ORNL/ANS/INT-36/S7/RA

RELIABILITY, AVAILABILITY, AND MAINTAINABILITY (RAM) PLAN

Document Type 4

October 1994

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

ORNL/ANS/INT-36, PLANS	INT-36/S7	Revision A
	Revision Date: September 30, 1994	
Reliability, Availability, and Maintainability (RAM) Plan	ANS PROJECT	
WBS Number: 1.2.2.3.12		

APPROVALS

Approvers	IT Prepared		Energy Systems Prepared	
IT ORGANIZATION	Signature	Date	Signature	Date
IT Responsible Author	________	________	N/A	
IT Project Manager	________	________	N/A	
ANS PROJECT ORGANIZATION				
ANS WBS Manager	________	________	________	________
ANS Principal Engineer	________	________	________	________

ANS Engineering Manager ____________________ ________
Date

ANS Project Director ____________________ ________
Date

CHANGE CONTROL RECORD		TITLE Reliability, Availability, and Maintainability (RAM) Plan	Document No. INT-36/S7
Revision No.	Date	Description/Pages Affected/Comments	
A	06/94	A general revision was made to incorporate design evolution. Initial inherent availability allocations were made.	

CONTENTS

FIGURES

TABLES

ACRONYMS

A/E	architect/engineer
ANS	Advanced Neutron Source
CM	construction manager
DOE	Department of Energy
E-SPEC	equipment specifications
ES	Martin Marietta Energy Systems
FMEA	failure mode and effects analysis
FY	fiscal year
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PDR	Plant Design Requirements
PC	prime contractor
QA	quality assurance
QC	quality control
R&D	research and development
RAM	reliability, availability, and maintainability
RM	reactor manufacturer
SDD	system design document
TBD	to be determined

ABSTRACT

The Advanced Neutron Source (ANS) reactor is a nominal 330-MW(f), nuclear research reactor being developed for future construction at a site within the Department of Energy's (DOE's) Oak Ridge Reservation (ORR) located at Oak Ridge, Tennessee. The ANS reactor will provide a source of hot, thermal, cold, and ultra-cold neutron beams for research in neutron scattering, nuclear and fundamental physics, and materials analysis. Additionally, ANS will provide isotope production and materials irradiation testing facilities.

This report describes the reliability, availability, and maintainability (RAM) analysis activities planned for the ANS. The objective of the ANS RAM program is to ensure that ANS meets its availability design requirements. This objective will be achieved through evaluations of equipment systems failures (reliability) and the time it takes to return the plant to normal operation once failures occur (maintainability). Guidelines for implementing a RAM engineering program are given. The elements of a reliability engineering program also are described in this report.

1. INTRODUCTION

The Advanced Neutron Source (ANS) is a new research facility that will provide hot, thermal, cold, and ultra-cold neutrons. The primary component of the facility is a 330-MW(f) heavy-water-cooled and -moderated reactor. The reactor, which will have between 5 and 10 times greater neutron flux than existing reactors, will provide neutron beams for experiments and materials research as well as the isotope production facilities. The reactor will be housed in a central reactor building; supporting equipment will be located in an adjoining reactor support building. An array of cold neutron guides fan out into a guide hall, which will house about 30 neutron research stations. Office, laboratory, and shop facilities are included to provide a complete user facility. ANS is scheduled to begin operation at the Oak Ridge National Laboratory (ORNL) near the beginning of the next decade.

It is most important that this facility operate reliably and provide a dependable source of neutrons. A RAM program will be undertaken to ensure that it does so. This document describes the RAM analysis engineering activities planned for ANS. It is intended to specify the actions necessary to fulfill the RAM requirements defined in Chap. 5 of the ANS Plant Design Requirements (PDR) document, particularly Sects 5.1 and 5.2. This document specifies the RAM work plans, actions, and organizational structure necessary to accomplish successfully the design and operation of ANS. The appendix of this plan provides a RAM engineering guide for system development. The elements described herein apply to all activities associated with the ANS Project. This plan serves as a guide for contractors in preparing more detailed schedules for analyses of their systems.

This ANS RAM Plan defines the top-level administration and technical requirements for planning and performing tasks from the start of the project conceptual design through the completion of the plant operational test. This document has been prepared to satisfy the requirements defined in the ANS Systems Engineering Management Plan.

ANS Project phases and associated schedule and major milestones are defined in the ANS Project Management Plan. The project phases include Research and Development (R&D), Safety/Licensing, Conceptual Design, Advanced Conceptual Design, Preliminary Design (Title I), Final Design (Title II or Detailed Design), Procurement/Construction, and Acceptance Test (Title III).

1.1 OBJECTIVE

The objective of the RAM program is to ensure that ANS meets its availability and predictability requirements as stated in Chapter 5 of the PDR document (ORNL/TM-11625). Availability goals are defined in two ways: operational and inherent. Sect. A.1.5 of the appendix defines these in detail. Basically, the operational goal is established by dividing operating time by total calendar time. For ANS, the operational availability goal is equal to the average number of operating days scheduled each year divided by 365 (See Sect. 5.2 of the PDR. The inherent availability goal (or factor) is established by dividing operating time by operating plus repair time. The ANS inherent plant availability goal in Sect. 5.1 of the PDR forms the basis for the apportionment of overall plant availability among plant systems and subsystems. This apportionment will become the availability design criteria of systems and subsystems.

The scientific community has stressed the importance of predictable plant operation. Thus a central focus of the RAM program is to ensure that ANS meets, or exceeds, its predictability goal (See Sect. 5.2 of the PDR). Predictability, as defined for ANS, is not included within traditional RAM analyses. To investigate predictability, one must first define an operating schedule for the facility. Simulations and assessments associated with predictability also require that an operation and maintenance strategy be assumed. The approach taken here is to search for the operating schedule, operating and maintenance strategy, and system design features that optimize predictability. Results from these optimization studies will be available to the design team early in Title I design so that appropriate design features can be incorporated.

1.2 JUSTIFICATION

A number of first-of-a-kind systems will experience operation for the first time in ANS; it is important that these systems operate reliably. The RAM analysis accelerates the maturing of emerging technology by identifying weaknesses during the design and test phase and will ensure that the ANS availability (and predictability) requirements are satisfied.

2. APPLICABLE DOCUMENTS

Program Document:	ANS Plant Design Requirements, ORNL/TM-11625 ANS Project Management Plan ANS Quality Assurance Plan ANS Systems Engineering Management Plan
DOE Orders:	Project Management System (4700.1) Safety Analysis and Review System (5481.B) Quality Assurance (5700.6C) General Design Criteria (6430.1A) Technical Safety Requirements (5480.22)

3. MASTER PLAN

3.1 DESIGN AND ANALYSIS

RAM program objectives will be achieved through a concurrent engineering process involving system designers and reliability engineers working together throughout the design process. The task will be performed through evaluations of equipment systems failures (reliability) and the time to return the plant to normal operation once failures occur (maintainability). Implementation of this plan will be the responsibility of the ANS RAM program leader or his/her designated alternate(s). Equipment reliability design and analysis will be performed by responsible system design organizations. Actual RAM analysis will be part of the system design activity. The ANS RAM program will be coordinated by the prime contractor (PC), and an ANS Project team will provide technical oversight.

The source of the subsystem reliability requirements for the designers will be the ANS System Design Description (SDD). The analysis will be a joint effort linking system development design engineering with the ANS RAM program. The reliability engineer will contribute a format and a discipline for the study and ask key "what if" questions that probe for failure modes and mechanisms. The design engineer will contribute detailed knowledge of the equipment system, including how it functions and copes with component failure. The result is a more thorough probing than could be done by either engineer alone and a greater transfer of knowledge and perspective across normal disciplinary boundaries.

The RAM program leader will specify reliability engineering design requirements through the statement of work for each subcontractual agreement. The specific RAM program will be as delineated in the appendix of this report ("Reliability, Availability, and Maintainability Engineering Guide for ANS Component Development Systems"). The RAM program will be invoked as applicable in each subcontract. Figure 3.1 shows the relationship among organizations conducting RAM assessments.

