated qualitative and quantitative methods.^{3,10,11} This is done from the top down. That is, the plant availability goal is allocated among facilities. Each facility goal is likewise allocated among systems and so forth.

An availability profile is one complete set of component or system availability requirements that satisfy the overall plant availability goal. Theoretically, an infinite number of such profiles exist. In practice, however, known engineering constraints generally limit the profiles to a manageable number. Initially, an availability profile is chosen such that the component or system availability specifications seem most reasonable in light of engineering and economic considerations.

Each individual component or system allocation within the chosen profile can be represented (in the asymptotic case) as a simple function of the component average failure rate, λ , and mean downtime, τ .

$$\text{Availability}_{\text{comp}} = \frac{1}{1 + \lambda \tau} \quad \text{J.2}$$

Many combinations exist that numerically satisfy the component availability requirements. Therefore, trade-offs are possible between reliability (λ) and maintainability (τ) requirements.

Failure rate and mean downtime allocations are made for all components within the chosen availability profile. If for any component there cannot be found a feasible (λ, τ) doublet, the component availability profile must be adjusted. This requires a "second iteration" to determine another combination of component availability allocations that will satisfy the plant goal. In the event that no suitable component availability profile is found, and no acceptable compensation can be found, the plant design must be changed, or the availability goal must be adjusted.

The process of determining the feasibility of or verifying component failure rates and mean downtimes is a major objective of the Reliability and Maintainability Engineering Programs and is described in the Appendix, Parts K and L.

J2.3 Availability Verification Through Modeling

This section describes the principal analysis effort of the AEP for the HRRF. Steps in the procedure include logic model construction, determining system modes of failure, common cause failure analysis,^{3,12} and quantitative evaluation of system availability characteristics.

These efforts are largely undertaken as subtasks of TASK 100, Studies and Analyses, in the HTGR Fuel Recycle Development Program.

The system logic model bridges the gap between the system and the analyses.

J.2.3.1 Logic Model Construction

The system logic model^{7,8} bridges the gap between the system and the analyses. Logic models, such as block diagrams, fault trees, or event trees, can be developed to analyze the HRRF design for main system failures of interest that effect plant availability.

J2.3.2 Determine System Modes of Failure

This section describes procedures for analyzing the HRRF system logic models to determine system modes of failure, that is, those combinations of component malfunctions that result in a specific system failure. This step is sometimes combined with the logic modeling step when performing a Failure Modes and Effects Analysis (FMEA), which is quite adequate for many analyses.

Using the HRRF system plant logic model, the combinations of component failures are determined for the main failure of interest that effects HRRF availability. These system modes of failure are oftentimes referred to as cut sets. Cut sets represent the HRRF plant logic model from this point on in the analysis.

Many methods exist for determining the cut sets of a system logic model. Some of these methods have been computerized, and obtaining one such program is recommended as an aid to analysis, since manual analysis of complex logic models is not feasible. Available qualitative analysis computer programs include MOCUS,¹³ PREP,¹⁴ SETS,¹⁵ and others.

J2.3.3 Common Cause Failure Analysis

Dependencies between HRRF systems components that affect availability are identified in this step. These dependencies may result in system failure through multiple component failure due to a single event or condition. If common cause failures are a significant contributor to the availability of the plant, re-allocation, redesign, or both are required. Common cause failure analysis is also tedious, even when a computer is used to help with the bookkeeping. Computer aids, such as BACFIRE II¹⁶ and COMCAN,¹² are available.

J2.3.4 Quantitative Evaluation of System Availability Characteristics

The quantitative failure characteristics of the HRRF are calculated from detailed models in this step. These results are compared with the availability allowed for the system as defined in the principal plant factors. If the allocation requirements are not achieved, then trade-off studies and re-allocation may be performed.

Quantitative analysis of HRRF system logic models is performed using the cut sets determined in the qualitative analysis. System characteristics that should be calculated include plant unavailability,

the expected number of failures (ENF) of components and systems, and component unavailability importance. Many computer programs are also available to perform this analysis step. They include: SUPERPOCUS,¹⁷ KITT,¹⁴ SETS,¹⁵ SAMPLE,¹⁸ RAS,¹⁹ and FRANTIC.²⁰

Results from the quantitative analysis may be used in verifying achievement of plant availability goals. Expected number of failures is input to MEP to help determine component support requirements. Component unavailability importances indicate which components or systems contribute most to HRRF unavailability. This information is useful in determining which components should be prototyped. Also, when charting availability growth, these components should be monitored closely. Component importance information is a crucial input to on-going component design and development tasks within the HTGR Fuel Recycle Development Program.

J2.4 Detailed Allocation and Relaxation Studies

If the availability allocations specified in the principal plant factors of the HRRF are not achieved, it may be necessary to live with the reduction in anticipated system performance. If this is unacceptable, then trade-offs, considering reduction in failure rates and mean times to repair, addition of component or system redundancy, or both may be made.

Availability allocations are a part of the design level requirements assessment (Appendix, Part A) and are made at each level of the plant design (See Figure 3-2, HRRF Design Logic).

The combined allocations on any given level are called a level availability profile and must satisfy the availability goals for the next level of design. For clarity, this allocation process discussed herein is described in terms of the following plant design structure (Appendix, Part C) and terminology.

PLANT	(Level 0)
FACILITY	(Level 1)
SYSTEM	(Level 2)
COMPONENT	(Level 3)

This procedure is not restricted to this structure and may be used in design analyses involving less or greater resolution (fewer or more levels). For the purposes of the Program, Level 2 represents the limit of resolution through the conceptual design. Situations that may result from the quantitative analysis are discussed in the next two sections.

J2.4.1 Component Goal Achievable

Consider the case in which each component (Level 3) satisfies its availability goal. That is, an achievable pair (λ, τ) has been determined from the REP and MEP that will satisfy this component's goal. The specified component (Level 3) availability profile satisfies the corresponding system (Level 2) goal.

System goals that comprise the Level 2 availability profile satisfy one of the corresponding facility goals that make up the facility (Level 1) availability profile. This facility profile satisfies the overall HRRF plant (Level 0) availability goal.

J2.4.2 Component Goal Unachievable

Four cases exist for a component that can't meet its goal. For example, component A, within a Level 3 availability profile, can't meet its availability goal; that is, no acceptable trade-off between λ and τ can be made so that component A's availability goal is met.

1. The availability goals of other components within the specified Level 3 profile may be adjusted to compensate for the needed decrease in component A's availability. If this is possible, and if the new Level 3 availability profile satisfies the corresponding Level 2 system goal, then all higher level availability profiles are still valid, and the overall HRRF goal is maintained.
2. No acceptable trade-off can be made between other component goals within the Level 3 profile in order to compensate for component A. In this case, a new Level 3 availability profile reflecting a reduced system (Level 2) goal is needed. This system goal requires a new system (Level 2) availability profile. If acceptable adjustments to other Level 2 goals can be made while still maintaining the corresponding facility (Level 1) goal, then all higher level profiles are still valid, and the overall HRRF plant availability goal is achieved.
3. If no acceptable system (Level 2) availability goal adjustments can be made while maintaining the facility (Level 1) goal, then a reduction in this facility's availability goal is indicated. This requires a new facility (Level 1) availability profile. If acceptable adjustments to other facility goals can be made while maintaining the plant (Level 0) goal, then no reduction of the HRRF plant goal is required.

4. If no acceptable compensations to other facility goals can be made, then the plant (Level 0) availability goal must be reduced or a new design considered.

J3.0 HRRF AVAILABILITY GROWTH

Knowledge of plant availability growth is important in assuring the final plant design will be able to meet the prescribed availability goal. The concepts discussed in the following sections are applicable during the laboratory, engineering, prototype and demonstration phases, and the plant operation phase. However, the major effort in availability growth monitoring is directed towards component development and testing through the conceptual design phase within the on-going HTGR Fuel Recycle Development Program. Accurate determination of availability growth is difficult because of the statistical nature of availability and the limited number of prototypical tests.

The major effort in availability growth monitoring is directed towards component development and testing through the conceptual design phase.

J3.1 Monitor Availability Growth

During the HRRF design process, prototypes of important components will be built and tested by other program tasks. The specific reliability and maintainability testing requirements are described in the Appendix, Parts K and L. Increase in plant availability may be possible because of components performance beyond original design expectations. On the other hand, if the availability growth does not measure up to standard, or a forecast predicts that component goals will not be achieved, then re-allocation, redesign, or both may be required.

Monitoring plant, facility, system, or component availability growth involves charting availability performance over a period of years from the feasibility stage of design through the preconceptual and conceptual design stages (Figure J3-1). Components and systems availability performance is observed from prototypical testing. Data for charting facility and plant availability growth is derived from analyses that predict plant and facility availability increases from increases in system and component availability.

J3.2 Verify Achievement or Forecast Changes in Plant Availability Goals

Changes in component performance detected during prototype testing in design or during operation will result in changes in forecasted plant availability. During the design process, analyses should be performed to determine the effects due to component performance changes on overall plant availability to assure that progress is being made toward achieving the plant availability goal. After plant operation begins, data concerning plant system and component output, efficiency, and availability are required to verify achievement of design availability goals. Also, forecasts of future output may be modified to reflect perturbations in component and system availability.

When analyzing progress toward an availability goal, attention should be placed on the rate of approaching the goal, as well as the "distance" away from the goal. A large slope indicating a high "speed of approach" is likely to be seen during the initial stages of design and testing. As the component "matures," the slope of the availability

Figure J3-1. Availability Growth Analysis.

growth line may become horizontal. If the trend line has leveled off before reaching the specified availability goal, then appropriate trade-offs with regard to reliability and maintainability must be made in order to achieve the desired availability goal.

J3.3 Collect Information for Future Design

Improvements in plant availability forecasted during design or observed during testing and operation should be documented for use in future HRRF design activity.

J4.0 INTERACTION

The basic format of the Availability Engineering Program allows for feedback from all stages of the analysis. The result is a highly interactive iterative process between the Reliability, Maintainability, and Availability Engineering Programs and all levels of HRRF design activity.

Achievement of availability goals requires the achievement of reliability and maintainability goals for systems or components.

J4.1 Integration Into Design

Acceptability of the design based on availability criteria, as is applicable to licensing, is established and input to the licensing process. In the event the plant design does not meet availability goals, two options exist:

1. Return to the Principal Plant Factors Analysis (Appendix, Part B) for re-evaluation of plant availability goals and plant requirements.
2. Change the plant design or components reliability characteristics in order to achieve acceptable availability.

J4.2 Relation to Reliability and Maintainability Engineering Programs

The Availability Engineering Program coalesces the results of the Reliability and Maintainability Engineering Programs. The interaction between the AEP and the REP and MEP was graphically illustrated in Figure J2-1. Component reliability and maintainability concerns are

factored into the design using the availability analysis procedure presented in this Guideline. Preliminary values for component failure rates and mean downtime, as determined from the allocated availability (Section J2.2), are provided to the MEP and REP by the AEP. The primary objective of the REP and the MEP is the validation of component failure rates and mean downtimes. A more detailed discussion of Figure J2-1 is given in Section J3.0

J4.3 Design Reviews

The AEP should be included in the design review activities for the HRRF. These reviews must follow the design review procedures established in Program Management Document P-017. The AEP results can be used as a comparative base during trade-off studies between alternative designs and decisions concerning overall design logic (Appendix, Part A).

J5.0 EXAMPLE

J5.1 System Definition

The system considered is the Size Reduction System (SRS) of the Reprocessing Facility. To accurately define the problem, the relationships between the Size Reduction System and the overall HRRF scheme must be identified (Section J2.1).

Figure J5-1 is a block diagram of the HRRF Plant (Level 0) indicating the relationships between the facilities which make up the plant. This example addresses the Reprocessing Facility (Level 1), shown in Figure J5-2.

The Primary Crushing segment of the facility operation utilizes the Size Reduction System (Level 2), shown by the block diagram in Figure J5-3.

This example analysis is also subject to the following assumptions and boundary conditions.

1. Assuming available storage and surge storage is full, all facilities must be operational for the plant (Level 0) to be available. More simply, any facility failure results in plant failure.
2. In the Reprocessing Facility (Level 1, Figure J5-2), the Thorex and Purex systems constitute a single system from an availability standpoint, i.e., both must be operational for the facility to operate.
3. Any system failure in the Reprocessing Facility (Figure J5-2) results in failure of the Reprocessing Facility.

Figure J5-1. HRRF Plant (LEVEL 0) Functional Diagram.

Figure J5-2. Reprocessing Facility (LEVEL 1) Functional Diagram.

Figure J5-3. Size Reduction System (LEVEL 2) Functional Diagram.

4. Failure of the oversize pulverizer in the Size Reduction System (Level 2, Figure J5-3) is assumed to have no effect on system availability.
5. Failure of any component in the Size Reduction System, except the oversize pulverizer (Assumption 4), results in failure of the system.

This establishes the functional relationships between the plant (Level 0), the facility (Level 1), and the Size Reduction System (Level 2).

Other assumptions include:

1. Component failures are statistically independent.
2. Component repairs are statistically independent.
3. Plant availability is assumed to have reached asymptotic, or steady-state, conditions. This does not necessarily imply that plant production has reached steady-state conditions.
4. The mathematics used in the example require that $MTTF > 0.1 \text{ MDT}$. This allows the use of the λ, τ approximation for unavailability calculations and prevents overconservative results.
5. The plant goal of 80% availability is based on 233 effective 24-hour operating days, allowing 30 days accountability and 90% efficiency.

The function of the Size Reduction System is to crush the raw HTGR fuel elements to a size suitable for burning. The components of the Size Reduction System are arranged in a vertical frame, allowing gravity feed from the primary crusher to the secondary crusher, from the secondary crusher to the tertiary crusher, and from the tertiary crusher to the

screeners. The system is analyzed for the event "Loss of capability to provide crushed product." No drive system failures are considered. Also, the analysis assumes that the SRS is shutdown for one shift every six months for scheduled maintenance. The scheduled shutdown's contribution to the system's unavailability is considered. Therefore, the contribution to the unavailability due to preventive maintenance need only be considered on the system as a whole, not on individual components. This is a typical example of how policy effects unavailability calculations (Appendix, Part L).

J5.2 Availability Allocation

The plant availability goal and preliminary system logic models are required for availability allocation (Section J2.2). In the example, the plant (Level 0) availability goal is assumed to be 80%. Preliminary system logic models (in the fault tree format) for each level of the analysis are shown in Figures J5-4, J5-5, and J5-6. In this example, the availability goal is allocated in terms of unavailability profiles. The plant unavailability is allocated among facilities, each facility's allocation is allocated to its systems, and the systems' to its components. Component requirements are then described in terms of a failure rate and mean downtime.

Figure J5-4. HRRF Plant Failure Logic Model.

Figure J5-5. Reprocessing Facility Failure Logic Model.

FIGURE J5-6. SIZE REDUCTION SYSTEM FAILURE LOGIC MODEL.

J5.2.1 Level 1 Allocation

The total plant unavailability is 0.20. This unavailability is allocated to each facility within the plant (Figure J5-4). The Level 1 unavailability profile is given in Table J5-1.

J5.2.2 Level 2 Allocation

The Reprocessing Facility's unavailability allocation (Table J5-1) must now be allocated to the systems within the facility (Figure J5-5). The Level 2 unavailability profile is given in Table J5-2.

J5.2.3 Level 3 Allocation

The Size Reduction System's unavailability (Table J5-2) is allocated to each component in the system (Figure J5-6). The Level 3 unavailability profile is given in Table J5-3, including the contribution from scheduled downtime. In addition to the unavailability allocation, preliminary component specifications are determined in terms of the component failure rate and mean downtime. These failure rates and mean downtimes (Table J5-4) are input to the Reliability and Maintainability Engineering Programs for verification.

J5.3 Combining the Results of the REP and MEP -- Reallocation and Relaxation Studies

This portion of the analysis combines the results of the REP and MEP to determine if reallocation of system unavailability or design changes are necessary. At the conclusion of this assessment, an achievable system unavailability profile is determined (Section J3.4).

TABLE J5-1
LEVEL 1 UNAVAILABILITY PROFILE

Facility	Allocation
Fuel Element Handling	0.02
Reprocessing	0.06
Refabrication	0.05
Waste Treatment	0.04
Waste Handling	<u>0.03</u>
Total Plant Unavailability	0.20

TABLE J5-2
LEVEL 2 UNAVAILABILITY PROFILE

System	Allocation
Primary Crushing (Size Reduction System)	0.020
Primary Burning	0.013
Particle Classification	0.006
Secondary Crushing and Burning	0.010
Dissolution and Feed Adjustment	0.003
Thorex And Purex	0.005
Product Handling	<u>0.003</u>
Total Facility Unavailability	0.060

TABLE J5-3
LEVEL 3 UNAVAILABILITY PROFILE

Component	Allocation
Primary Crusher	0.003
Secondary Crusher	0.003
Tertiary Crusher	0.002
Screeners	0.010
Scheduled Downtime	<u>0.002</u>
Total System Unavailability	0.020

TABLE J5-4
PRELIMINARY COMPONENT RELIABILITY AND
MAINTAINABILITY SPECIFICATIONS

Component	Unavailability Goal	Failure Rate Goal (hr. ⁻¹)	Mean Downtime Goal (hrs.)
Primary Crusher	0.003	3×10^{-4}	10
Secondary Crusher	0.003	3×10^{-4}	10
Tertiary Crusher	0.002	2×10^{-4}	10
Screeners	0.010	3×10^{-4}	4

J5.3.1 Primary and Secondary Crusher Results

The results of the REP (Appendix, Part K, Section K5.0) and the MEP (Appendix, Part L, Section L5.0) show that an achievable and acceptable failure rate--mean downtime pair has been determined for the primary and secondary crushers. These results also show that the unavailability goals of the primary and secondary crushers can be tightened in view of the achievable failure rate and mean downtime.

J5.3.2 Tertiary Crusher Results

The REP results show that an achievable failure rate has been found to satisfy the failure rate goal. The MEP results indicate that the mean downtime goal is not satisfied. However, the unavailability goal can be satisfied with the achievable mean downtime and failure rate from the REP, since the achievable failure rate is well within the range specified by the MEP.

J5.3.3 Screener Results

The REP results show that the screener's failure rate goal is not achievable. The data indicate an achievable failure rate of 2×10^{-2} hr.⁻¹. The MEP results show that the mean downtime goal has been satisfied, and that the component unavailability goal can only be satisfied with a failure rate less than 2.5×10^{-1} hr.⁻¹. Since the achievable failure rate does not meet this requirement, it is necessary to reallocate the system unavailability.

J5.4 Reallocation

The system unavailability profile can be reallocated in terms of the achievable failure rate--mean downtime pairs (Section J2.4.2). This results in larger allocations to those components for which an acceptable failure rate--mean downtime pair has not been determined. This new unavailability profile is input to the REP and MEP for verification of failure rates and mean downtimes. These verification efforts need only consider those components for which an acceptable pair has not been found, since the remaining components' allocations are based on an achievable and acceptable failure rate--mean downtime pair. The new system unavailability profile is given in Table J5-5. The parameters for the screener are input to the REP and MEP to see if the components' new unavailability goal can be met.

J5.5 Results of Screener Re-evaluation

The REP and MEP screener re-evaluation results show that the system unavailability goal cannot be met with the achievable failure rate and mean downtime of the screener (Section J2.4.2). Two choices of action are available to still meet the plant availability goal.

1. Increase the unavailability allocation to the Size Reduction System. This involves developing a new unavailability profile for the Reprocessing Facility (Level 2).
2. Redesign the screener within the existing system unavailability profile.

This example evaluates a design change in the screener. The design change calls for addition of a second screener unit in parallel with the

TABLE J5-5
LEVEL 3 REALLOCATION

Component	Unavailability Goal	Failure Rate Goal (hr. ⁻¹)	Mean Downtime Goal (hrs.)
Primary Crusher	0.0003	4×10^{-5}	7
Secondary Crusher	0.0003	4×10^{-5}	7
Tertiary Crusher	0.0002	1.4×10^{-5}	14
Screeners	0.0172	2×10^{-5}	4

existing unit. The second screener is an installed spare, that is, only one of the screeners is operating at a given time. The design change assumes that the tertiary crusher is capable of providing feed to either screener.

J5.6 Evaluation of the Design Change

The unavailability of the redundant screener unit can be approximated by the product of the unavailabilities of the two screener units plus the unavailability contribution of possible common cause failure of the two screeners (Section J2.3.3). The inclusion of a contribution due to common cause failure is necessary to account for common power supplies, drive system, or inherent defects which may cause both screeners to fail from a single event. Figure J5-7 is a failure logic diagram, in fault tree format, for the event "Loss of screening capability." In this example, the common cause contribution is illustrated as a basic event with a failure rate equal to 10% of the failure rate of a single screener ($2 \times 10^{-3} \text{ hr.}^{-1}$) and a mean downtime of five hours. The unavailability contribution of the screener function can be calculated, using the achievable failure rate and mean downtime of the screeners, with the following equation:

$$\bar{a}_{s1} = (\lambda_{s1} \tau_{s1} + \lambda_{s2} \tau_{s2}) + \lambda_{cc} \tau_{cc} \quad \text{J.5}$$

where

$\bar{a}_s$ = unavailability contribution of the screener function

λ_{s1}, g_{s2} = achievable failure rate for the two screeners

τ_{s1}, τ_{s2} = achievable mean downtime for the two screeners

g_{cc}, τ_{cc} = assumed failure rate and mean downtime for the common cause contribution.

Figure J5-7. Failure Logic Model for the Example Design Change.

Results show that the unavailability contribution of the screener function is equal to 0.0164, which satisfies the unavailability goal specified in the current system unavailability profile (Table J5-5). The final system unavailability profile is given in Table J5-6, showing a total system unavailability of 0.0192. This satisfies the system goal of 0.020.

J5.7 Availability Growth Analysis

The availability allocation step (Section J5.2) resulted initially in an unachievable component availability profile. A change in the design of the Size Reduction System (Section J5.5) was made. The change called for addition of a second screener in parallel with the existing unit. Subsequent evaluation of the new design indicated that the overall plant availability goal could be achieved if the proposed component allocations were met.

The availability analysis showed that the screener is a very important component in regard to availability. That is, the screening unit contributes an overwhelming portion (85%) of the Size Reduction System's unavailability allocation. This constitutes a factor that should be considered when selecting components to be developed as prototypes. Any improvement (or degradation) in availability performance during prototype development and testing may significantly improve (or degrade) overall HRRF plant availability. Moreover, availability growth studies are useful in predicting whether component, system, facility, or plant goals will be reached.

TABLE J5-6
FINAL SYSTEM UNAVAILABILITY PROFILE

Component	Unavailability Goal
Primary Crusher	0.0003
Secondary Crusher	0.0003
Tertiary Crusher	0.0002
Screening Function	0.0064
Common Cause Contribution	0.0100
Scheduled Downtime Contribution	<u>0.0020</u>
Total System Unavailability	0.0192

Consider a case in which one of the screeners in the proposed redundant screener unit is undergoing development and testing at the same time plant, facility, and system availability growth is being charted. Typically, many other components may be under similar development, and improvements in their availability may result in additional HRRF availability growth.

The improvements in screener availability, resulting from a combination of reliability and maintainability growth (Appendix, Parts K5.0 and L5.0), are input to the availability growth analysis. Figure J5-8 is a graph of availability growth of the redundant screening process unit. This improvement was due to an increase in the observed single screener prototype availability from 0.95 to 0.995. The portion of unavailability due to common cause failure was assumed to remain constant (0.01). This resulted in availability growth from 0.94 to 0.985 for the redundant screening unit (See Section J5.6 for redundant screener failure logic.).

The increase in screener availability passed the original availability allocation results in an increase in Size Reduction System Availability (Figure J5-9). This assumes all other component goals are met exactly. Similarly, the Reprocessing Facility availability increases (Figure J5-10), which in turn results in overall HRRF plant availability growth (Figure J5-11). This improvement in predicted plant availability represents an increase of 0.175%. Greater growth may be seen if other components also surpass their initial availability allocations. It must be recognized, however, that monitoring availability growth is tedious

Figure J5-8. Screening Process Availability Growth.

Figure J5-9. Size Reduction System Availability Growth.

Figure J5-10. Reprocessing Facility Availability Growth.

Figure J5-11. HRRF Plant Availability Growth.

and statistical in nature. Because of this, only the most important (with respect to availability) components should be monitored for availability growth.

J6.0 DEFINITIONS

This section contains definitions of availability engineering terms that may be useful in understanding many of the concepts used in the Availability Engineering Guideline.

ALLOCATION--Apportionment of a portion of a goal or requirement to a component, system, facility, or plant.

ASYMPTOTIC UNAVAILABILITY--The ratio of the mean downtime to the mean downtime plus the mean uptime.

AVAILABILITY (A)--The probability that the failure of interest does not exist at some specified time in the future.

AVAILABILITY ENGINEERING--The segment of the engineering discipline that is directed towards minimizing system downtime by limiting individual component failures and their subsequent downtime.

AVAILABILITY GROWTH--An increasing in system or component availability due to a decreasing incidence of component failures (reliability growth) and reduced component maintenance times (maintainability growth) as the life cycle of new systems progresses from the early development stage to production and then operation.

AVERAGE AVAILABILITY (INHERENT)--The ratio of mean system uptime to mean system uptime plus mean system downtime, where downtime includes only unscheduled maintenance time and not administrative or accountability contributions.

AVERAGE AVAILABILITY (OPERATIONAL)--The ratio of mean system uptime to mean system uptime plus mean system downtime, where downtime includes all downtime contributions (MTTR, PM, LS, AD, etc.).

AVERAGE PLANT AVAILABILITY (HISTORICAL)--The ratio of the number of hours that the system is available to total number of hours in the specified period of interest.

BASIC EVENT--A basic system component failure that defines the limit of resolution of the analysis. The dependence among basic events is treated in the common cause failure analysis.

BLOCK DIAGRAM²--A diagram containing logically connected component success modes used as a success model in reliability analysis. A path through the diagram is a system success mode.

- BURN-IN PERIOD²**--The early period of a component's life, usually distinguished by an above average failure rate that is due to initial weakness, defects, weak parts, bad assembly, etc.
- CAUSE-CONSEQUENCE ANALYSIS⁸ (CCA)**--A method of system reliability and risk analysis that is a combination of fault tree analysis (cause) and inductive analysis (consequence).
- COMMON CAUSE FAILURE**--The occurrence result of more than one component malfunction due to the same cause of failure.
- COMMON CAUSE FAILURE ANALYSIS (CCFA)**--An analysis which attempts to identify those events which result in system failure through the common cause failure of a group of system components.
- COMPONENT**--A basic system constituent for which failures are considered basic events during logic model construction.
- COMPONENT UNAVAILABILITY IMPORTANCE**--The probability that a basic event failure is contributing to the TOP event failure at some specified time given the TOP event is failed at that time.
- EXISTING EVENT**--A system boundary condition that specifies events that are assumed to be certain to occur.
- EXPECTED NUMBER OF FAILURES**--The statistically expected number of occurrences of an event during a specified time interval.
- FAILURE MODES AND EFFECTS ANALYSIS (FMEA)³**--An analysis directed towards qualitative assessment of contributory component failure modes and identifying the resulting effect on the system. The basic premise of this type of analysis is "what happens if?"
- FAILURE RATE**--The failure rate as a function of time is the probability of failure during t to $t + dt$, given no failures before t .
- FAILURE RATE CURVE²**--A graph of failure rate versus time, sometimes characterized by a "bathtub" shape. The initial decrease is the burn-in period. The failure rate is then sometimes nearly constant over some period of time before it begins to increase due to wear-out failures.
- FAULT EVENT**--A failure situation resulting from the logical interaction of basic events.
- FAULT TREE³**--The graphical representation of the logical development of the TOP event to the level of basic event failures, mainly using AND and OR logic gates.
- FAULT TREE ANALYSIS⁸**--A technique of system reliability and probabilistic safety analysis based on analysis of a fault tree.