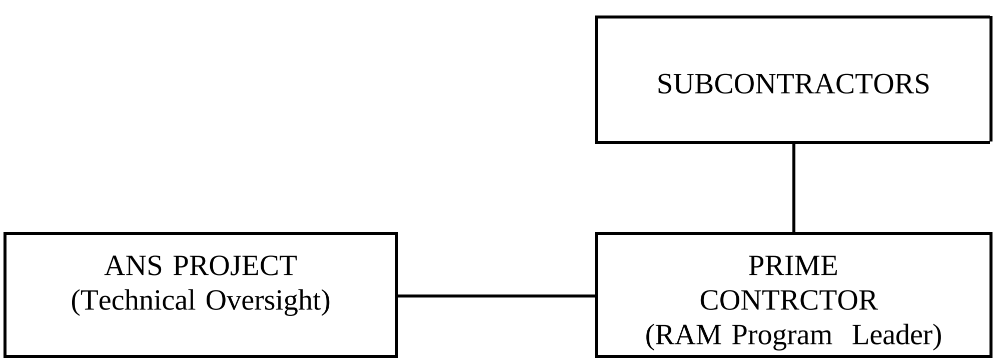

Fig. 3.1. Relationship among organizations conducting RAM analyses.

3.2 ORGANIZATION

The responsibilities and duties of all project participants are discussed in the ANS Project Management Plan. Specific responsibilities related to the RAM program are defined in this section.

3.2.1 Department of Energy

DOE is the owner of the ANS site and facility and has delegated overall responsibility for planning and conduct of the ANS RAM programs to Martin Marietta Energy Systems, Inc. (ES) and ORNL. DOE approves all top-level criteria including the plant availability design requirements.

3.2.2 Energy Systems/Oak Ridge National Laboratory

ES/ORNL, under prime contract to DOE, has responsibility for all aspects of the ANS RAM program, including direct responsibility for ANS project management research and development (R&D) program, experiment systems design, and ANS plant operations.

As the experiment system designer, ES/ORNL is responsible for all technical aspects of RAM for the assigned systems through project completion.

3.2.3 Prime Contractor

The PC, under contract to ES/ORNL, has responsibility for all work performed by the architect/engineer (A/E), reactor manufacturer (RM), and construction manager (CM). The PC has direct responsibility for planning all RAM programs and for interfacing with all system designers and operations.

3.2.4 Architect/Engineer

The A/E is responsible to the PC as the system designer for balance-of-plant systems. The balance-of-plant system designer is responsible for all technical aspects of RAM analysis for the assigned system through completion of the project.

3.2.5 Reactor Manufacturer

The RM is responsible to the PC as the system designer for all reactor systems and is responsible for all technical aspects of reactor RAM analysis and testing associated with the assigned system through project completion.

3.2.6 Construction Manager

The CM is responsible for the planning, construction, and testing of the system before the system is turned over to the plant operator. The CM will support corrections of any deficiencies discovered during operational test programs.

3.3 RESPONSIBILITIES

As contractor to DOE for all aspects of the ANS project, ES/ORNL will have technical oversight responsibility for the RAM program. The designated PC will conduct RAM analyses. The division of responsibility will be along the following broad guidelines:

- ORNL is responsible for establishing the overall RAM requirements and assessment plan;
- the PC (under ORNL technical oversight) will coordinate and conduct RAM analyses among participants;
- the PC may choose to subcontract portions of the total RAM assessment (the contracting organization is responsible for the quality of the subcontracted work);
- the results of RAM analyses shall be integrated with system design reviews and incorporated into system design, equipment specifications, and equipment procurement documents as appropriate; and
- recommended equipment configuration changes that result from the RAM analyses will be approved by the appropriate ANS change control boards.

Table 3.1 provides a matrix of organizational responsibilities.

3.4 TESTING PLANS

RAM testing will be integrated with the equipment and system testing program as defined by the ANS test and evaluation plan.

3.4.1 Critical Items

Critical items are those whose failure could affect significantly the ability of the system to achieve its availability goals. A critical items list is the result of the quantification of system reliability and maintainability; it is prioritized in terms of the fractional contribution to total unavailability of each item in the system. Critical items may be subjected to life testing. These tests will be performed by the responsible equipment system task, the program element which provides the equipment, to verify the predicted reliability of the equipment. Subcontractors will provide recommendations and suggestions for the test program as to test parameters, recommended test data, and similar inputs that would contribute to a meaningful test program. The equipment system task will provide test program guidance that will provide the top-level overview of the test program, facilities, and equipment required and the scope of the tests to be performed.

Table 3.1 RAM program responsibility matrix

	DOE	ES/ORNL Project	ES/ORNL R&D/ Safety	ES/ORNL Experiment designer	ES/ORNL Operations	Prime Contractor (PC)	Reactor Manufact. (RM)	Architect/ Engineer (A/E)	Construction Manager (CM)
Establish facility availability goals (Sect. 1.1)	A	P	S	S		C	C	C	C
Apportion facility availability among systems (Sect. 4.1.3)		A	S	S		P	C	C	C
Perform reliability assessments (Sect. 4.1.4)									
Reactor		A	S	S		C	P	S	C
Experiment systems		A	S	P		C	C	C	C
Balance-of-plant system		A	S	S		C	C	P	C
Identify critical items and resolve (Sect. 3.4.1)									
Reactor		A	S	S		C	P	S	C
Experiment systems		A	S	P		C	C	C	C
Balance-of-plant system		A	S	S		C	C	P	C
Perform maintainability assessments (Sect. A.3.8)		A	S	S		C	P	S	S
Verify that reliability predictions and goals meet (Fig 4.4)		A	S	S		P	S	S	C
Component testing		A	C		P	S	S	S	S
ANS cold and hot operational testing		A	C		P	S	S	S	S
Establish reliability and maintainability data base (Sect. 3.4.2)		A	S	S		P	S	S	S
Verify that availability predictions and goals meet (Fig. 4.4)		A	S	S		P	S	S	S

A—Approve C—Comment P-Perform S-Support

3.4.2 Equipment Testing

A reliability and maintainability data base will be established and maintained current with system qualification, acceptance, and operability testing. The equipment system tasks, in conjunction with the RAM program, will seek input from vendors and reliability data bases to establish the requirements of, and tests to be performed on, equipment systems. Each equipment development task may conduct tests of complete systems in test facilities. Interface devices to component systems may be tested by qualified subcontractors or vendors. Testing only for reliability purposes will be minimized because it is expensive and difficult to obtain a statistically significant failure rate. Several items of the specific equipment in question must operate over a long period. Frequently, the most effective reliability test effort is devoted to monitoring the whole array of tests to obtain the most useful information from the data. Preoperational tests, initial criticality tests, low power tests, and power ascension tests are planned. Specific reliability or maintainability tests may be conducted on critical items as a necessary aspect of the overall test program.

3.5 QUALITY ASSURANCE

This plan delineates interfacing reliability and quality activities per Sect. A.1.4 of the appendix. The interfacing documents will be the *ANS Quality Assurance Program Plan* and implementing documents. The specific quality assurance (QA) requirements will be imposed on subcontractors through the applicable contract. Design reviews are a QA requirement. Confirmation that predicted system availability meets a system availability goal is an element of the design review.

4. ELEMENTS OF THE RAM ENGINEERING TASK

An overview of the tasks to be performed is presented in Fig. 4.1. Whole-facility availability predictions will be updated at the end of Titles I and II design phases. A near-term schedule of RAM activities is shown in Table 4.1. These RAM activities, listings, and schedules may be updated periodically or adjusted as reliability and maintainability assessments are completed. The scope of failure analyses and availability predictions will be specified by the RAM program and may include entire systems, subsystems, or discrete components.