INDEPENDENT FAILURE--A failure that occurs statistically uncoupled from other failure events.

INITIAL CONDITIONS--The operating state of the components in the working system that is to be analyzed (examples: valve A is closed; relay T is open).

LOGIC MODEL--A Boolean logic (success or failure) representation associated with the development of a particular event for a particular system (examples: block diagrams, fault trees, and cause consequence charts).

LOGIC MODEL CONSTRUCTION--The logical development of a particular failure of interest to the level of basic component failures.

MAINTAINABILITY--The probability that a specified item will again function correctly at a given time after the instant the item began to malfunction.

MEAN DOWNTIME--The mean time a specific malfunction exists. The mean of the maintainability density function.

MEAN TIME BETWEEN FAILURE (MTBF)--The mean time between failures, including both operating time and repair time contributions.

MEAN TIME TO REPAIR (MTTR)--The mean time required to return a failed component to the unfailed state.

MINIMAL CUT SET--A set of basic events that guarantees system failure if they all occur. If any event is removed from the set, the system failure is not guaranteed to occur.

PHYSICAL SYSTEM BOUNDS--The limit of the system hardware and software being analyzed.

QUALITY OF CONFORMANCE--The degree to which a product meets its design specifications.

QUALITY OF DESIGN--A product's inherent worth as defined by its component cost, manufacturing cost, and value in the eyes of the consumer.

QUALITY OF PERFORMANCE--A function of quality of design and quality of conformance, i.e., maintaining both at a high level will render a high quality of performance.

QUANTITATIVE ANALYSIS--Determining numerical reliability information, such as availability, reliability, expected number of failures, and mean time to failure, for a particular system failure from the reliability characteristics of the components in that system.

RELIABILITY--The probability that a specified item has experienced no failures during a specified time interval.

SYSTEM BOUNDARY CONDITIONS--The conditions which define the situation for which a logic model is to be developed.

SYSTEM MODES OF FAILURE--The minimal cut sets for the system.

TOP EVENT--The main system failure of interest.

UNAVAILABILITY--The probability that the specified failure of an entity does exist at some specified time.

UNRELIABILITY--The probability that a specified time has experienced one or more failures during a specified time interval.

UPTIME--The time a component, system, or plant is available and operating.

WEAROUT PERIOD--The period of a component's life distinguished by an increased number of failures due to old age and deterioration.

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APPENDIX - PART K
RELIABILITY ENGINEERING GUIDELINE

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K1.0 INTRODUCTION

Reliability engineering is that portion of the design effort that is directed toward limiting the number of system failures by minimizing individual component failures.^{1,2} A component failure is defined as a malfunction of a specified system constituent. This constituent represents the limit of resolution of the analysis and is defined based on the requirements of the analysis. Reliability analysis results are useful in analyzing system design, performing trade-off studies, demonstrating compliance with availability and safety requirements, and justifying system changes or additions.

Reliability analysis results are useful in analyzing system design, performing trade-off studies, demonstrating compliance with availability and safety requirements, and justifying system changes or additions.

K1.1 Scope and Objective

This guideline specifies requirements for a comprehensive Reliability Engineering Program (REP) during the design of the HTGR Recycle Reference Facility (HRRF). These requirements include both general and specific considerations of overall plant design and operation. Guidelines for specific assessments of component failure characteristics are described, but specific analysis methods are not specified. The objective of this guideline is to outline a series of steps for systematically incorporating reliability engineering techniques throughout the HRRF design process. These steps include:

1. Component reliability predictions as input to determining preliminary component specifications.
2. Monitoring component performance and reliability growth.
3. Verifying achievement of reliability goals.
4. Overall management of the REP.

The Reliability Engineering Program (REP) objective is to support plant availability and overall performance goals.

This guideline must be used in conjunction with the Availability Engineering Guideline (AEG) and the Maintainability Engineering Guideline (MEG) to provide the inputs for the Availability Engineering Program (AEP) for the design of the HRRF. This guideline is thereby directed toward component performance. However, because the AEG is directed toward a tiered analysis concept, component performance can be considered system performance as the limit of resolution of the engineering effort is extended. The procedures and techniques addressed are applicable during feasibility studies, preconceptual, conceptual, and final design phases, and throughout the operational life of the plant.

The results of the procedures presented in this guideline will judge the acceptability of the component failure rates specified during the availability allocation effort as described in the AEG. If these specified component failure rates are found to be achievable, then these failure rates can be used in the remainder of the availability modeling and analysis. If the failure rates are judged to not be achievable, it

is necessary to re-allocate the component failure rates. This iteration continues until achievable failure rates are determined.

K1.2 Required Inputs

The required inputs to the PEP include:

1. Safety regulations
2. The proposed HRRF design and layout
3. The equipment (component) failure rates specified during the availability allocation effort
4. Feedback from the Availability and Maintainability Engineering Programs.

The specific values for these inputs may change as the design progresses through the conceptual design stage.

K1.3 Relation to Quality Assurance

Reliability^{3,4} is defined as the probability that an entity has experienced no specified failure during a specific time interval. Product quality⁵ is not mathematically linked to a time period. It may best be defined as the quality of conformance of the product to the applicable specifications, standards, and workmanship criteria. Quality control efforts are directed toward achieving high quality of conformance and design, two of the key elements in the quality assurance function. The third key portion of quality assurance is the quality of performance. While reliability does not address the capability (quality of conformance and design) of the product, it can be used as a measure of the product's

ability to perform. Quality assurance is thus a function of reliability and capability, that is, reliability engineering and quality control.

K1.4 Organizational Requirements

Reliability engineering activities shall be planned and implemented as an integral part of the HRRF design effort. The reliability management regularly reviews and evaluates the status and adequacy of the reliability engineering activities. Reliability management must interface with all technical activities, design reviews, and quality assurance. Design decisions based on reliability considerations will be made by the Standing Committee (Appendix, Part B) under Subtask 930 of the National Program.

K2.0 RELIABILITY ENGINEERING PROGRAM ELEMENTS

The technical elements of the Reliability Engineering Program for the HRRF design project are discussed in this section. The REP elements consist of:

1. Component failure rate verification
2. Establish component reliability performance
3. Determine preliminary component specifications.

All elements of the REP are interactive and interface with the availability and maintainability engineering efforts (Figure K2-1).

The three technical elements of the REP include component failure rate verification, establishment of component reliability performance, and determination of preliminary component specifications.

Reliability can be defined as the probability that an entity experiences no failures over a specific time interval. Reliability, $R(t)$, is a time dependent quantity and can be expressed exactly as,⁶

$$R(t) = 1 - \int_0^t f(t') dt' \quad K.1$$

where $f(t') =$ density of time to first failure.

In terms of the time dependent failure rate, $\lambda(t)$, reliability can be expressed as,

$$R(t) = \exp(-\int_0^t \lambda(t') dt') \quad K.2$$

where $\lambda(t') =$ time dependent failure rate.

FIGURE K2-1. HRRF RELIABILITY ENGINEERING PROGRAM.

In actual practice, $\lambda(t)$, is usually represented by its average value, λ . Consequently, reliability is often estimated using,

$$R(t) = \exp(-\lambda t) \quad K.3$$

K2.1 Component Failure Rate Allocation

The establishment of a numerical reliability goal allows the analyst to judge whether the system is adequate or if design changes are advisable. The overall reliability goal is allocated to the individual system components, taking into account the system function, as well as the system design. For the reliability engineering activities, these goal allocations take the form of component failure rates.

K2.1.1 Establish Preliminary Component Requirements

The results of the availability allocation effort provide component availability goals to the REP. The component availability goal can be expressed in terms of the component failure rate and mean downtime. The REP determines and verifies component failure rates in order to assure that the goals of the AEP are met. Allowable component mean downtimes are specified in view of these achievable failure rates. These mean downtimes are the subject of the Maintainability Engineering Program (MEP).

K2.1.2 Allocation to Component Failure Modes

More than one failure mode is possible for a component. Depending on the component's application, a particular failure mode may be more

important or dominant than other failure modes. The component failure rate requirements determined in K2.1.1 are allocated proportionally to the various component failure modes.

K2.2 Establish Component Reliability Performance

Analyses using the allocated component failure rates are performed to predict the component's reliability performance.^{7,8,9} A basis for comparing the predicted performance is established by analysis, utilizing historical failure data for identical or similar components. These efforts would be largely undertaken as subtasks of TASK 100, Studies and Analyses, within the HTGR Fuel Recycle Development Program. Testing of component prototypes then verifies component reliability predictions.

K2.3 Determine Preliminary Component Specifications

The results of the REP are used to help establish preliminary component reliability specifications for the next design phase. These specifications are stated in terms of the required failure rate, operating lifetime and capability, and plant design and layout.

K3.0 COMPONENT RELIABILITY GROWTH

Monitoring component reliability growth^{10,11} involves charting the reliability performance of components and systems over a period of years, from the feasibility stages of design through the preconceptual, conceptual, and final design stages, and possibly during the operational life of the plant. Reliability performance forecasts based upon design developments aid in evaluating whether components and systems will achieve their allocated reliability goals. Analyzing reliability growth during plant operation allows:

1. Forecasting capacity or throughput changes
2. Verifying achievement of reliability goals set during design
3. Assists in evaluating preventive maintenance policies
4. Optimizes component replacement intervals by identifying performance degradation trends.

Efforts to monitor the reliability growth of HRRF components will be encumbered by the statistical nature of reliability and the limited amount of prototype equipment.

Reliability performance forecasts based upon design developments aid in evaluating whether components and systems will achieve their allocated reliability goals.

K3.1 Reliability Growth During Design

Charting component reliability growth during design involves plotting component failure rates, obtained from prototype testing and ongoing development work, over a period of years, beginning at the feasibility phase and continuing through the conceptual design phase (Figure K3-1). Steady improvement in component performance is indicated in the graph by the trend line. Failure to reach the reliability goal allocation would require compensation involving reliability and maintainability trade-offs in order to maintain the overall plant goal. The reliability growth results are combined with maintainability growth results (Appendix, Part L) and are input to the plant availability growth analyses. Analyzing reliability growth is most effective when performed during design of the plant.

K3.2 Reliability Growth During Operation

Typically, correction of infant mortality or "burn-in" failures during early plant operations results in reliability growth. This growth period is a learning process when initial defects in design and plant operational problems are recognized and corrected. The capability to monitor component performance during the design, prototype testing, and subsequent life cycle of the HRRF is required. Monitoring component reliability growth during the life cycle involves charting component failure rates observed over the plant lifetime and forecasting component and plant performance perturbations due to these observed changes in component performance.

Figure K3-1. Reliability Growth Analysis

K3.2.1 Failure Recognition and Reporting

Prompt detection and accurate reporting of component failures is necessary to establish component reliability performance. The failure report should include:

1. Component type and description
2. Time since last failure (best estimate)
3. Time of detection
4. Component failure mode
5. Location
6. Plant operation conditions at time of failure
7. Time the component was down before restoration or replacement
8. Any external or adverse environmental conditions that contributed to failure.

This information is organized and classified according to component and failure mode, failure cause, and operating history. This failure data is analyzed using conventional statistical techniques to establish component failure rates and is input to the reliability analysis.^{2,3}

K3.3 Evaluation of Reliability Growth Analysis Results

The information obtained during the reliability growth period is analyzed to forecast whether component reliability goals will be met, or to verify achievement of the reliability goals allocated during design. These analyses provide insights that may indicate what system improvements are most effective.

The results of reliability growth analyses during design allow the forecasting of plant reliability and availability.

The results of reliability growth analyses during design allow the forecasting of plant reliability and availability. Increases in component reliability performance observed during each design phase (engineering, prototype, etc.) result in increased plant availability or allow maintainability requirements to be relaxed with no sacrifice in plant availability.

Conventional reliability analysis predicts the reliability performance of the components and system from component failures reported during prototype testing. A component reliability importance analysis indicates which components yield the greatest benefit, increase in system reliability and availability, from upgrading the reliability of that component. These results also reflect possible design weaknesses which might benefit from the addition of redundancy, replacement with higher quality components, or improved maintainability.

K4.0 INTERACTION

K4.1 Integration Into Design

The REP must be an integral part of the overall HRRF design plan. The REP should interface with all activities during the design, construction, testing, and operational phases of the HRRF. This interface is accomplished primarily through the AEP. Acceptability of the design based on reliability (failure rate) criteria is established and input to the AEP and the licensing process.

In the event that the component does not meet its reliability goals, certain options exist:

1. Compensate the decrease in reliability by decreasing the component's mean downtime
2. Introduce some type of redundancy, installed spare, or hot standby, to effectively increase the reliability of the function performed by the original component
3. Re-evaluate plant design and/or plant availability allocation.

K4.2 Relation to Availability and Maintainability Engineering Programs

The results of the REP permit verification of an acceptable (achievable) failure rate and reliability performance characteristics for individual components. The interaction between the REP and the AEP and MEP is graphically illustrated in Figure K2-1. The REP interfaces with the availability engineering program to form an iterative process until acceptable and achievable component failure rates are determined. Once

these failure rates are verified, they are input to the plant availability analysis and verification segment of the Availability Engineering Program (AEP). The REP failure data is also input to the reliability growth analysis to monitor component development performance.