Table 4.1 Near-term schedule of RAM analyses

Milestone	Date
Work by ES/PC	
Complete quantifications of overall ANS inherent availability and predictability goals	September 1994
Allocate ANS availability goal among systems and subsystems	June 1995
Prioritized systems for RAM assessments	September 1995
System i	TBD
System ii	TBD
System iii, etc.	TBD
Maintenance system assessment	TBD
Work by reactor manufacturer	
Detailed component systems failure analysis and availability prediction	
System ai	TBD
System aii	TBD
System aiii, etc.	TBD
Work by architect/engineer	
Detailed component systems failure analysis and availability prediction	
System bi	TBD
System bii	TBD
System biii, etc.	TBD

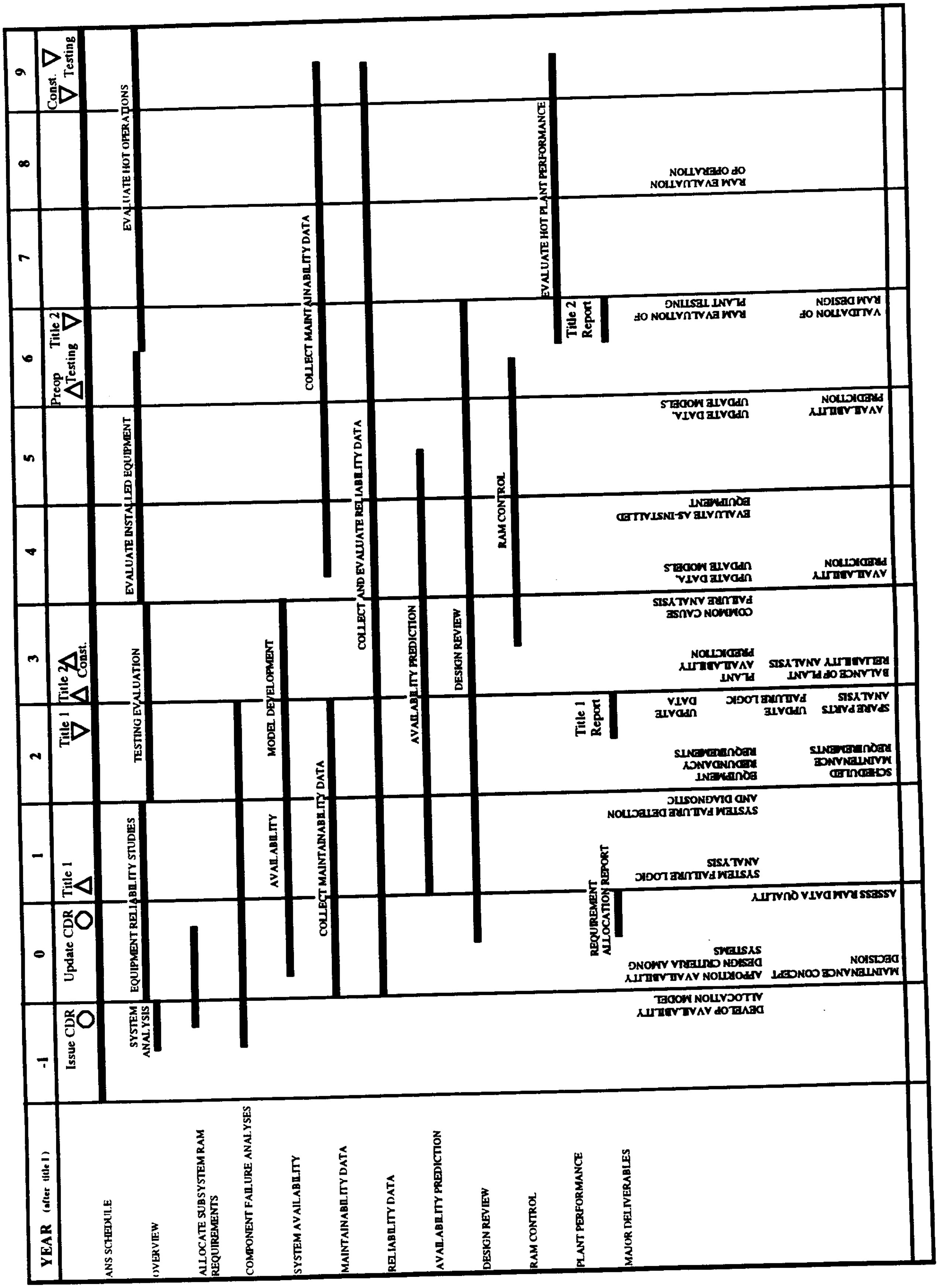

Fig. 4.1. ANS RAM task schedule.

4.1 STRUCTURE

The elements of the ANS RAM program are presented in Fig. 4.2. The figure indicates the major tasks to be performed and related subtasks. A brief description of each task follows.

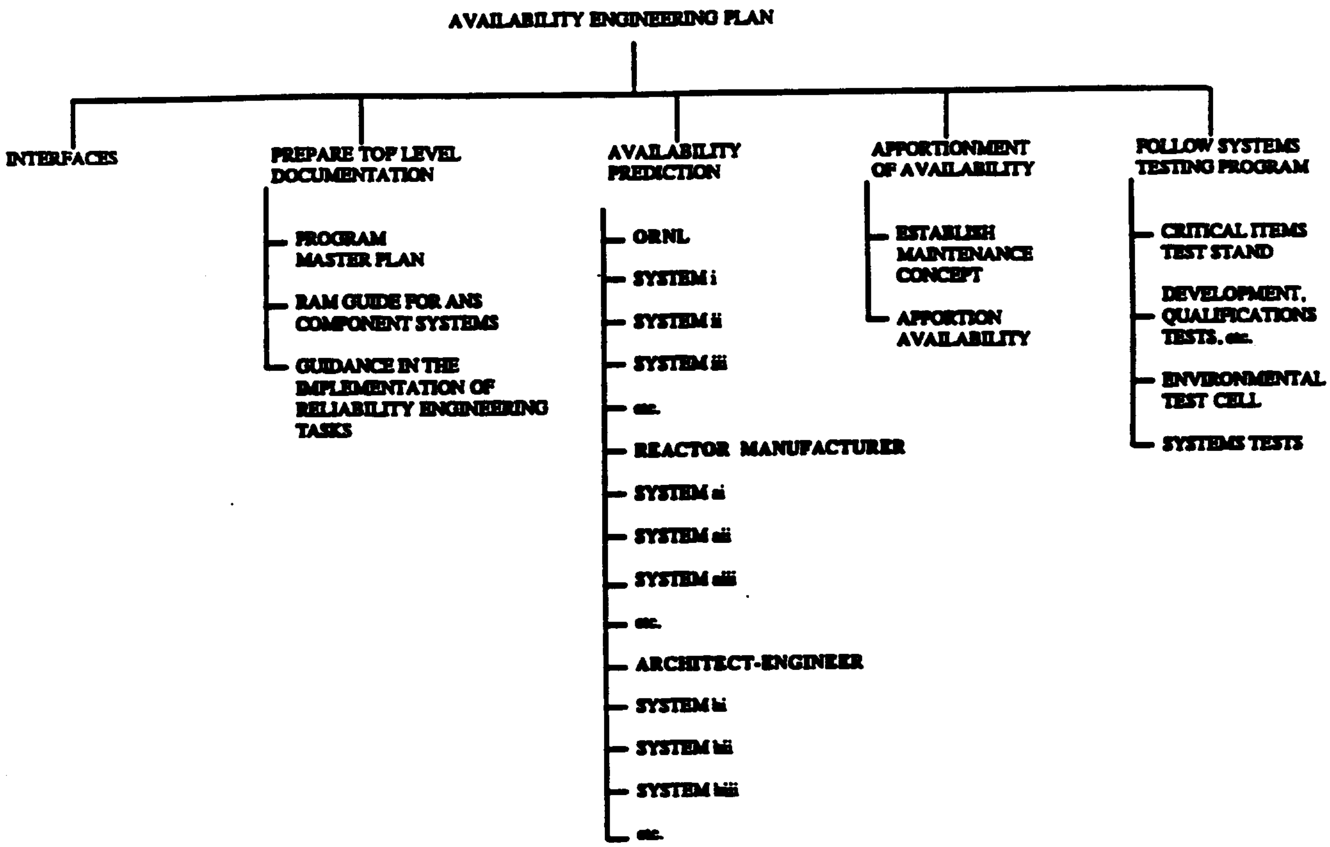

Fig. 4.2. Elements of the RAM assessment program.

4.1.1 Interfaces

ANS RAM activities will augment and closely interface with the established ANS Project support functions of QA, safety, equipment testing, and procurement. All programmatic elements and work activities of the ANS RAM plan shall be integrated with, and executed in concert with, these interfacing functions. Referencing documentation of the interfacing programs are given in Sect. 2.

The division of responsibilities among ORNL, DOE, and designated subcontractors is described in Sect. 3.2 and shown in Table 3.1. ORNL and designated subcontractors will perform RAM assessments. ORNL will have the lead role in RAM assessments and methodologies for ANS.

4.1.2 Documentation

The objective of the RAM program master plan is to define the general requirements of RAM analyses to be conducted to support the ANS program. The appendix of this document provides details and guidance for implementing the RAM plan for ANS.

4.1.3 Apportionment of Availability

The whole-facility overall inherent availability goal will not change throughout the course of the project. Initial allocation of these overall goals among systems and subsystems will change during the course of the design as trade-offs and optimization occur.

An initial availability apportionment will be performed using the overall availability goals referenced in Sect. 1. The availability apportionment will be made using a top-down methodology based on interviews with nuclear reactor experts. Availability requirements, distributed proportionately among the facility's systems, will be based on each system's capability for meeting a design objective. Initial estimates of overall facility availability among major plant systems will be reported as shown in Table 4.2.

Table 4.2. Inherent availability goals for the ANS

Functional system	Inherent availability
Site and buildings	TBD
Reactor systems	TBD
Plant systems	TBD
Experiment systems	TBD
Operations	TBD
Overall facility	80%

[Note: values for the TBDs in Tables 4.2 and 4.3 must be supplied from the allocation task now being documented]

Several major categories of the ANS program are presented in Table 4.2. The site is defined as land improvements (fencing, site preparation and earthwork, paving, and drainage); outside utilities (electrical, natural gas, diesel oil systems, water systems, steam system, compressed air system, and rail lines); outside services (sanitary sewage, communications, safety alarm system, site monitoring, site security, fire alarm systems, and noncontaminated waste water treatment); and other structures (support building stack, cooling tower). Operations are defined as plant operations, plant maintenance, security administration, operator training, and heavy water fuel and cask inventory. Reactor systems, plant systems, and experiment systems are defined in detail in Table 4.3, which also contains the format for initial WBS level 3 inherent availability goals during periods of neutron production. These

Table 4.3. Equipment systems inherent availability goals

Work breakdown structure No.	Title	Availability criteria
1.3	Reactor Systems	TBD
1.3.1	Rector assembly	TBD
1.3.2	Refueling	TBD
1.3.3	Instrumentation and control	TBD
1.3.4	Fuel assemblies	TBD
1.3.5	Reactor assembly mockup	TBD
1.3.6	Reactor maintenance	TBD
1.4	Experimental systems	TBD
1.4.1	Neutron beam transport	TBD
1.4.2	Neutron scattering instruments	TBD
1.4.3	Nuclear physics instruments	TBD
1.4.4	Transuranium production facilities	TBD
1.4.5	Materials irradiation facilities	TBD
1.4.6	Isotopes production facilities	TBD
1.4.7	Analytical chemistry facilities	TBD
1.4.8	Instrument support facilities	TBD
1.4.9	Computer and data handling	TBD
1.4.10	Cold source assemblies	TBD
1.4.11	Hot source	TBD
1.6	Plant systems	TBD
1.6.1	Reactor water	TBD
1.6.2	Electrical and communication	TBD
1.6.3	Environmental	TBD
1.6.4	Plant water	TBD
1.6.5	Plant service	TBD
1.6.6	Fire protection	TBD
1.6.7	Plant waste	TBD
1.6.8	Heavy waste detritiation	TBD
1.6.9	Plant instruments and data	TBD
1.6.10	Plant maintenance	TBD

initial allocations are documented in a Category A reference to the Plant Design Requirements document. [1]

4.1.4 Availability Predictions

An availability assessment will be made for each ANS system. Detailed reliability and maintainability analyses will be conducted for selected elements of the work breakdown structure according to the critical system list (see Sect. 3.4.1). Maintenance concepts and availability apportionment studies will indicate particularly important systems. A prioritized listing of the major availability predictions will be developed.

In each of these critical systems, the RAM program will invoke availability requirements and monitor progress through design reviews and will participate actively in the work to ensure meaningful accomplishment of the overall availability goals. Availability prediction is the inverse process of availability apportionment. In a prediction process, measured or estimated mean time between failures and mean time to repair parts and subsystems are used as the basis for computing system availability. In an allocation, the process starts with an overall plant requirement (or goal) that is converted to an availability goal permitted for each system. The apportionment in no sense indicates that the particular level of availability can be achieved. It merely means that if the apportioned values are achieved, the system will meet its goal or requirements.

System availability prediction models must be developed. The model must depict actual operation at each functional level—facility, system, subsystem, component—and must represent actual equipment configuration and operating modes. The starting point for developing the models is preparation of a functional diagram of each process system. This diagram is based on a thorough understanding of the ANS conceptual flowsheets and later-generation flow diagrams. Functional diagrams and flowsheets show whether functions are in parallel or series with each other and whether switching provisions are provided where redundancy exists. The availability of the entire facility often can be predicted by showing the functional relationship between systems on such a diagram. Reliability and maintainability data are input to the availability model. Figure 4.3 shows the network of RAM analysis tasks. A variety of models are discussed in the appendix.

Once the apportionment (target or design criteria) availability is established and an availability prediction assessment has been done, a comparison of the two is made to determine whether the facility and its systems meet the facility goals. This assessment flow is shown schematically in Fig. 4.4. Years are required to develop the necessary data and analytical methods. Thus, this comparison occurs in the latter part of plant design. It is done repeatedly in greater and greater detail, and it may cause redesign of plant systems and subsystems. The comparison between predicted availabilities and apportioned availability goals (Fig. 4.4) will be reviewed at the completion of Titles I and II design phases to ascertain if any design changes have occurred or new information has been found that could impact achieving the ANS reliability and maintainability goals. If agreement is not reached between allocated and expected availability, it is necessary to change the design of the facility in some way, for example:

- improving component quality and/or diversity,
- modifying environmental considerations,
- building in monitoring devices,
- improving ease of maintenance,

---

[1] R. S. Booth, *Initial RAM Assessments and Availability Allocations for ANS*, *ANS-1202-94-7*.

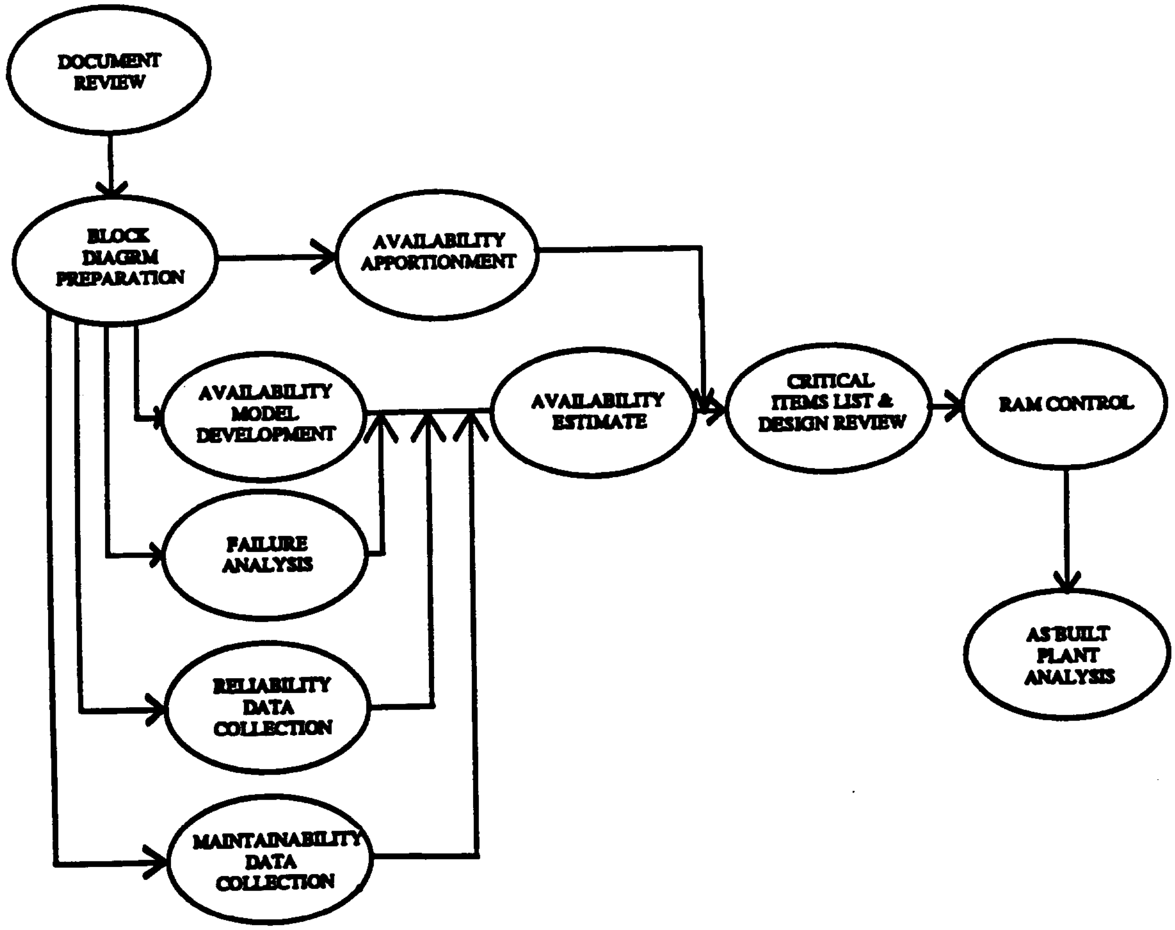

Fig. 4.3. Activity network for RAM analysis.