K4.3 Design Reviews

The REP is part of the design review activities. Reliability engineering techniques can be applied at any level of system design and can be useful for performing trade-off studies, demonstrating compliance with availability and safety requirements, and justifying system changes or additions. These reviews must follow the design review procedures established in Program Management Document P-017.

K5.0 EXAMPLE

The REP interacts extensively with the AEP and the MEP. The inputs to the REP are the components unavailability and failure rate goals (Section K2.0) from the initial availability allocation effort (Appendix, Part J, Section J2.2). Each component is evaluated individually to determine if these goals are achievable. The output of the REP is an achievable failure rate for each component and an allowable mean downtime for the component based on the achievable failure rate and unavailability goal.

This example problem considers the Size Reduction System in the Reprocessing Facility. The problem definition and initial unavailability allocation effort is discussed in the Availability Engineering Guideline (Appendix, Part J, Sections J5.1 and J5.2). The inputs to the Reliability Engineering Program, that is, unavailability and failure rate goals for each component in the example, are given in Table K5-1. Sections K5.1 through K5.3 describe the evaluation of the unavailability and failure rate goals for each component in the Size Reduction System.

K5.1 Primary and Secondary Crusher Evaluation

The Primary and Secondary Crushers are almost identical components and only one evaluation is necessary to describe both components. Available data for similar jaw type crushers indicate that a realistic and achievable value for the failure rate is $4 \times 10^{-5} \text{ hr.}^{-1}$. This value is acceptable in view of the failure rate goal specified in Table K5-1.

Figure K5-1. Screener Reliability Growth

TABLE K5-1
INITIAL UNAVAILABILITY AND FAILURE RATE GOALS
FOR THE EXAMPLE PROBLEM

Component	Unavailability Goal	Failure Rate Goal (hr. ⁻¹)
Primary Crusher	0.003	3×10^{-4}
Secondary Crusher	0.003	3×10^{-4}
Tertiary Crusher	0.002	2×10^{-4}
Screeners	0.010	3×10^{-3}

The maximum acceptable mean downtime for this failure rate and unavailability goal can be found from:

$$\tau = \frac{\bar{a}}{\lambda} \quad \text{K.4}$$

The maximum acceptable mean downtime for these components to meet the unavailability goal is 75 hours.

K5.2 Tertiary Crusher Evaluation

Available data for roller type crushers similar to the tertiary crusher indicate that an achievable failure rate is $1.4 \times 10^{-5} \text{ hrs.}^{-1}$. This value satisfies the failure rate goal for the tertiary crusher (Table K5-1). The maximum acceptable mean downtime for the tertiary crusher to meet its unavailability goal is 143 hours.

K5.3 Screener Evaluation

Available data for similar type screeners indicate that the achievable failure rate is $2 \times 10^{-2} \text{ hrs.}^{-1}$. This failure rate does not meet the failure rate goal specified by the AEP. With this failure rate, the unavailability goal can be met only if the mean downtime is less than 0.5 hours. If the MEP shows that this mean downtime is unachievable, reallocation of system unavailability or system design changes are necessary.

K5.4 Screener Re-evaluation

The AEP evaluation of the screener results indicate that the screener's failure rate goal is unachievable (Appendix, Part J, Section J5.3.3). The system unavailability goal is reallocated, and new unavailability and failure rate goals are specified for the screener (Appendix, Part J, Section J5.4). These new goals are input to the REP for re-evaluation. The screener re-evaluation involves determining the maximum allowable mean downtime for the known achievable failure rate and the reallocated unavailability goal. Substituting the reallocated parameters into Equation K.4 gives a maximum allowable mean downtime of 0.86 hours.

This information is input to the AEP (Appendix, Part J, Section J5.5) along with the MEP results (Appendix, Part L, Section L5.4) to determine the acceptability of the new unavailability profile.

K5.5 Reliability Growth Analysis

It has been determined from the availability analysis of the Size Reduction System (Appendix, Part J, Section J5.7) that the screening unit is a very important component with respect to availability. Simply, the screener's contribution to the Size Reduction System's unavailability is about 85%. Thus, the screener is recognized as being a component that may be selected for reliability growth studies.

Consider a case in which a single screener unit prototype is undergoing development and testing. The average failure rate observed from this testing over a period of years is decreasing (Figure K5-1). In

ract, the reliability goal (failure rate) of $2 \times 10^{-2} \text{ hr.}^{-1}$ is exceeded. The demonstrated failure rate of the single screener prototype is $1.8 \times 10^{-2} \text{ hr.}^{-1}$ (see Appendix, Part J, Section J5.6 for details of the redundant screening unit). This decrease in failure rate, combined with the results from the maintainability growth analysis (Appendix, Part L, Section L5.5), results in an increase in availability of the redundant screener unit. This availability growth results in subsequent increases in expected system, facility, and plant availability (Appendix, Part J, Section J5.7).

K6.0 DEFINITIONS

This section contains definitions of reliability engineering terms that may be useful in understanding many of the concepts used in the Reliability Engineering Guideline.

ALLOCATION--Apportionment of a portion of a goal or requirement to a component, system, facility, or plant.

ASYMPTOTIC UNAVAILABILITY--The steady-state value of unavailability reached by repairable items. The ratio of the mean downtime to the mean downtime plus the mean uptime.

AVAILABILITY (A)--The probability that the specified failure of an item does not exist at some specified time.

AVERAGE AVAILABILITY (INHERENT)--The integral average of the unavailability when the entity of interest does not operate only because of failures of the system components. The ratio of mean system uptime to mean system uptime plus mean system downtime, where mean downtime includes only unscheduled maintenance time and not administrative or accountability contributions.

AVERAGE AVAILABILITY (OPERATIONAL)--The ratio of mean system uptime to mean system uptime plus mean system downtime, where downtime includes all downtime contributions (MTTR, PM, LS, AD, etc.).

BASIC EVENT--A basic system component failure that defines the limit of resolution of the analysis. The dependence among basic events is treated in the common cause failure analysis.

BURN-IN PERIOD⁴--The early period of a component's life, usually distinguished by an above average failure rate that is due to initial weakness, defects, weak parts, bad assembly, etc.

COMPONENT--A basic system constituent for which failures are considered basic events during logic model construction.

EXPECTED NUMBER OF FAILURES--The statistically expected number of occurrences of a fault event during a specified time interval.

FAILURE RATE--The failure rate as a function of time is the probability of failure during t to $t + dt$, given no failures before t .

FAILURE RATE CURVE⁴--A graph of failure rate versus time, sometimes characterized by a "bathtub" shape. The initial decrease is the burn-in period. The failure rate is then sometimes nearly constant over some period of time before it begins to increase due to wear-out failures.

MAINTAINABILITY--The probability that a specified item will again function correctly at a given time after the instant the item began to malfunction.

MEAN DOWNTIME--The mean time a specific malfunction exists. The mean of the maintainability density function.

MEAN TIME TO FAILURE (MTTF)--The average time a component operates before experiencing failure.

QUALITY OF CONFORMANCE--The degree to which a product meets its design specifications.

QUALITY OF DESIGN--A product's inherent worth as defined by its component cost, manufacturing cost, and value in the eyes of the consumer.

QUALITY OF PERFORMANCE--A function of quality of design and quality of conformance, i.e., maintaining both at a high level will render a high quality of performance.

QUANTITATIVE ANALYSIS--Determining numerical reliability information, such as availability, reliability, expected number of failures, and mean time to failure, for a particular system failure from the reliability characteristics of the component of that system.

RATE OF FAILURE--The expected number of failures per unit time at time t .

REDUNDANCY--The practice of exceeding the capability requirement of a function by installing more items than required, such that the capability is maintained even if N items fail, where N is a property of the system design.

RELIABILITY--The probability that a specified item has experienced no failures during a specified time interval.

RELIABILITY CHARACTERISTICS--Time-dependent, probabilistic parameters that predict a system's failure behavior, e.g., reliability, availability, rate of failure, and expected number of failures.

RELIABILITY GROWTH--The reduced incidence of component failures indicating improving reliability, often observed as the life cycle of new equipment progresses from the early development stages to production and then operation.

RELIABILITY TESTING--Component testing designed to determine or verify component performance characteristics. Specifically, this testing involves verifying feasibility of allocated component failure site goals.

UNAVAILABILITY--The probability that the specified failure of an entity does exist at some specified time.

UNRELIABILITY--The probability that a specified item has experienced one or more failures during a specified time interval.

UPTIME--the time a component, system, or plant is available and operating.

WEAROUT PERIOD--The period of a component's life distinguished by an increased number of failures due to old age and deterioration.

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APPENDIX - PART L

MAINTAINABILITY ENGINEERING GUIDELINE

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L1.0 INTRODUCTION

Maintainability engineering is that portion of the design effort that is directed to limiting system downtime by minimizing component maintenance and repair time requirements.^{1,2} Maintainability is a characteristic of design and installation which is expressed as the probability an item will conform to specified conditions within a given period of time, when maintenance action is performed in accordance with prescribed procedures and resources.

Maintainability is a characteristic of design and installation which is expressed as the probability an item will conform to specified conditions within a given period of time, when maintenance action is performed in accordance with prescribed procedures and resources.

L1.1 Scope and Objective

This guideline specifies requirements for a comprehensive Maintainability Engineering Program (MEP) for the HTGR Recycle Reference Facility (HRRF) that involves both general considerations of overall plant design and specific assessments of component maintenance and repair characteristics. The objective of this guideline is to outline a series of steps for systematically incorporating maintainability engineering techniques throughout the HRRF design process. These steps include:

1. Component maintainability predictions as input to determining preliminary component specifications

2. Monitoring component performance and maintainability growth
3. Verifying achievement of maintainability goals
4. Overall management of the MEP.

This guideline must be used in conjunction with the Reliability Engineering Guideline (REG) to provide inputs to the Availability Engineering Program (AEP) described in the Availability Engineering Guideline (AEG) for the design and operation of the HRRF. This guideline is thereby directed toward component maintainability. However, because the AEG is based upon a tiered analysis concept, component maintainability can be considered system maintainability as the limit of resolution of the engineering effort is extended. The procedures and techniques addressed are applicable during feasibility studies, conceptual and final design phases, and throughout the operational life of the plant.

Maintainability Engineering Program (MEP) objectives support plant availability and overall performance goals.

The results of the procedures presented in this guideline will judge the acceptability of the component mean downtimes specified during the availability allocation effort as described in the AEG. If these specified component mean downtimes are found to be achievable, then these mean downtimes can be used in the remainder of the availability modeling and analysis. If the mean downtimes are judged to not be achievable, it

is necessary to reallocate the component mean downtimes. This iteration continues until achievable mean downtimes are determined.

L1.2 Required Inputs

The inputs to the MEP include:

1. Safety regulations
2. The proposed HRRF design and layout
3. The equipment (component) mean downtimes specified during the availability allocation effort
4. Special skills required for maintenance and repair
5. Feedback from the Availability and Reliability Engineering Programs
6. Remote maintenance considerations.

The specific values for these inputs may change as the design progresses through the conceptual design stage.

L1.3 Relation to Logistics Support

Integrated Logistics Support (ILS)³ is concerned with repair, maintenance and test procedures, personnel, parts, supplies, and the interaction of these factors with maintainability. Maintainability interfaces with logistics support (Appendix, Part M) in determining the overall availability of the plant, facility, system, or component. Maintainability is a characteristic of design which is expressed as the ability to restore equipment to some level of capability of conformance with specifications within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources.

There will be constant interaction between the MEP and the ILS program. Inputs to the logistics support analysis include:

1. Component corrective and preventive maintenance frequency
2. Maintenance requirements for dominant component failure modes
3. Plant operating profile
4. Component importance relative to the availability of the HRRF.

Various stages of the MEP will specify requirements for ILS. These requirements will be continuously revised based on results of the MEP, as well as other elements of the HRRF design process. ILS will provide information for the MEP in the form of what support will or will not be available.

L1.4 Organizational Requirements

Maintainability engineering should be planned and implemented as an integral part of the HRRF design effort. Maintainability engineering management will regularly review and evaluate the status and adequacy of the MEP. Maintainability engineering management must interface with all technical activities, design reviews, and ILS activities. Design changes based on maintainability considerations will be made by the Standing Committee (Appendix, Part B) under Subtask 930 of the National Program.

L2.0 MAINTAINABILITY ENGINEERING PROGRAM ELEMENTS

The technical elements of the Maintainability Engineering Program for the HRRF design project are discussed in this section. The MEP elements include:

1. Component mean downtime allocations
2. Determine preliminary component specifications
3. Verify component maintainability performance.

The results of these elements are used in conjunction with the results of the REP and the AEP to determine preliminary component specifications (Figure L2-1).

The technical elements of the MEP include the component mean downtime allocations, determination of preliminary component specifications, and verification of component maintainability performance.

Maintainability can be defined as the probability that an entity undergoes a successful repair over a specific time interval. Maintainability, $M(t)$, is a time dependent quantity and can be expressed exactly as,⁴

$$M(t) = \int_0^t r(t') dt' \quad L.1$$

where $r(t)'$ = density of time to repair.

t = time after the entity began to malfunction.

FIGURE L2-1. MAINTAINABILITY ENGINEERING PROGRAM.

In terms of the time dependent repair rate, $\mu(t)$, maintainability can be expressed as,

$$M(t) = 1 - \exp\{-\int_0^t \mu(t') dt'\} \quad L.2$$

where $\mu(t') =$ time dependent repair rate.

In practice, $\mu(t')$, is sometimes represented by its average value, μ , which is numerically equal to the inverse of the mean time to repair, MTTR. Then,

$$M(t) = 1 - \exp(-\mu t) \quad L.3$$

Often the mean time to repair is a small portion of the total downtime for a component.⁵ Other downtime contributions due to preventive maintenance, logistics support, and administrative actions may overshadow the MTTR. In this case, the exponential repair density assumption (Equation L.3) becomes invalid, and a more complex method for calculating $M(t)$ (Equations L.1 and L.2) must be used.