- adding redundant equipment, and
- changing the equipment configuration.

The first phase of a redesign is to identify the critical items or areas where expected availability is significantly lower than allocated availability. Subsequent redesign or elimination of a critical item in that system can, by analysis, significantly reduce downtime. Items so identified then are included on a "critical item list." Finally, a design review of the critical items is implemented, and options to reduce unavailability are evaluated. Some options do not require actual redesign of equipment, etc., but simply require different maintenance procedures, training, spare parts management, etc. After the

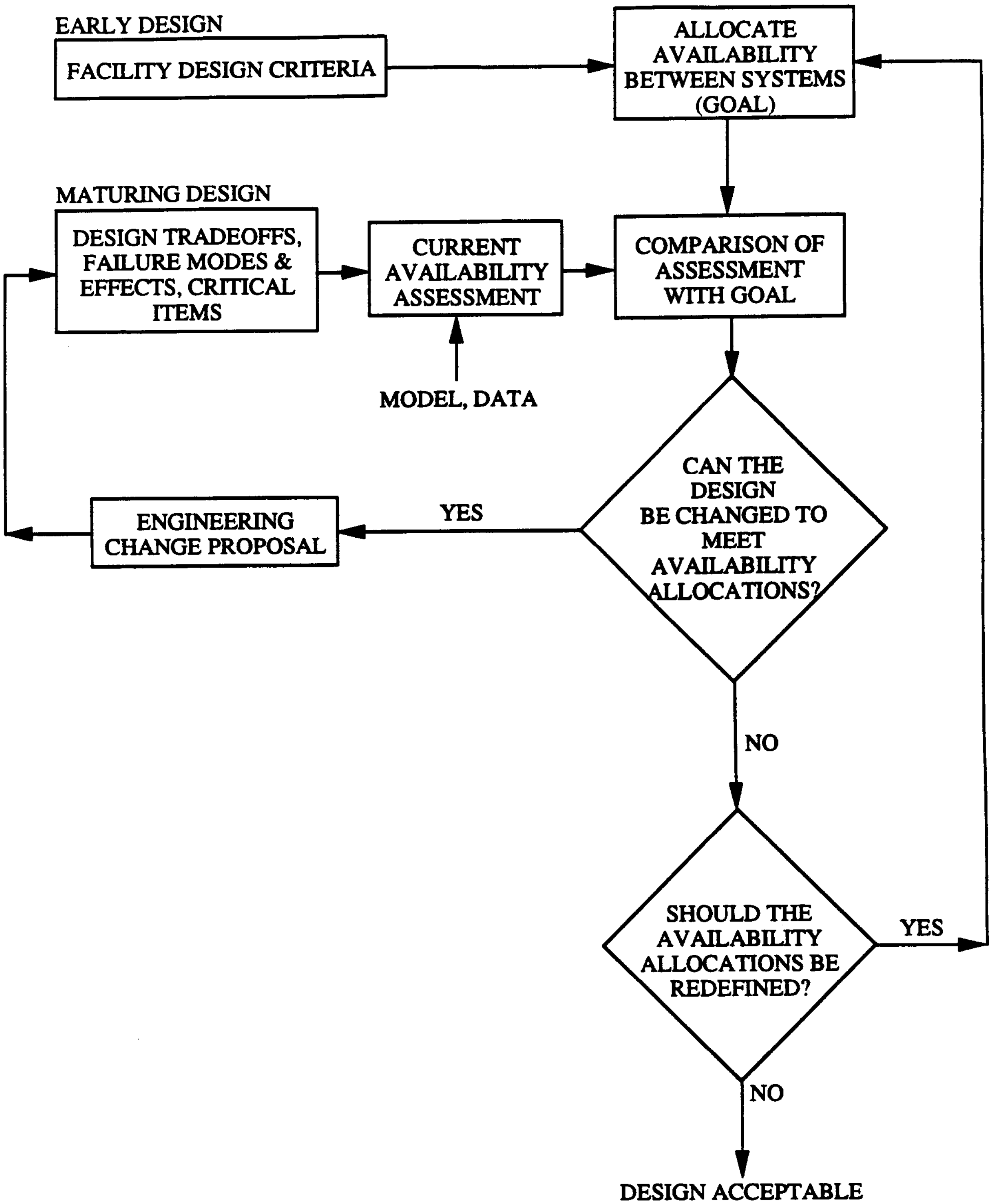

Fig. 4.4. Availability assessment flow.

- Availability-related requirements are developed and incorporated into design and procurement specifications for ANS equipment.
- Inspection and test requirements during equipment manufacture and facility construction are established, and procedures are prepared and implemented.
- Preventive and predictive maintenance requirements are identified, and procedures are prepared for use during operation of ANS.
- All design changes are reviewed and evaluated with respect to meeting the ANS availability goals.

4.1.5 Testing Program

Each equipment system development task is responsible for conducting test programs; the ANS RAM program will provide guidance in the conduct of the tests. As noted previously in Sect. 3.4.2, life tests may be conducted on certain critical items. The tests shall conform to Sects. A.3.12 of the appendix.

The following suggested steps normally will occur:

- issue a test facility specification;
- design a test facility;
- procure test facility equipment;
- issue a test stand specification;
- design and build a test stand;
- install, debug, and calibrate the facility; and
- issue test documents.

Additionally, each significant system activity will conduct endurance tests of the system as a whole and, combined with other systems, in the test facilities.

5. DELIVERABLE DOCUMENTS

The following documents containing RAM assessments will be released during the design phases:

- *Initial RAM Assessments and Availability Allocations for ANS, ANS-1202-94-7.*
- the ANS Plant Availability Assessment at the end of the Titles I and II design phases; and
- the ANS Maintainability and In-Service Inspection Assessment at the end of the Titles I and II design phases.

These assessments will discuss the results of all analyses and tests conducted that show compliance to the RAM requirements. These documents will be updated during the construction and testing phase to incorporate the latest testing data on various subsystems.

Appendix A

RELIABILITY, AVAILABILITY, AND MAINTAINABILITY ENGINEERING GUIDE FOR ANS COMPONENT DEVELOPMENT SYSTEMS

A.l. INTRODUCTION

A.l.l SCOPE

This appendix provides guidelines for implementing a RAM engineering program. It contains information on the various reliability engineering disciplines or tasks and supplies a basis for the RAM program to determine what studies are to be performed and documented. The reliability disciplines involved may be directed toward matters of safety related reliability and operating availability or maintainability.

A.1.2 APPLICABILITY

This appendix applies to those efforts that involve design, development, fabrication, testing, and modification of component systems for the ANS. Specifically, this appendix applies to those systems and related components whose satisfactory performance is required for operation, maintenance, and unplanned servicing of the ANS.

A.1.3 METHOD OF APPLICATION

This appendix describes elements of a reliability engineering program. The RAM Project will provide guidance on which reliability engineering tasks will be required for the component development systems. In accordance with this document, the RAM Project will determine the specific reliability engineering tasks to be accomplished and the results to be documented.

The PC will implement this appendix in all phases of the component development program including design, development, testing, and fabrication. Where necessary, the PC will impose all or portions of this appendix on selected subcontractors.

Reliability design goals or requirements will be specified and controlled through approved RAM program documents. The types of documentation to be employed for this purpose are a PDR, SDDs, and Equipment Specification (E-SPEC).

A.1.4 RELATION TO QUALITY ASSURANCE

The RAM engineering program is an adjunct to, and directly dependent on, the existence of effective QA activities. The RAM program will provide the requirements necessary to ensure that component equipment reliability is not compromised during any phase of the project. All QA documents pertaining to RAM activities shall relate to the QA program plan. Those QA requirements that apply to subcontractors will be specified by the RAM program in the statement of work. RAM documents should be used in conjunction with the QA requirements document and other applicable standards and codes. These documents shall also delineate interfaces and specify the method of implementation and related responsibilities. To avoid duplication of effort for those activities covered by both, interfacing reliability and quality activities will be coordinated by the RAM program.

A.1.5 DEFINITIONS

A.1.5.1 Availability

The characteristic of an item is expressed by the expected fraction of time it will be operational, (i.e., perform its specified functions). Availability measures are concerned with both reliability and maintainability.

A.1.5.2 Inherent Availability

The best measure of equipment performance is inherent availability. For components, it is defined as operating time divided by operating time plus repair time. Or, it is defined as mean time between failures divided by mean time between failures plus mean time to repair. Note: Such occurrences as administrative downtime and preventive maintenance are not time elements in this definition. The plant inherent availability applies most directly to those days during which neutron production is scheduled, the plant state associated with power operation. For this plant state, it is defined as operating time divided by operating time plus downtime. It excludes other plant states such as refueling, replacement of components, and maintenance. An overall plant inherent availability can also be defined, which is the weighted average of the inherent availability for the plant during all its states. Documentation assocuated with allocation of inherent availabilities to plant systems (See Sect. 5) explains more fully how plant inherent availability will be defined and used for the ANS.

A.1.5.3 Operational Availability

Operational availability is defined as operating time divided by total calendar time.

A.1.5.4 Common Cause Failure

Common cause failure refers to multiple failures that are attributed to a common cause.

A.1.5.5 Failure

Failure is defined as termination of the ability of an item to perform its required function.

A.1.5.6 Maintainability

Maintainability is the characteristic of design and installation expressed as the probability that an item will be returned or restored to a specific condition within a given period when maintenance is performed in accordance with prescribed procedures and resources. Maintainability measures are concerned with the expected duration of an outage.

A.1.5.7 Reliability

Reliability is defined as the characteristics of an item expressed by the probability that it will perform a required mission under stated conditions for a stated mission time. Reliability measures are concerned with the expected frequency of failure.

A.2. MANAGEMENT ELEMENTS

The PC RAM program leader will provide the resources necessary to develop, implement, and control component reliability engineering activities as a coordinated effort with other ANS activities. The PC will provide for organizing and training of personnel, planning and implementating reliability engineering activities, preparing and approving required documentation, and performing of program control evaluations and audits.

A.2.1 ORGANIZATION

The organizational structure, functional responsibilities, and lines of internal and external communication for the management and execution of RAM engineering activities shall be documented in the RAM program plan, as specified in Sect. A.2.3 of this appendix. RAM engineering activities will be led by personnel who are familiar with, and have demonstrated proficiency and skill in, reliability engineering. The specific organizational approach to be used in implementing reliability engineering shall be established in the RAM program plan.

The PC RAM program personnel will provide knowledge of RAM analysis methodologies, and equipment systems designers will provide detailed design knowledge of their respective systems. RAM assessments will be a cooperative effort among groups.

A.2.2 INDOCTRINATION AND TRAINING

Indoctrination and training shall be provided to familiarize personnel with the applicable standards and reliability engineering practices to be employed and with guidance regarding limitations and applications of these standards and practices.

A.2.3 RAM PLAN

RAM engineering activities will be planned and implemented as an integral part of design. The RAM plan describes the work plans and actions to be performed during the course of the program and the organizational structure required to accomplish this work. All technical activities, design reviews, approvals, and reference to the RAM requirements will be included and specifically identified in the plan. An index identifying the procedures to be used in conducting the tasks also shall be included in the plan. The plan shall be submitted for review and approval. The RAM plan will be kept current during the life of the program.

The reliability activities will be implemented in accordance with established practices and procedures delineated in the RAM plan description. The elements describing reliability engineering activities are included in Sect. A.4 of this appendix and will form the basis for component systems program practices and procedures. All reliability engineering activities, including assumptions and results, will be documented.

In instances where equipment design or development is performed by a subcontractor, the subcontractor must describe what reliability assessments will be made and how they will be conducted. The PC will incorporate reliability requirements in the statement of work for the subcontractor.

A.2.4 RELIABILITY PROGRAM CONTROL

PC RAM program management routinely will evaluate the status and adequacy of the reliability engineering activities. The evaluation will verify achievement of the required levels of reliability, meeting of requirements, and the effective implementation of the necessary follow-up and corrective actions. Findings will be documented. The ANS Project, in conjunction with the PC RAM Program, will review the reliability engineering tasks to ensure that the practices and procedures employed are in accordance with accepted practices.

A.2.5 SUBCONTRACTOR CONTROL

Purchased equipment and services will be subject to the reliability requirements. The PC will be responsible for the reliability related specifications of the total purchased equipment and will determine to what extent the reliability requirements will be passed on to the subcontractor. The PC RAM program, in liaison with the technical and ANS Project RAM oversight group and QA/quality control (QC), will arrange reviews to provide assurance of subcontractor performance concerning equipment reliability.

A.2.6 ANS RAM PROGRAM ACTIONS

All subcontractors will be subject to inspection, evaluation, and audit by the ANS RAM program at any time during the course of the program. In the statement of work to the subcontractor, the PC will indicate the estimated occurrence of these audits. Upon request, the subcontractor will furnish, or provide access to, contract-related reliability engineering information, documents, records, and other items required by the PC RAM program. The PC RAM program will have access to the subcontractor's plant, facilities, and equipment work, materials, and tests related to the contract.

A.3. TECHNICAL ELEMENTS

This section describes several interrelated tasks which, when selectively implemented into project activities, will provide the reliability engineering techniques necessary in the design, development, fabrication, test, installation, operation, and modification phases of an equipment component development program. The results of such techniques are intended to provide a basis to ensure that the component equipment meets the reliability requirements or objectives, or both, and to establish the requisite confidence in obtaining safe operation and acceptable on-line availability of the system.

This section delineates specific reliability requirements, techniques, or tasks the PC RAM program may select as appropriate. As an alternate, the PC may request a subcontractor to review the tasks and propose those tasks the subcontractor considers necessary to meet the reliability requirements and objectives. Figure A.1 is a block diagram giving some references associated with specific tasks. Figure A.2 identifies the sections of each reference that apply to a specific task. Appendix B provides reference material keyed to Figs. A.1 and A.2.

A.3.1 AVAILABILITY REQUIREMENTS AND GOALS

An availability requirement is mandatory, and compliance must be demonstrated. An availability goal is a target that serves as a focus for design and operation of the equipment. It depends on a combination of analytical techniques and available test data for confirmation but does not require formal demonstrations. In some cases, the RAM program may choose to use both objectives and requirements—for example, specify an objective in terms of the probability of failure confirmed by a reliability analysis and specify that a demonstration run can be performed.

This appendix does not stand alone but depends on other documents to provide availability requirements and objectives and other necessary information. Availability requirements or objectives, or both, will be defined in the PDR, SDDs, or E-SPEC prepared for each equipment system, subsystem, or component. The specifications will define the necessary requirements including functional, performance, environmental, reliability, safety, design life, and others. The SDDs and PDR will describe system operation, define system failures, and determine the equipment and components that must be operable to perform specific system functions. The documents shall be specific in delineating system and equipment reliability requirements and objectives and shall be upgraded continually in the course of the program.

A.3.2 APPORTIONMENT

Apportionment is the assignment of top-level quantitative RAM requirements or objectives, or both, to the lower-tier elements of the overall facility. Values initially assigned to the most practical lower-level elements (e.g., major subsystems) will, as the design matures, eventually result in an appropriate requirement or objective for each element in the design. Apportionment is a continuous process during design and development, with subsequent reallocation interactions as further information regarding the contribution of the various system elements to the top-level requirement or objective becomes available. The apportionment should be based on factors such as design complexity, sensitivity analysis, importance of function performed, environmental considerations, and previous experience. Apportionment, when coupled with prediction, provides the information for