L2.1 Component Mean Downtime Allocation

Establishment of a numerical maintainability goal allows the analyst to judge whether the system is adequate with respect to repair policy or if design changes are advisable to improve maintainability. The overall maintainability goal is allocated to the individual system components, taking into account the system function, as well as system design. For maintainability engineering activities, these goal allocations take the form of component mean downtimes.

The availability allocation effort provides component availability goals. The component availability goal implies a component failure rate and mean downtime. The AEP provides preliminary component mean downtime. The MEP verifies component mean downtimes in order to assure that the goals of the AEP are met. Allowable component failure rates are specified in view of these achievable mean downtimes. These failure rates are the subject of the Reliability Engineering Program (REP).

L2.2 Determine Preliminary Component Specifications

The MEP provides technical justification for trade-off concerning support items considered in the Logistics Support Analysis (Appendix, Part M) as are required to achieve the preliminary component mean downtime. These support concerns include:^{6,7,8,9}

1. Maintenance procedures
2. Tools, testing, and diagnostic equipment
3. Maintenance scheduling
4. Provisioning
5. Personnel requirements
6. Testing.

Maintenance procedures include the documentation needed for performing corrective and preventive maintenance. Special tools, testing, and diagnostic equipment must be provided in adequate quantities. Maintenance allocation involves deciding what maintenance functions will be performed at a specific location (in plant or out of plant) with accompanying personnel and equipment requirements.

Provisioning involves specifying the type, number, and location of spare parts and other related support material. Personnel requirements are important, especially in case of failures requiring the repair of more than a single component. Sufficient numbers of repair crews must be available so that assumptions of independent repairs are valid and so that downtime due to lack of repair crew availability can be minimized. To assure prompt discovery of failed components and incipient failures, a comprehensive testing program is required.

More detailed discussion concerning these items and concerning trade-offs between maintainability and reliability factors is given in the Appendix, Part M. The results of the MEP are used to aid in establishing preliminary component maintainability specifications for the next design phase.

L2.3 Verify Component Maintainability Performance

Analyses with input that includes the support item information described in the preceding section are performed to predict the to predict the component's maintainability performance.^{10,11,12} Analyses utilizing historical repair data for identical or similar components can be used to check the predicted component maintainability performance. These efforts would be largely undertaken as subtasks of TASK 100, Studies and Analysis, within the HTGR Fuel Recycle Development Program.

Component repair data must be acquired for preliminary comparison with component downtime allocation. If component downtime allocated is optimistic:

1. Determine if reliability allocation has been met or exceeded from REP. If the reliability allocation has been exceeded, the component downtime requirements can be relaxed.
2. Reduce mean downtime through maintainability growth.
3. Perform trade-offs within AEP between component in question and components whose availabilities exceed allocation.

Maintainability testing and repair simulation of component prototypes aid in verifying component maintainability predictions.

L3.0 COMPONENT MAINTAINABILITY GROWTH

The ultimate goal of the MEP is to provide for and assess maintainability growth during the plant design and operating lifetime. Maintainability growth during plant design results from changing the placement of equipment in order to make it more accessible, or specifying a more easily maintained piece of equipment for a given function.

During the lifetime of the plant, maintainability growth will result primarily from maintenance personnel becoming more familiar with plant equipment and maintenance procedures. In addition, components that prove unsatisfactory from a maintainability standpoint can be upgraded or improved by installed spares, modular construction, or improved access.

Maintainability performance forecasts based upon design developments aid in evaluating whether components and systems will achieve their allocated maintainability goals.

Monitoring component maintainability growth involves charting the maintainability performance of components over a period of years from the feasibility stages of design, through the preconceptual, conceptual, and final stages, and during the operational life of the plant. Maintainability performance forecasts based upon design developments aid in evaluating whether components and systems will achieve their allocated maintainability goals. Analyzing maintainability growth during plant operation allows:

1. Forecasting capacity or throughput changes
2. Verifying achievement of maintainability goals set during design
3. Evaluating corrective maintenance concepts
4. Optimizing component preventative maintenance needs by identifying performance degradation trends.

Efforts to monitor the maintainability growth of HRRF components will be encumbered by the statistical nature of maintainability data and the limited experience with prototypical equipment.

L3.1 Maintainability Growth During Design

Charting component maintainability growth during design involves plotting component mean times to repair, observed from prototype testing and repair simulation work, over a period of years, beginning at the feasibility phase and continuing through the final design phase (Figure L3-1).

When analyzing progress toward a maintainability goal, attention should be placed on the rate of approaching the goal, as well as the "distance" away from the goal. A large slope indicating a high "speed of approach" is likely to be seen during the initial stages of design and testing. As the component matures and maintenance requirements become more well defined, the slope of the trend line may become horizontal. If the trend line has leveled off before reaching the desired maintainability goal, then appropriate trade-offs with reliability must be made in order to achieve the desired overall availability goal.

Figure L3-1. Maintainability Growth Analysis.

The maintainability realized in the HRRF can be substantially different from that measured from prototypical equipment because of factors that include logistics downtime. Remote maintenance may reduce some of the logistics downtime. However, being dependent on remote maintenance equipment also has drawbacks which require other trade-offs with regard to availability because of potential malfunctions in the remote maintenance equipment itself. In any event, the maintainability growth studies during design are intended to indicate progress toward achieving an allocated mean downtime.

L3.2 Maintainability Growth During Operation

Generally, correction of maintenance policy and logistics support deficiencies during plant operation result in maintainability growth. The capability to monitor maintenance performance during operation is required. Monitoring component maintainability growth during the life cycle involves charting component mean downtimes, observed over the plant lifetime, and forecasting component and plant performance perturbations due to these observed changes in component maintenance performance.

L3.3 Evaluation of Maintainability Growth Analysis Results

Maintainability growth efforts should focus primarily on those maintenance and repair actions which have been shown to be most important by the AEP. These actions will be closely monitored, and any economically attractive methods to reduce maintenance and repair times

will be employed. Actual component downtimes should be recorded for all component failures.

Adjustments must be made to the maintenance and repair policy as experience with plant equipment is gained. Improvements in technique, as well as equipment, may increase component maintainability. Unnecessary maintenance actions are phased out, and other maintenance actions are initiated if it is determined that plant availability will be improved as a result.

Assessments of the maintainability performance are necessary to determine the effects of the maintainability growth effort. Increases in component maintainability during pre-operational testing and on-going development may increase plant availability or may allow increases in component failure rates without decreasing plant availability.

L4.0 INTERACTION

L4.1 Integration Into Design

The MEP must be an integral part of the overall HRRF design plan in order to maximize the benefits from the availability engineering activities. The MEP should interface with all activities during the design, construction, testing, and operational phases of the HRRF. This interface is accomplished primarily through the AEP. Acceptability of the design based upon component maintainability (mean downtime) criteria is established and input to the AEP and the logistics support analysis (Appendix, Part M).

In the event that the component does not meet its maintainability goals, certain options exist:

1. Compensate for the increased mean downtime by decreasing the component failure rate.
2. Improve component maintainability through better logistics support.
3. Re-evaluate plant design and/or plant availability allocations.

L4.2 Relation to Availability and Reliability Engineering Programs

The results of the MEP permit verification of an acceptable (achievable) mean downtime and maintainability performance characteristics for individual components. The interaction between the MEP and the AEP and REP is graphically illustrated in Figure L2-1. The MEP interfaces with the availability allocation effort to form an iterative process until

acceptable and achievable component mean downtimes are determined. Once these mean downtimes are verified, they are input to the plant availability analysis and verification segment of the AEP. The MEP interacts with the REP so that acceptable failure rate-mean downtime pairs are provided to the AEP. The MEP results are also input to the maintainability growth analysis to monitor component maintenance performance.

L4.3 Design Reviews

The MEP is part of the design review activity. Maintainability engineering techniques can be applied at any level of system design and can be useful for performing trade-off studies, demonstrating compliance with availability and safety requirements, and justifying system or maintenance policy changes or additions. These reviews must follow the design review procedures established in Program Management Document P-017.

L5.0 EXAMPLE

The MEP interacts extensively with the AEP and REP. The inputs to the MEP are the components unavailability and mean downtime goals (Section L2.0) from the availability allocation effort. Each component is evaluated individually to determine if these goals are achievable. The output of the MEP is an achievable mean downtime and allowable failure rate for each component based on the achievable mean downtime and unavailability goal.

This example problem considers the Size Reduction System in the Reprocessing Facility. The problem definition and initial unavailability allocation effort is discussed in the Availability Engineering Guideline (Appendix, Part J, Sections J5.1 and J5.2). The inputs to the Maintainability Engineering Program, that is, unavailability and mean downtime goals for each component in the example, are given in Table L5-1. Sections L5.1 through L5.3 describe the evaluation of the unavailability and mean downtime goals for each component in the Size Reduction system.

L5.1 Primary and Secondary Crusher Evaluation

The Primary and Secondary Crushers are similar components and are considered identical for maintenance purposes. Available data for similar jaw type crushers indicate that an achievable value for the mean downtime is seven hours. This value is acceptable in view of the mean downtime goal specified in the AEP. The maximum acceptable failure rate

TABLE L5-1
INITIAL UNAVAILABILITY AND FAILURE RATE GOALS
FOR THE EXAMPLE PROBLEM

Component	Unavailability Goal	Mean Downtime Goal (hrs.)
Primary Crusher	0.003	10
Secondary Crusher	0.003	10
Tertiary Crusher	0.002	10
Screeners	0.010	4

for this mean downtime and the unavailability goal can be found from

$$\lambda = \frac{\bar{a}}{\tau} \quad \text{L.4}$$

The maximum acceptable failure rate for these components to meet the unavailability goal is $4.3 \times 10^{-4} \text{ hr.}^{-1}$.

L5.2 Tertiary Crusher Evaluation

No data were available for roller type crushers similar to the Tertiary Crusher. However, based on knowledge of the component and engineering judgement, 14 hours is considered to be an achievable mean downtime. This value does not satisfy the mean downtime goal specified in the AEP. With this mean downtime, the unavailability goal can be met only if the component failure rate is less than $1.4 \times 10^{-4} \text{ hrs.}^{-1}$. If the REP shows that this failure rate is unachievable, reallocation of system unavailability or system design changes are necessary (Appendix, Part J, Section J2.4).

L5.3 Screener Evaluation

No data were available on the maintenance characteristics of screeners similar to the screener envisioned for the Size Reduction System. However, a mean downtime of four hours is considered achievable, based on engineering judgement. This value of the mean downtime satisfies the mean downtime goal specified in the AEP (Table L5-1). The maximum acceptable failure rate for the screener to meet its unavailability goal is $2.5 \times 10^{-3} \text{ hr.}^{-1}$.

L5.4 Screeners Re-evaluation

The AEP evaluation of the REP and MEP results indicate that the screener's unavailability goal has not been met (Appendix, Part J, Section J5.3.3). Even though the screener's mean downtime goal was met (Section L5.3), the screener must be re-evaluated in terms of the reallocated unavailability goal (Appendix, Part J, Section J5.4). The screener re-evaluation involves determining the maximum allowable failure rate for the known achievable mean downtime and the reallocated unavailability goal. Substituting the reallocated parameters into Equation L.4 gives a maximum allowable failure rate of $4.3 \times 10^{-3} \text{ hr.}^{-1}$.

This information is input to the AEP (Appendix, Part J, Section J5.5) along with the REP results (Appendix, Part K, Section K5.4) to determine the acceptability of the new unavailability profile.

L5.5 Maintainability Growth Analysis

The screening unit is an important component with respect to availability (see the Appendix, Part J, Section J5.7). This is a factor that may be considered when selecting components for prototypical development and subsequent maintainability growth analysis.

Consider in this example a single screener unit that is undergoing development and testing. The mean downtime observed from repair simulation over a period of years is decreasing (Figure L5-1). The observed mean downtime has surpassed the original maintainability goal of four hours. The maintainability growth combined with similar reliability growth (Appendix, Part K, Section K5.5) results in an increase in the redundant screener unit availability. This increase, over the original

Figure L5-1. Screener Maintainability Growth

allocation, affords an increase in system, facility, and plant availability (Appendix, Part J, Section J5.7).

L6.0 DEFINITIONS

This section contains definitions of maintainability engineering terms that may be useful in understanding many of the concepts used in the Maintainability Engineering Guideline.

ALLOCATION--Apportionment of a portion of a goal or requirement to a component, system, facility, or plant.

AVAILABILITY (A)--The probability that the specified failure of an item does not exist at some specified time.

BASIC EVENT--A basic system component failure that defines the limit of resolution of the analysis. The dependence among basic events is treated in the common cause failure analysis.

BURN-IN PERIOD⁴--The early period of a component's life, usually distinguished by an above average failure rate that is due to initial weakness, defects, weak parts, bad assembly, etc.

COMPONENT--A basic system constituent for which failures are considered basic events during logic model construction.

COMPONENT UNAVAILABILITY IMPORTANCE--The probability that the basic event failure is contributing to the TOP event failure at some specified time in the future, given the TOP event is failed.

CORRECTIVE MAINTENANCE--Maintenance performed to correct a failed component, and unscheduled activity.

DOWNTIME--The time a component or system is down due to corrective or preventive maintenance, logistic support delays, or delays due to accountability and quality control.

EXPECTED NUMBER OF FAILURES--The statistically expected number of occurrences of an event during a specified time interval.

FAILURE RATE--The failure rate as a function of time is the probability of failure during t to $t + dt$, given no failures before t .

FAILURE RATE CURVE⁴--A graph of failure rate versus time, sometimes characterized by a "bathtub" shape. The initial decrease is the burn-in period. The failure rate is then sometimes nearly constant over some period of time before it begins to increase due to wearout failures.

MAINTAINABILITY--The probability that a specified item will again function correctly at a given time after the instant the item began to malfunction.

MAINTAINABILITY ENGINEERING--The segment of the engineering discipline that is directed towards improving repair and maintenance action performance to minimize system downtime and support requirements.

MAINTAINABILITY GROWTH--The reduced time required to perform maintenance on a component indicating improving maintainability, often due to personnel becoming more familiar with required maintenance tasks, tools and procedures, and better logistics support.

MAINTAINABILITY TESTING--Component maintenance testing designed to determine or verify component maintenance time and support requirements. Specifically, this testing involves verifying feasibility of allocated component mean time to repair goals.

MEAN DOWNTIME--The mean amount of time an item is inoperative.

MEAN TIME BETWEEN FAILURE (MTBF)--The mean time between failures, including operating time and repair time contributions.

PREVENTIVE MAINTENANCE--Scheduled maintenance performed on an item for the purpose of extending the component's useful life and reducing unscheduled maintenance.

QUALITY OF CONFORMANCE--The degree to which a product meets its design specifications.

QUALITY OF DESIGN--A product's inherent worth as defined by its component cost, manufacturing cost, and value in the eyes of the consumer.

QUALITY OF PERFORMANCE--A function of quality of design and quality of conformance, i.e., maintaining both at a high level will render a high quality of performance.

RELIABILITY--The probability that a specified item has experienced no failures during a specified time interval.

REPAIR RATE--The repair rate is the time-dependent probability of repair during t to $t + dt$, given no repair from the time the malfunction began to t .

SUPPORT EQUIPMENT--Items and supplies that are necessary for the operation and/or maintenance of the component or system but are not physically part of the component or system.

UNAVAILABILITY--The probability that the specified failure of an entity does exist at some specified time.

UNRELIABILITY--The probability that a specified item has experienced one or more failures during a specified time interval.

UPTIME--The time a component, system, or plant is available and operating.

WEAROUT PERIOD--The period of a component's life distinguished by an increased number of failures due to old age and deterioration.

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APPENDIX - PART M
LOGISTIC SUPPORT ANALYSIS

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M1.0 INTRODUCTION

Two categories of logistics considerations would need to be evaluated during the development of a conceptual design for the HRRF. The logistics support analysis would consider the logistics requirements 1) arising from hardware support, and 2) due to the transportation, handling, and storage of materials.

Logistics requirements for the HRRF project would result from two sources: 1) hardware support and 2) transportation, handling, and storage of materials, which includes the requirements for buffer storage and supply storage provisions for the fuel materials, process-related materials, and waste materials.

The Transportation, Handling, and Storage of Materials Analysis (THSA) would consider the requirements for buffer storage and supply storage provisions for the fuel materials, process-related materials, and waste materials. The considerations would include the movement to and from the HRRF plant (Level 0), the movement between facilities in the plant (Level 1), and the movement between systems in a facility (Level 2). The various interface and functional requirements for this analysis are discussed in Section M5.0 in this guideline.

Logistics Support Analysis (LSA) would interface with maintainability in determining the overall availability of the plant, facility, or system. Additionally, logistics support analysis is the process used to arrive at engineering decisions concerning equipment support and to

evaluate logistic influences on design. The support items considered include:

- Maintenance Procedures
- Tools, test and diagnostic equipment
- Maintenance Allocation
- Provisioning
- Personnel Requirements
- Testing

The major interfaces to be considered include reliability, maintainability, device design, human factors, and safety. Through careful examination of the design options provided for each system functional delineation, the logistics support functions necessary to support that option can be identified and adequately evaluated with regard to the established criteria. The examination of these design options would identify the functions necessary to accomplish logistics support, the level at which the support functions take place, and the accommodations that would be made in the design process in order to accept the new support system.

The logistic support requirements would be determined by the maintenance concept adopted for the facility. In this guideline, three maintenance concepts are examined and are applied for the fuel element size-reduction system. The logistic support analysis is discussed in Sections M2.0, M3.0, and M4.0 in this guideline.

M1.1 Integrated Logistics Support

Integrated Logistics Support (ILS) is the overall planning process designed to provide timely and effective support of systems and equipment based on the concept that cost and adequacy of support are equal to those of the end item. The process would require continual decisions through all phases of the system design and represents the integration of Reliability, Availability, Maintainability (RAM) and Logistics considerations. This guideline forms one part of the Integrated Logistics Support Analysis needed for the HRRF conceptual design.

The major items for consideration under the Integrated Logistics Support (ILS) include:

- Cost effectiveness
- Relationship of functional design to maintainability and cost

The current technical environment provides for new innovations and multimillion dollar equipment, significantly increasing the importance of equipment downtime. The cost of maintenance has been shown to often exceed the system acquisition cost. Also, a large percent of the acquisition cost is for maintenance related support equipment, which is defined as tools, test equipment, technical data, repair parts and facilities. Thus, it is highly desirable to maximize time-between-failures and to minimize time-to-repair. (See Appendix, Part K.)

In the process of system engineering and development, the design requirements would consider the reliability and maintainability goals, which in turn, determine the logistics support requirements. Any

improvement in these areas would normally have an accompanying positive impact on safety. Since design improvements usually shorten or improve efficiency of processes, safety would be a prime consideration.

M1.2 Scope and Objectives

The Logistics Support Analysis Guideline is designed to provide a general method for integrating logistics requirements in the HRRF plant design. Input from the logistics engineering group would be used during both the requirements assessments and systems synthesis analyses.

This logistic guideline considers both the movement of material to and through the plant and the support of equipment in the plant. The methodology outlined provides for a comparison of various support concepts with a baseline spectrum between availability and cost.

M1.3 Organizational Requirements

Logistics support analysis would be performed by a logistics engineering group that is part of the larger specialty engineering group. The logistics engineers would work closely with the reliability, maintainability, and availability engineering groups. The logistics input would provide one element of the Integrated Logistics Support Analysis.

M2.0 INTEGRATED LOGISTICS SUPPORT FUNDAMENTALS

Before addressing the key issue of Maintenance Allocation, a short description of the basic principles associated with elements of ILS is needed. The items described represent the more significant elements of the logistics process when considering equipment support.

Support Planning

Support planning refers to the management technique designed to ensure that all elements necessary to support HRRF during its life cycle are considered.

Maintenance Planning

The maintenance concept for the HRRF plant will be influenced significantly by the logistics support requirements and by the cost of the logistics needed to meet the availability requirements of the elements being analyzed. Thus, the maintenance planning function must address each element of the maintenance support structure to ensure an economic and technically efficient balance.

Repair Parts

This item represents or can be identified as one that can be separated from an assembly or other parts. The concept of repair parts is related to the operational readiness of HRRF equipment with downtime being the key factor.

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Personnel and Training

This element pertains to the identification of requirements for equipment operators, maintenance personnel, training and documentation to support HRRF.

To determine requirements to satisfy these needs, it is first necessary to perform those analyses that will identify:

- How will the equipment be operated?
- What maintenance will be performed and where?
- What tools and test equipment will be utilized?
- What parts will be located where?

From these analyses, skill levels and documentation requirements can be established which determines the personnel requirements, documentation preparation, and training needs.

Reliability, Availability, and Maintainability (RAM)

The RAM framework is an integral part of a system development process by which required levels of effectiveness are achieved and maintained at minimum cost throughout the total life of the system. The effectiveness of the system will vary according to the reliability and maintainability. Since reliability can be increased mainly during the development phase, continuous efforts must be applied to achieve maturity and preclude excessive cost and downtime in the follow-on operation phases.

Significant actions during the development phase include:

- Analysis of component and system MTBR and MTTR.
- Establish failure definitions.
- Strive to develop firm numbers to replace initial estimated values.
- Establish test patterns to evaluate RAM improvements stemming from a fixed program. (See Appendix, Part K.)

Testing

The common denominator for performance during all life cycle phases is testing. Performance, reliability, and the resulting cost can all be evaluated through proper testing. Test planning brings together the thoughts and needs of engineers, quality, test, and support personnel. An important part of a test program is the establishment of "fault analysis" procedures. A strict criterion should be established and adhered to for the evaluation of any fault (see Appendix, Part L).

M3.0 METHODOLOGY FOR LOGISTICS SUPPORT ANALYSIS

M3.1 Introduction

The logistic concept for the HRRF conceptual design would be influenced significantly by the support requirements, the cost of high availability, the overall cost of ownership, and safety. The approach for defining a viable logistics support would require a full component analysis with appropriate trade-offs. The results would be an economic balance of skilled personnel, support equipment and spares.

The methodology associated with the hardware analysis would be keyed to an investigation of the system major items, assemblies, and sub-components, in terms of mean-time-between-failures (MTBF) and mean-time-to-repair (MTTR).

The methodology associated with this analysis would be keyed to an investigation of the system major items, assemblies, and sub-components, in terms of mean-time-between-failures (MTBF) and mean-time-to-repair (MTTR). With this data available, the HRRF support structure can be established and examined under the varying conditions of personnel, tools/equipment and parts/assemblies and the logistics requirements can be analyzed.

The maintenance structure and product would be designed to depict what maintenance will be accomplished at what level of support and with what assets.

M3.2 Maintenance Support Structure

The general maintenance support structure utilized in this guideline is shown in Figure M3-1. The degree of maintenance and the related logistics support requirements to be performed at each of the three levels depicted in the figure will emerge from the evaluation of the logistics support factors including tools, test equipment, transportation cost, repair parts, and training and documentation.

Figure M3-1. General Maintenance Support Structure

M3.3 Logistics Support Analysis

The analysis of each support concept to be considered must follow a procedure that establishes the degree of support required at each level which can be translated into cost and time. The steps required for HRRF support application can be addressed in terms of onsite versus offsite maintenance and consider the following items:

- Parts supply required
- Assemblies supply required

- Tools
- Test equipment
- Personnel training
- Documentation
- Transportation
- Facilities
- Repair time

A cost can be identified for each HRRF support concept as derived from the above required functions. However, these costs must then be balanced against those other important factors which are required in a complete analysis, including equipment downtime, safety, and human factors.

The trade-offs that emerge between various maintenance concepts for hardware support will center around minimized downtime and associated cost.

The trade-offs which will emerge center around minimized downtime and associated cost. A system with built-in-test-equipment (BITE) and storage of assemblies at the operational site with mini-skilled maintenance technicians will provide for a minimum downtime condition. However, cost of spare assemblies, transportation and contractor repair cost will normally be high. At the other end of the spectrum is full repair onsite, calling for high density parts storage, highly skilled technicians and extensive test equipment. Under this condition contractor support and space assembly and transportation cost will be low. However, downtime will be longer.

A summary of the logistics support analysis logic is shown in Figure M3-2. The primary input is from the maintainability analysis. The results from the logistics support analysis will provide one input to the Integrated Logistics Support Program and will aid in the determination of the optimal maintenance concept.

M3.4 Maintenance Allocation (Failure Rate and Time-to-Repair Analysis)

The allocation of maintenance into functions, location, and personnel and equipment (tools and test gear) is determined through the reliability and maintainability analysis. For each system/sub-system that is being evaluated, the information necessary for the logistics support analysis includes the component under consideration and the associated failure rate, module involved, method of detection, and time to detect.

Once the failure rate analysis has been accomplished, the time-to-repair becomes the remaining critical element to the system availability analysis. In this case, the logistics support analysis requires the time estimates for fault isolation, replace/repair, and checkout for each component of the system. (See Appendix, Part K.)

A significant output of the repair analysis is the data generated to support repair-in-place versus direct exchange decisions. Based on this data, the trade-off between downtime versus cost of spare equipment can be evaluated. The MTBF and MTTR output of the repair analysis also provides the basis for organization of the maintenance concepts. The approach is through the establishment of selected support structures and the evaluation of a matrix of factors having impacts in both cost and time.

FIGURE M3-2. LOGISTICS SUPPORT ANALYSIS.

LOGISTICS SUPPORT ANALYSIS

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M3.5 Support Alternatives

Three maintenance support alternatives are appropriate for investigation in support of the HRRF. The first alternative is to provide maximum repair onsite. The second alternative is to replace a defective assembly onsite, but repair the assembly at the facility. The third alternative is to ship all defective assemblies to an equipment vendor for repair.

Each of these three concepts would be examined under the varying conditions of personnel, equipment, and parts. A comparative analysis would then be performed, considering trade-offs, to arrive at the most viable support structure.

The three maintenance support concepts considered in this guideline are:

- Concept A. Repair of equipment in-place by resident maintenance (remote and/or contact).
- Concept B. Replacement of a major item, with repair at the HRRF plant by resident maintenance.
- Concept C. Replacement of a major item by resident maintenance, with the vendor repairing the item at his facility.

The pertinent logistics functions would be identical for each maintenance support concept for the particular failure mode under consideration. The logistics functions can be identified through the use of a form as shown in Figure M3-3. The required logistics data would then be documented in the body of the form for each maintenance support item. An analysis of the required logistic support functions for the failure mode

under consideration will provide an indication of the differences in support necessary for each of the maintenance concepts.

Another useful method for presenting the HRRF support requirements in detail is through the use of a Maintenance Allocation Chart (MAC) as shown in Figure M3-4. A presentation of this type will depict each item that can be repaired and show at what level in the support structure specific maintenance functions will be accomplished. This format could be expanded to include personnel skills, parts, and specialized equipment required.

When the total maintenance allocation has been completed for all items, an analysis can be conducted to determine the requirements of each concept for:

- personnel skills,
- parts/assemblies, and
- tools/test equipment, etc.

Once these requirements are identified, the information can be converted to dollars and analyzed with other operational impacts. This information could be summarized on a form such as that shown in Figure M3-5. The body of the form would be a compilation of the cost information compiled from the requirements detailed on the Maintenance Allocation Chart.