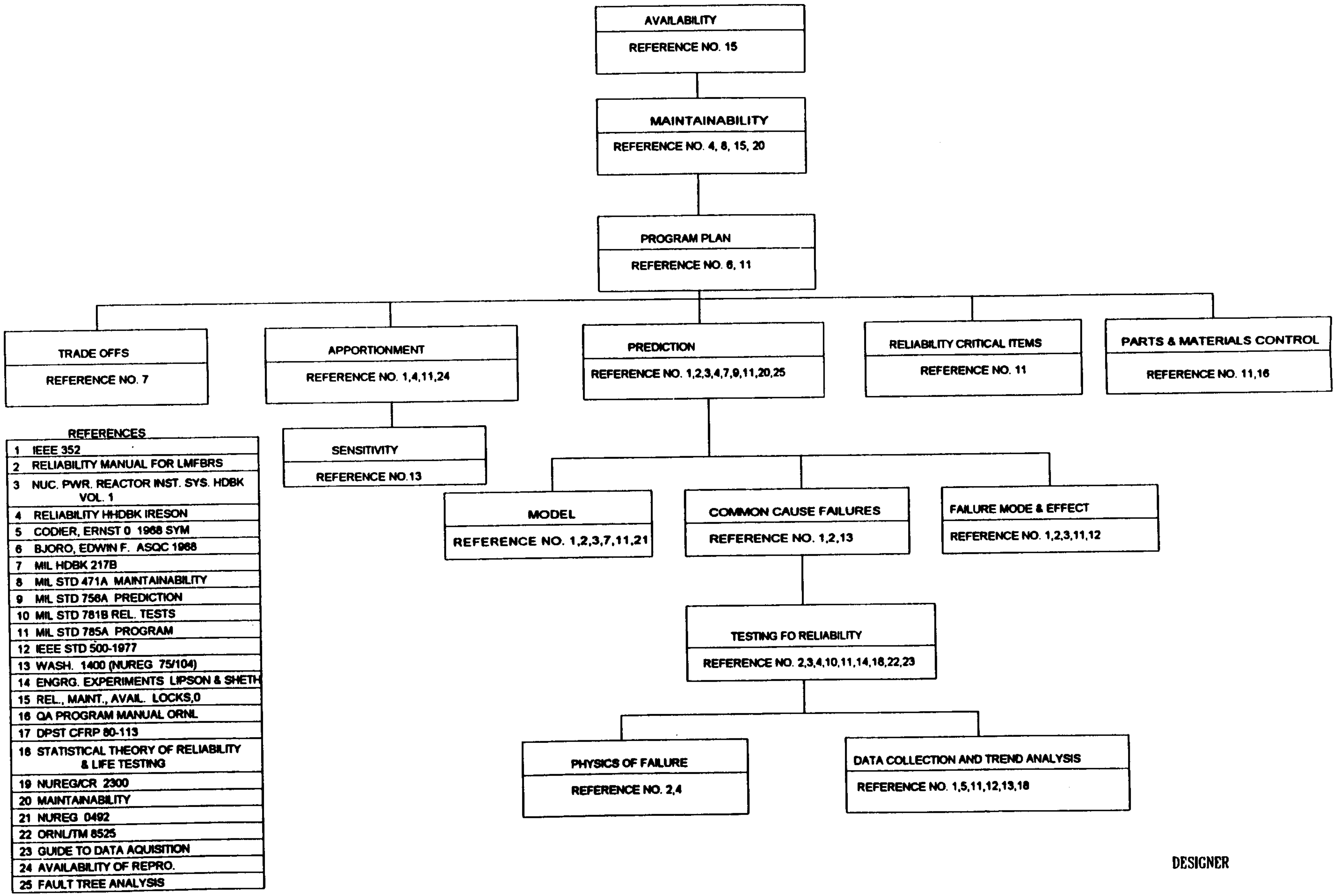

Fig. A.1. Elements (and associated references) of the RAM program.

TASKS \ REFERENCES	1 IEEE 362	2 RELIABILITY MANUAL FOR LMFBRS	3 NUC. POWER REACTOR INST. SYS. HANDBOOK VOL	4 RELIABILITY HANDBOOK IRESON	5 CODIER, ERNST O 1968 STM	6 BJORO, EDWIN F. ASQC 1968	7 MIL-HDBK-217B	8 MIL-STD-471A MAINTAINABILITY	9 MIL-STD-756A PREDICTION	10 MIL-STD-781B REL. TESTS	11 MIL-STD-785A PROGRAM	12 IEEE STD 500-1977	13 WASH-1400 (NUREG - 75/104)	14 ENGRG. EXPERIMENTS LIPSON & SHETH	15 REL. MAINT., AVAIL. LOCKS, O	16 QA PROGRAM MANUAL ORNL	17 DPST-CFRP-80-113	18 LIFE TESTING	19 PRA PROCEDURES GUIDE NUREG/CR-2300	20 MAINTAINABILITY	21 FAULT TREE HANDBOOK	22 DATA ACQUISITION	23 GUIDE FOR DATA ACQUISITION	24 AVAILABILITY APPORTIONMENT	25 FAULT TREE ANALYSIS
APPORTIONMENT	7.1			14.2							5.2.2													3	
FMEA	4.0	5.0 6.0	11-3								5.2.4	APP D							3.6						
MODEL	5.2	3.0	11-3				APP A				5.2.2								3.5		ALL				
PREDICTION	5.2	3.0	11-3	5			APP A		5.0		5.2.2														ALL
TRADE OFFS							APP A																		
SENSITIVITY	5.6.2		11-3																						
MAINTAINABILITY				11				ALL							10					ALL					
AVAILABILITY															10				ALL						
COMMON CAUSE FAILURES	4.5.3	7.0											APP IV						3.7						
PHYSICS OF FAILURE		13.0		9																					
TESTING FOR RELIABILITY		10.0 11.0	11-3	1						ALL	5.3			5.0				ALL							
DATA COLLECTION AND TREND ANALYSIS	6.3				PP 468, 469						5.4.1	APP D	APP III				ALL		5			ALL	ALL		
RELIABILITY CRITICAL ITEMS											5.2.6														
PARTS & MATERIAL CONTROL PROGRAM																									
DESIGN REVIEW											5.2.7					3.0									
PROGRAM PLAN						PP 2-3 2-25					4.4								2.3						

MICROSOFT EXCEL

Fig. A2. Note: References are identified in Sect. A.5. The numbers in the matrix refer to the applicable paragraphs of the documents referred to.

evaluating whether stated requirements or objectives are achievable, enables the selection of alternate viable configurations, identifies reliability problem areas, and provides information for redirection of the program into more productive areas when necessary. The procedure for coupling, or comparing availability design requirements with predicted availability, is shown in Fig. 4.4. Frequently, apportionment and trade-off studies go together so that the overall goal is apportioned in a manner that will optimize some other important parameter, such as total cost or number of independent loops. For this reason, apportionment and trade-off studies are best done early in the design stage while configuration changes are possible. Unless this preliminary work is performed, the RAM program and system designer should be alert to stated availability goals that are not compatible with the required systems configuration and state-of-the-art design. The overall tasks of apportionment, especially when exercised with trade-off studies, require an analyst with a high degree of skill and experience.

A.3.3 FAILURE MODES AND EFFECTS ANALYSIS

Failure modes and effects analysis (FMEA) is performed to identify all significant component failure modes and the effects of failure on the operation of the system. It is an iterative process of a systematic nature for proceeding item-by-item through the system, from lower levels through the higher levels of assembly, to assess failure consequences. The FMEA may use either actual failure modes from vendor field data or hypothetical failure modes derived from design analyses, reliability prediction activities, and experience relative to the manner in which components may fail. The failure modes are analytically deduced for each component, and failure effects are evaluated and noted, including severity and expected frequency (or probability) of occurrences. Test results also are used, when available, to augment the analytical findings.

The FMEA is the basis for many of the reliability engineering tasks described in Sect. 4 and is almost always performed, although it may not be formally documented for publication. Throughout the course of a system design, the FMEA should be reviewed and updated to reflect design changes and new sources of information from vendors, field data, or tests.

The FMEA may well require the most effort of any single reliability task in the list of tasks. However, a well-done FMEA likely will save subsequent effort and avoid errors in the performance of other tasks. By determining the effect of failures on the total system, the FMEA can support appropriate studies in the areas of safety related reliability and operating plant availability and related studies in maintainability. It provides the information needed to prepare a model and carry out apportionments, trade-offs, and sensitivity studies. Although the FMEA is basically a single-failure analysis and may be used to satisfy such a requirement, it also provides an excellent background for common cause failure analysis, especially if extended by consideration of the failures cascading into secondary failures.

Top-level or system-level FMEAs are performed to evaluate the consequences of system-level failures. Lower-level FMEAs are performed to evaluate the consequences of lower-tier failures and may be justified only when the system-level failure consequences are unacceptable.

Frequently, the FMEA is a joint effort linking design engineering with reliability engineering. The reliability engineer can contribute a format and discipline for the study and ask key “what if” questions probing for failure modes and mechanisms. The design engineer contributes his or her detailed knowledge of the equipment system, including how it functions and how it copes with component failure. The result often can be a more thorough probing than could be done by either engineer alone and a greater transfer of knowledge and perspective across the normal disciplinary boundaries.

Typically, the FMEA generates many pages of material on large-sized worksheets. Reducing this to a readable format for publication is a major effort, and the expense may not be warranted in view of the rather limited readership. In lieu of full formal publication, the RAM program may choose to publish only the information that leads to an identification of the "reliability critical items" in summary form as formal documentation. In this event, the original worksheets become a part of the design record file and are subject to QA audit, as applicable.