The total information in the body of Figure M3-5 would provide sufficient data to permit an evaluation of the relationship of the logistics support analysis to the design process. Other considerations

include the associated human factors and safety. In summary, this guideline provides for the relevant management decision factors (cost-design, RAM, safety, human factors), permitting design and logistics adjustments with only one fixed factor, safety.

Concepts			
Maintenance Support Items	In-Place Support Remote/Contact	Plant Support	Vendor Support
Operator Training			
In-Place Maintenance			
Tools			
Test Equipment			
Repair Parts			
Documentation/Manuals			
Transportation			
Personnel Skill			
Provisioning (Assemblies)			

Figure M3-3. Logistic Functions.

Concepts			
Equipment	In-Place Support Remote/Contact	Plant Support	Vendor Support
Crusher*			
Pitman Outboard Bearing			
Screener			
Motor			
Crusher**			
Pin Joint			

(Fill in applicable)
repair or exchange entry.)

*Primary or secondary jaw crusher.

**Pitman/toggle connection on primary and secondary jaw crushers.

Figure M3-4. Maintenance Allocation Chart.

Cost Analysis for Logistic Support			
Requirements Categories	Maintenance Concepts		
	A	B	C
Personnel (Skills-Training)			
Tools-Test Equipment			
Manuals			
In-Place			
Facility			
Vendor			
Transportation			
Downtime			
Provisioning			
Parts			

Figure M3-5. Cost Analysis for Logistics Support.

M4.0 METHODOLOGY FOR TRANSPORTATION, HANDLING, AND STORAGE OF MATERIALS

The HRRF design effort should consider the requirements of transportation and materials handling. These requirements would address the external interfaces for the HRRF plant and the interfacility and intra-facility (system) interfaces within the plant. The requirements would result from the buffer and supply storage provisions necessary to support fuel materials, process-related materials, and waste materials. Figure M4-1 summarizes these various interface and functional requirements.

The requirements for transportation, handling, and storage of materials (THS) would address the external interfaces for the HRRF plant and the interfacility and intrafacility (system) interfaces within the plant and would result from the buffer and supply storage provisions necessary to perform these functions.

The analysis approach to the assessment of the materials transportation, handling, and storage requirements and the evaluation of design options would follow closely the method described in Section M3.0 for the logistics support analysis. First, the HRRF plant would be viewed as a total system to identify the parameters associated with the receipt and shipment of spent and reprocessed fuels and supporting material. The second step would be to identify the parameters associated with the expected throughput received and released from each facility. Next, the

FIGURE M 4-1. INTERFACE AND FUNCTIONAL REQUIREMENTS.

individual systems within each facility would be analyzed from the standpoint of input and output of material.

The above analysis would closely parallel the functional analysis at each level of design detail but with major emphasis being placed on the material flows and rates. The initial analysis would concentrate on the product, e.g., the spent and reprocessed fuel, at all stages. The reason for this concentration is that the quantities and rates of the supporting process materials and waste streams would be a function of the product process rates.

After the end-to-end block diagrams have been developed for the receipt, in-process handling and storage, and shipment of the product, the next step would be to define the receipt, in-process storage and handling, and shipment of process-related materials and process-generated waste materials. The functional analysis methodology would be applicable, but in reverse order. The requirements of the lowest level functional block diagram elements would be defined in terms of input and output of process-related materials and wastes. These parameters would then be summed to higher levels of operation; first, to the individual facility and second, to the HRRF plant.

The fuel products, process materials, and waste flow diagrams would then be analyzed to define the mismatched interface requirements, e.g., the output from the first stage process--a batch process--may not equal the input rate of the second stage. Where this occurs, the design should provide for in-process surge storage. The problems of material control and criticality would be considered in developing the required

design options. At the plant level, the input to all subordinate level equipment would be analyzed to determine if single or multiple support systems would be necessary for process materials. In the same manner, the waste outputs of the various facilities and systems would be analyzed to determine if a single storage system would suffice.

Once the quantity and rate balances have been defined, including sufficient sensitivity analysis to ensure that the system will support unexpected surges and logical accidents, the problems associated with safety, security, property control, and operating procedures would be addressed. This process is summarized in Figure M4-2.

FIGURE M4-2. TRANSPORTATION, HANDLING, AND STORAGE OF MATERIALS.

M5.0 INTERACTION

The impact of logistics requirements on design is keyed to down-range cost. The ILS objective is to achieve a proper balance between operational capabilities, logistic requirements and economic factors.

The logistics support analysis interacts with the availability, reliability, maintainability, and safety areas to form the Integrated Logistics Support package. The analysis proceeds with input from the maintainability analysis. Transportation, handling, and storage of materials would be a part of the requirements assessment and the trade studies. The choice of an optimal set of processes, process, and unit operations would involve these considerations. Information on unit operations and site layout would be needed as input for this analysis.

M6.0 EXAMPLE

The example chosen for this guideline will represent the use of logistic support analysis. The logistics support analysis will be considered through an examination of the size reduction system of the re-processing function. The relationship of the system design and each logistics element will be addressed to provide insight to cost, reliability and safety trade-offs. For the purpose of the example used herein, the functional elements of the system are defined as Primary Crusher, Secondary Crusher, Tertiary Crusher, Screener, and Oversize Pulverizer.

Maintenance Allocation

The division of maintenance as to what functions will be performed at what location and with what personnel and equipment (tools and test gear) is determined by the reliability and maintainability studies. In the case of the HRRF crusher equipment, the failure modes are created around bearings overheating, motor failures, and material separation. A "mean time between failures" analysis would be conducted by listing each of the five (5) crusher components and their failure rate and percent of total system failure. (See Table M6-1.) This will provide an insight to the mean time between failures for the total crusher system and to the major contributing components.

TABLE M6-1
FAILURE RATE ANALYSIS

Crusher Assembly	Failure Rate	% of Total	Module Involved	Method of Detection	Time to Detect
1. Primary Crusher					
2. Secondary Crusher					
3. Tertiary Crusher					
4. Screener					
5. Oversize Pulverizer					

When the failure rate analysis has been accomplished, time-to-repair becomes the remaining paramount factor to the system availability analysis. Once again, the five (5) major components of the system are examined. This time each component is analyzed for cause-of-failure and method and time-to-repair.

TABLE M6-2
TIME-TO-REPAIR ANALYSIS

Crusher Assembly	Time Fault Isolation	Time Replace/Repair	Time Checkout
1			
2			
3			
4			
5			

The following example utilizes the three maintenance concepts previously described, with emphasis placed on concepts A and C. The maintenance functions to be considered are:

1. The pitman outboard bearing will be repaired with the equipment in place.
2. The pitman assembly will be replaced and the bearing repair accomplished by the contractor at his facility.

A layout of the pertinent logistic functions would be as follows:

CONCEPT "A"

	In-Place Support (Contact)	Facility Support	Vendor Support
Operator Training	A. Isolate cause B. Assist onsite maintenance	-----	-----
Onsite Maintenance Training		Remove & replace bearing	
Tools	Adj. tools only	Those necessary for bearing replacement	*
Test Equipment	BITE	Special & Common for jaw and bearing	*
Repair Parts	Common hardware lubes	Select bearing items based on MTBF analysis	*
Documentation/ Manuals	Preventive	Total maintenance and assembly procedures for bearing replacement	*
Transportation	-----	Movement of replace- ment parts only	-----
Personnel	Operators to include BITE	Equipment specialist for crusher (in-depth knowledge-parts)	*
Provisioning (Assemblies)	None	Sub-Assemblies/major components for crusher per MTBF analysis	

CONCEPT "C"

	<u>In-Place Support (Contact)</u>	<u>Facility Support</u>	<u>Vendor Support</u>
Personnel	Operators to include BITE	Major Assembly knowledge only	Total system specialist
Operator	A. Isolate cause B. Assist in jaw replacement		Rebuild training crusher jaw
Onsite Maintenance Training	-----	Exchange major item (Pitman Assembly)	
Tools	Adjustment tools only	Pitman Assembly items only	Total spectrum for bearing replacement
Test Equipment	BITE	Limited Assembly testers (Pitman Assemblies)	Special for bearings and jaws
Repair parts	Common hardware and lubes	Emergency items only per MTBF	Total coverage for bearing and jaw
Documentation/Manuals	Preventive maintenance only	Procedures for jaw replacement	Total crusher procedures
Transportation	-----	Movement of jaw assembly	Movement of replacement jaw
Provisioning	None	Major Assemblies i.e., jaw per MTBF	Total spectrum to include bearings and parts

A summary analysis of concepts "A" and "C" reveals a significant difference in logistic requirements in basically all areas. However, in general, if Concept "C" is used, the onsite logistics requirements are reduced to meeting only a major assembly exchange which in turn requires the minimum capability in terms of personnel abilities, repair parts, tools and documentation.

An example of the Maintenance Allocation Chart for the HRRF Size Reduction System is shown below.

Concept			
	In-Place Support Remote/Contact	Plant Support	Vendor Support
Crusher			
Pitman Assembly	Replace	-----	-----
Pitman Outboard Bearing	Replace	-----	Repair
Screeners			
Motor	Replace	-----	Repair
Crusher			
Pin Joint	Repair	-----	-----

When the total MAC for all equipment and operations has been completed, an analysis would be conducted to determine the requirement of each concept for:

- personnel skills,
- parts/assemblies, and
- tools/test equipment, etc.

Table M6-3 compares the logistic requirements of Concepts "A," "B," and "C." Concept "B" has not been fully addressed since the only significant difference between it and Concept "A" is that the jaw is removed and replaced but still repaired onsite.

When the relationships shown on Table M6-3 are converted to dollars and analyzed with other operational impacts, logical decisions can be obtained. Table M6-4 presents an example of such a presentation.

Table M6-4 provides sufficient data to permit an evaluation of the logistic and design relationship. The other factors which also present considerations at the same time are human factors and safety. In summary, the management decision factors (cost-design, RAM, safety, human factors) are present permitting design and logistic adjustments with only one - SAFETY - being fixed.

This presentation of ILS has addressed only one component of the crusher assembly. Thus, the total ILS program will require such an evaluation for each major component of the recycle process equipment.

TABLE M6-3
MAINTENANCE CONCEPT REQUIREMENTS

	A	B	C
Personnel (Skill & Training)			
Operator	-	-	-
Onsite	+	+	-
Contractor	+	+	+
Tools & Test Equipment			
Operator	-	-	-
Onsite	+	+	-
Contractor	+	+	+
Documentation			
Operator	-	-	-
Onsite	+	+	-
Contractor	+	+	+
Provisioning (Assemblies)			
Operator	-	-	-
Onsite	-	+	-
Contractor	+	+	+
Parts			
Operator	-	-	-
Onsite	+	+	-
Contractor	+	+	+

(- Minimum; + Maximum)

TABLE M6-4
MAINTENANCE CONCEPT SUMMARY

	Concept Cost		
	A	B	C
Cost			
Personnel (Skills-Trng.)			
Tools-Test Eq.			
Manuals			
Operator	Low	Low	Low
Onsite	High	High	Low
Contractor	Low	Low	High
Transportation	Low	Low	High
Downtime	High	Low	Low
Provisioning	Low	High	High
Parts	High	High	Low

M7.0 DEFINITIONS

ANNUAL SUPPORT COST (ASC)--This is the direct annual cost of maintenance personnel, repair, parts and transportation for all corrective (either on-system, off-system, or both) and preventative maintenance actions.

CRITICAL ITEM--Any part or item that (1) prevents satisfactory operation of the system or creates unwarranted safety hazards if it fails to function, (2) is sufficiently complex to warrant special production techniques or controls, (3) requires special treatment or handling during transport or storage, (4) imposes a heavy maintenance and supply support burden, or (5) has a long production lead time.

DEVELOPMENT PLAN (DP)--A document which records program decision, contains the user's requirements, provides appropriate analyses or technical options, and the life cycle plans for development, testing, production, training, and logistic support of material items.

EFFECTIVENESS--A measure of the extent to which an item satisfies a set of specific, preestablished requirements.

FAILURE MODES--The ways in which an item can fail, including the type of failure (e.g., short, open fatigue) and degree of failure (e.g., partial, total).

INTEGRATED LOGISTICS SUPPORT (ILS)--An improved planning process designed to provide timely and effective support of systems and equipment.

LIFE CYCLE--All phases through which an item passes from conception through disposition.

MAINTENANCE--All actions necessary for retaining an item in or restoring it to a specified condition.

MAINTENANCE ALLOCATION--A summary of task allocations by maintenance function and level. What maintenance is accomplished where.

MAINTENANCE ENGINEERING--A determination of where, when, why, how, and by whom action necessary to replace, restore or retain equipment will be taken.

MEAN-TIME-BETWEEN-FAILURE (MTBF)--For a particular interval, the total functioning life of an item divided by the total number of failures during the measurement interval. The definition applies to time, cycles, distance, events, or other measure of life units.

MEAN-TIME-TO-REPAIR (MTTR)--The total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time

PERSONNEL AND SKILL SUMMARY--An evaluation of maintenance skill specialties, training requirements, and equipment.

SPECIAL TOOLS--A listing of tools not available in common sets but which are required for certain maintenance functions.

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APPENDIX - PART N
LICENSING GUIDELINE

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N1.0 INTRODUCTION

The impact of regulatory requirements on nuclear facility design is substantial, and it is likely to continue to increase. Failure to factor licensing into the initial stages of a design can lead to unnecessary and extremely costly revisions and delays. In some cases, the lack of timely licensing input has led to (or been a substantial contributor to) delays and/or redesign so costly that projects have been abandoned. For example, in 1977 a pilot facility for an underground copper leaching operation was abandoned after the New Mexico Environmental Improvement Agency refused to issue a permit unless design changes were made. Also, the President's April 1977 decision on the Clinch River Breeder Reactor Plant probably would have met with much stiffer resistance by Congress if NRC-approved construction had been underway. NRC approval was originally planned for September 1975, but due to lack of data required for licensing, the construction date had been delayed to November 1977.

The importance of regulatory requirements has led to its designation as one of the four general impact areas in the Principal Plant Factors. This guideline describes in a general way how to implement the licensing task, which will ensure that regulatory requirements are factored into all phases of the HRRF plant conceptual design.

N1.1 Scope and Objectives

This guideline describes the licensing task and the general regulatory process. Included is a discussion of the need for efficient communication at the many interfaces: the regulatory agencies, the various

design groups, and the safety and environmental specialty groups. The guideline provides a general method for including regulatory requirements into the design process, from the initial decisions on plant requirements through the development of conceptual design criteria and specifications.

N1.2 Organizational Requirements

The licensing group would interface with essentially all design groups and other groups providing technical input to the project. Therefore, the members of the licensing group would have broad-based technical capability. This capability would be extremely valuable in various internal review roles. The licensing group would also review the HRRF conceptual design for regulatory compliance prior to its submittal to the regulatory agencies for review. Because of these two aspects of the licensing task (which are similar to the Quality Assurance task), the licensing group usually would report to a relatively high level of management to ensure objectivity. However, since the licensing group 1) would work very closely with the safety, environmental, and certain other critical design groups to ensure that design solutions to meet regulatory criteria are both timely and economical, and 2) would represent the first layer of technical expertise seen by the regulatory agencies, it would be necessary that good technical working relationships be developed--usually by having the licensing group report directly to the Project Manager. Because of the need for close communication regarding interpretation and application of regulatory requirements, the licensing, safety, and environmental groups are frequently grouped together. The safety

group as used in this guideline includes the specialty engineering groups of safety, criticality, and physical protection used elsewhere in this project plan.

The licensing group would interface with essentially all design groups and other groups providing technical input to the project.

N2.0 GENERAL REGULATORY PROCESS

A variety of local, state, and federal regulations may require as many as 50 to 100 licenses and permits to allow siting, construction, and operation of a nuclear facility (or even a fossil power plant). Most of these permits would not impact the HRRF conceptual design, and therefore are not a factor until a site-specific application is prepared. Even then they are not generally a technical problem. Certain key permits, however, require time-consuming environmental studies and/or the completion of detailed engineering and equipment selection before the permit application. The Nuclear Regulatory Commission (NRC) safety review pursuant to the Atomic Energy Act and their environmental review pursuant to the National Environmental Policy Act (NEPA) would have the major regulatory impact on the HRRF facility design. The Environmental Protection Agency's (EPA) non-nuclear review pursuant to the Clean Air Act or the Clean Water Act or a state's review pursuant to air or water quality regulations may have some limited design impact. The Clean Air Act Amendments of 1977 ended NRC's exclusive authority over radiological health and safety by delegating some responsibility to EPA. Potentially more important, the Amendments also gave state and local governments the right to pass regulations covering radiological releases as long as they are more stringent than federal regulations.

The Nuclear Regulatory Commission and the Environmental Protection Agency can have a major impact on facility and process design.

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Prior to the Amendments of 1977, the Clean Air Act provided that federal facilities comply with state and local air pollution requirements, which was construed by the Supreme Court as compliance only with the substantive requirements. Under the amended Act, federal facilities must now comply with both the procedural and substantive requirements. This should not have design impact, but will be an important factor in the licensing schedule, since the process may take several years. Permits from other federal agencies, e.g., Federal Aviation Administration, Federal Communications Commission, and the Department of Transportation, are also important from a licensing schedule standpoint, but are not likely to impact facility design.

Except for the new (and as yet unused) state powers under the Clean Air Act Amendments of 1977 mentioned above, state and local regulation or radiological matters were preempted by the Atomic Energy Act. Therefore, the state and local governments have relied upon land use control authority (zoning, building codes, etc.), which does rest with the states and the local governments, to voice their concerns over radiological control, even though the ostensible grounds were land use control. Although no state has yet refused site certification for a nuclear facility holding an NRC construction permit, these regulations can provide a procedural mechanism to effectively resist a federal nuclear project. Except for layout of access to the site, however, these permits will have no impact on facility design.

Because of its importance, the NRC licensing process is summarized below. The NRC regulations are found primarily in Part 50 of Title 10,

Code of Federal Regulations, and in numerous Regulatory Guides, Standard Review Plans, and so forth.

Environmental and safety reviews are required to verify conformance of design with regulatory guides and standards.

The NRC environmental review culminates in the issuance of a Final Environmental Statement (FES), which is prepared in cooperation with the EPA and is reviewed by other federal and state agencies. A three-man Atomic Safety and Licensing Board (ASLB) also conducts an environmental review during a public hearing held in an adjudicatory format. The culmination of the ASLB review is a decision on the findings of fact. Other federal or state agencies may elect to hold public hearings. If these environmental reviews are favorable, and if the NRC safety review discussed below has proceeded far enough to determine that 1) all design parameters impacting site suitability have been identified, and 2) the design conforms (or can be modified to conform) to the NRC Rules and Regulations, then a Limited Work Authorization (LWA) can be issued authorizing site preparation, excavation, and those phases of construction not subject to quality assurance considerations. Certain pre-LWA site activities can be carried on, and the NRC will consider approval of others.

A radiological safety review is conducted by the NRC staff in parallel to its environmental review, the culmination of which is issuance of a Safety Evaluation Report (SER). This safety review is based

on the applicant's Safety Analysis Report (SAR) and will involve vigorous interaction and technical interchange between the NRC and the applicant over twelve to eighteen months. The flow of information between the various NRC technical reviewers and the applicant's technical experts is controlled by the NRC Project Manager and by the applicant's licensing manager.

The next step is an independent safety review by the Advisory Committee on Reactor Safeguards (ACRS). The ACRS holds several meetings (which the public may attend) and furnishes its advice to the NRC Commissioners in a letter which becomes part of the public record. The third safety review is by the ASLB (which earlier conducted an environmental review), and as before, an adjudicatory hearing is held and a decision issued. If these reviews are favorable, a Construction Permit (CP), or an Operating License (OL), will be issued by the NRC.

The proceedings leading to the ASLB hearing may be quite extensive. First, intervenors are admitted based on an affected interest and a valid contention (issue). Secondly, the contentions are consolidated, focused, and perhaps some eliminated by an appeals process. Third, the opponent's case is discovered through interrogatories, admissions, and requests for documents. In the Clinch River Breeder Reactor Plant (CRBRP) Project proceedings, for example, over 4000 interrogatories and admissions were answered by the applicant.

N3.0 METHODOLOGY

N3.1 General Task Description

The licensing group would be responsible for the orderly and timely development and presentation of technical information to the regulatory agencies and for the development of an efficient and effective relationship with the regulatory agencies. In order to accomplish this task, the licensing group 1) would provide interpretations of the regulations and recommendations on positions with respect to those regulations to the functional engineering groups, 2) would serve as the single-point contact between the HRRF Project and the regulatory agencies, 3) would organize and review the safety analysis reports, environmental reports, and other technical documents required by licensing agencies, and 4) would review major plant features and proposed design changes for licensing impact. Because of the broad technical background required and the objective overview nature of the licensing task as described above, the licensing group would often be given the responsibility for various internal technical reviews.

N3.2 Method

The basic procedure for the licensing analysis would be to compare what is known about the design with what is known about the applicable regulations and to provide feedback into the design process based on that comparison.

The basic procedure for the licensing analysis would be to compare what is known about the design with what is known about the applicable regulations and to provide feedback into the design process based on that comparison. For the purposes of this guideline, the procedure has been divided into two sub-procedures, as shown in Figure N3-1. The first is the process leading to providing licensing input to Principal Plant Factors (PPF) development, and the second is a generic process applicable to the feasibility, preconceptual, and conceptual design phases.

Licensing analysis begins with the development of Level 0 Baseline Requirements through participation in the identification of Principal Plant Factors.

The development of the Principal Plant Factors is described in the Appendix, Part B, and the licensing aspect would begin with the receipt of the materials package. First, the existing technical information and the proposed goals and objectives of the facility would be reviewed. Second, the regulations, NRC Branch Technical Positions, Regulatory Guides, and so forth, would be reviewed to determine their applicability. Especially helpful would be the review of licensing applications for similar facilities. At this stage, the pertinent licensing criteria would be those that deal with concepts such as diversity, redundancy, and separation that would have a major impact on facility layout, the number of major components, the required diversity of large systems, and so forth. The types of design basis accidents that would be applicable will be an important input, since the fundamental design will make some

FIGURE N3-1. LICENSING ANALYSIS.

hypothetical major accidents more or less likely. This type of information would be compiled for input to the development of the PPF.

The general design criteria establish the licensing requirements to be used at each level of design analysis (facility, plant, system).

The scope of the regulatory requirements review for PPF development would be very broad, and the review time allotment likely would be fairly short. Therefore, as the feasibility design begins, a more time-consuming and detailed review would be required. An important product of this review would be a set of about fifty general design criteria (GDC) corresponding to those for light water reactors in Appendix A of 10CFR50. Other licensing philosophy would be developed, such as the general selection of design basis accidents and how to extrapolate/interpolate the existing criteria (e.g., Regulatory Guides, safety classes, codes, and standards) to the new situations. The licensing input would be developed by considering the existing design data and by communicating with the design groups to ensure that the input would be worded so that the desired safety goals are included, but the design would not be unnecessarily restricted by ambiguous or all-inclusive statements. This early (and continuous) communication with the designers would have the advantage of ensuring that the licensing group input would be understood and that the designers would recognize the impact of regulatory requirements from the outset.

As discussed in Section N2.0, non-NRC licenses and permits would not be likely to have a major impact on the facility design; however, a review of state and other federal requirements should be made at the outset to ensure that any design impact would be considered early and that any information requirements needed for later permit applications would be generated when it is most appropriate. The detailing of the numerous procedural matters can wait until a site-specific design is being prepared.

Active participation of licensing engineers in the design review process would ensure overall acceptance of design solutions.

As the various safety, environmental, and design analyses are performed, the licensing group would review the results for compliance with the regulatory criteria. The review scope would be more an overview from the perspective of a group in communication with the regulatory bodies, rather than an independent quantitative design review. Continuous communication between the licensing group and the other technical groups to assure an understanding of the regulatory requirements would be the primary means of assuring the acceptance of the design by the regulatory agencies. When a licensing-related design change becomes necessary, all groups would work together to determine the most economical revision. As other design changes become desirable, the licensing group would be included in the change control process.

Licensing also obtains, reviews, and distributes internally those external documents which could impact HRRF Project licensing activities. This would include formal and informal changes in the regulatory process, other licensing applications, and so forth.

The organization and review of the safety analysis report, the environmental report, and other technical documents would be the responsibility of Licensing. Regulatory submittals would usually be based on the completed, or nearly completed, conceptual design. At that time, detailed licensing schedules would be prepared, including all of the more procedural requirements discussed earlier.

N4.0 INTERACTION

The inclusion of regulatory requirements into all phases of the design process is crucial to avoid the potential for costly design changes. The licensing group would provide an interpretation of the regulatory requirements to all other technical groups. Output from the other groups would provide the technical basis for the evaluations by Licensing. The feedback between the groups would permit optimal resolution of required design changes.

N5.0 DEFINITIONS

GENERAL DESIGN CRITERIA--The minimum requirements for the principal design criteria establishing the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety. Light water reactor (LWR) general design criteria are specified in Appendix A to Title 10 of the Code of Federal Regulations, Part 50 (10CFR50). A representative LWR criteria is:

Criterion 21--Protection system reliability and testability. The protection system shall be designed for high functional reliability and inservice testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection system shall be sufficient to assure that 1) no single failure results in loss of the protection function and 2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated. The protection system shall be designed to permit periodic testing of its functioning when the reactor is in operation, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.

ADJUDICATORY FORMAT--A hearing before judge(s) where testimony is defended by witnesses under cross-examination by attorneys. In the other format, the legislative hearing, the questions are all asked by the judge(s); perhaps from those submitted to the judge(s) by the attorneys.

DESIGN BASIS ACCIDENT--The postulated event which imposes the most limiting conditions which must be included in the design of a particular system or component.

LICENSING PHILOSOPHY--The approach that will be taken to incorporate regulatory requirements into the design, e.g., will events less probable than the design basis be considered; if so, how?

NRC REGULATIONS--Strictly speaking, the NRC regulations are those published in Title 10 of the Code of Federal Regulations (10CFR). These regulations have the force of law, and, where applicable, compliance with them is required.

REGULATORY GUIDES--A series of guides describing one way for an applicant to meet the NRC regulations. There may be other, equally acceptable ways to meet the regulations, but the applicant carries the burden to provide a sufficient basis for the NRC to make a finding of acceptability.

BRANCH TECHNICAL POSITIONS--A specific requirement issued by a particular technical branch of the NRC, e.g., Mechanical Engineering Branch. These positions are usually attached to the Standard Review Plan that references them.

STANDARD REVIEW PLAN--A set of instructions to the NRC staff on how to conduct the technical review of the application. See References 1 and 2.

STANDARD FORMAT AND CONTENT GUIDE--A set of instructions to applicants describing what information is required by the NRC and what its format should be. See Reference 3.

REFERENCES

1. "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants--LWR Edition," NUREG-75/087, September 1975.
2. "Draft Environmental Standard Review Plans for the Environmental Review of Construction Permit Applications for Nuclear Power Plants," NUREG-0158, January 1977.
3. "Regulatory Guide 1.70, Standard Format and Content Guide of Safety Analysis Reports for Nuclear Power Plants, Revision 2," NUREG-75/094, September 1975.