A.3.4 MODELS

A model is a logical way of showing the interrelationships between the items that make up an equipment system and the attendant response as a result of failed items and other events. Many equivalent ways exist to model a given system, the most popular being event tree analysis, fault tree analysis, reliability block diagrams, truth (or state) tables, and Markov state diagrams. Any method that depicts relevant information in a form that is condensed, logical, and accurate is acceptable.

Models are employed to relate the arrangement and operational configuration of systems to those factors that impact RAM. Development of the model requires design evaluations of the system characteristics. Its basis will be the collection and analysis of data combined with failure modes relating system and equipment failures to environmental parameters, fabrication, testing, operation, and maintenance factors. The model is formulated to facilitate quantitative assessments of the equipment systems as they develop to define a basis for developing design improvement recommendations and to provide a capability for measuring system reliability status versus the reliability requirements and objectives.

A.3.5 PREDICTION

Prediction is the quantitative assessment of the RAM of a system during its design, development, and preoperational stages. It is a continuous process employed to provide evidence that requirements and objectives will be met. Prediction is obtained by determining the RAM of the lowest system level and proceeding through intermediate levels until the total system is reviewed. The prediction is based on appropriate logic diagrams, mathematical models that are time oriented, failure rates, failure distributions, environmental factors, test intervals, repair (renewal) rates, repair distributions, and system operating profiles. Factors to be included in the prediction are functions, duty cycle, failure modes, minimum acceptable system configuration, and others. The prediction is compared to the apportioned values to determine whether requirements and objectives are met.

In general, accurate predictive calculations for models are time consuming and expensive. Because data used in the prediction may be highly uncertain, an analysis of the propagation of uncertainties may be useful. The analyst may make approximations and simplifications as long as it can be shown that they do not bias or invalidate the result. Someone highly skilled in reliability assessment should direct the work and interpret the results.

A.3.6 TRADE-OFF STUDIES

Trade-off studies are analyses of alternate equipment designs for comparing the relative RAM of each viable alternate or configuration. The studies are conducted relative to mechanical, electrical, and thermal considerations; component quality; redundancy and diversity; built-in test equipment; ease of maintenance, and other considerations that may be defined in the course of design and development.

Trade-off reliability studies usually are done at the time the system configuration is being selected and in conjunction with the apportionment of overall goals. Thus, it is generally a task performed early in the design process. However, on highly developmental systems, configuration changes occasionally occur relatively late in the design cycle because of unforeseen difficulties in hardware or process development. Thus, it may be advantageous to keep the models current for this contingency.

These studies require not only an expertise in modeling but also a knowledge of equipment and cost. For this reason, they are best done as a cooperative effort between design and reliability engineering. In addition to providing a comparison of viable alternates, the trade-off studies provide information on the reliability-sensitive factors of the design and identify potential problem areas.

A.3.7 SENSITIVITY STUDIES

A sensitivity study is performed to determine the relative importance of the variations that can occur in a given function caused by changes in one or more parameters. Component failure rates, test intervals, repair times, etc., may be assessed to determine the effects on system reliability and availability. Then, the weakest elements may be identified and appropriate corrective action implemented.

Sensitivity studies are performed to fine-tune the design, to identify additional reliability critical items, and to identify areas of over-conservative design that are not cost-effective. They also may be used to optimize goal apportionments or trade-offs. After the design configuration is firm, sensitivity studies may be used to determine surveillance intervals and appropriate stocking levels of spare parts and to optimize repair activities. Sensitivity studies may be performed by a person of modest skill under competent supervision after the model and prediction tasks are done.

A.3.8 MAINTAINABILITY

Maintainability analysis provides the design and operational bases for ensuring that all required maintenance actions are complete and efficient and that they do not degrade the reliability or availability characteristics of the system. From analysis, maintenance information is developed for identifying limited-life items whose characteristics are incompatible with design-life requirements, establishing spares provisioning, establishing schedules and procedures to accomplish the preventive maintenance tasks at regular intervals, and establishing the maximum times for completion of maintenance actions. Maintenance considerations allow for reasonable ease of item repair or replacement, capability of on-line repair whenever possible, and performance of the actions within existing capabilities of personnel and equipment. Maintenance features provided primarily to enhance overall plant availability shall be examined carefully to avoid potential degradation of safety related reliability. Maintainability analysis is performed simultaneously with, and as an adjunct to, the various reliability engineering tasks described in this document.

A.3.9 AVAILABILITY

Availability analysis is used to determine the probability of a repairable system being in service during a scheduled operating period. In this application, a repairable system is one that is restored to service after a failure has occurred. Both availability and maintainability apply to repairable system analyses. In a repairable system, availability and maintainability assessment is a form of probability analysis that is very similar to that used for assessing the reliability of a system not intended for repair and restoration to service.

A.3.10 COMMON CAUSE FAILURE ANALYSIS

Common cause failure analysis is employed to identify events that could result in the simultaneous disabling of two or more independent equipment systems within a given critical time span. The results of common cause failure analysis are used to identify equipment functional deficiencies and design weaknesses and ensure that design diversity is employed to the extent required to reduce the probability of common cause failures affecting redundant items.

A.3.11 PHYSICS-OF-FAILURE

The physics-of-failure investigation is performed to determine what initial or induced nondestructive defects can be introduced into a part using the operating environment and the subsequent resulting failure modes. The physical mechanism by which a defect is introduced and the physical mechanism by which failure occurs are determined by this process. Physics-of-failure investigation is most useful in ultimately solving recurring failures in field or test experience. For physics-of-failure analysis, the scope of analysis shall be defined by the RAM program.

A.3.12 TESTING FOR RELIABILITY

Confirmation of analytically derived reliability and maintainability assessments and validation of design modifications based on such assessments are conducted in part by analysis of test data. To the extent possible, testing only for reliability purposes will be minimized through the examination of data from operating experience and data from existing tests or by appropriate test modification. However, as a necessary aspect of the overall test program, specific reliability or maintainability tests will be conducted for certain key critical equipment items.

A.3.12.1 Test Program Elements

Test planning and integration. Test data required either for analytic inputs or for validation of results will be identified or scheduled as early as possible in the program. All planned tests are examined to determine which ones may yield this information. The schedule and nature of development, qualification, and acceptance tests are sources of reliability data. If minor modifications or additions to existing tests allow extraction of the desired information, recommendations for such changes are made. In making such recommendations, considerations are given to potential dilution of the original test purpose, effects on test schedule and cost, and the existence of alternate, more efficient test data sources or procedures.

Test data review. Test data are systematically reviewed for possible reliability and maintainability implications. These may include detection of unanticipated failure modes, common-cause failures, single-point failures, deterioration in service, deviations from analytical assessments, and design improvement potential.

Test plan. A test plan specific to each component development test shall be prepared by the responsible task. The test plan shall consist of a flow chart, diagram, or narrative description of all test activities. The plan shall identify and schedule the required tests, schedule the review of test data, summarize the purpose of each prescribed test (e.g., the characteristic to be measured, method of measurement, and applicable acceptance criteria), and use other information as appropriate. The test will present a summary of all planned test activities and their various interrelationships.

Test procedure. Detailed test procedures will be prepared by the performer. Major paragraphs of the procedure shall include the following:

- purpose,
- applicability,
- reference equipment,
- detailed implementation procedures, and
- acceptance criteria.

Test notification. All tests performed by a subcontractor may be witnessed by the RAM task members at any of the facilities used by the subcontractor. However, the choice by the RAM task group not to witness any test will not be construed as a waiver of that test. Advanced notice of the initiation of the prescribed tests will be provided to the RAM task group as specified in the statement of work.

A.3.12.2 Reliability Tests

Tests specifically formulated for obtaining reliability information will be designed as reliability tests. Such tests will be conducted when a clear necessity for the data is indicated and data from completed, existing, or planned tests are believed to be inadequate. The following types of tests will be considered.

Parameter or distribution evaluation. Parameter or distribution evaluation tests will be conducted to determine the numerical value of a parameter (failure rate, mean time to repair, life, etc.) or to determine the mathematical nature of a failure or repair distribution (normal, exponential, Weibull, etc.) for a particular device. In certain circumstances, both parameter and distribution information may be required. For example, unit-to-unit variability in material properties, dimensions, duty cycle, handling, environmental time histories, and other areas may dictate the need for a sufficient sample size to verify operational reliability characteristics.

Environmental sensitivity. Environmental sensitivity tests will be performed to determine the effect of various environmental stresses on the device undergoing test. Such tests differ from the usual environmental and qualification tests when accelerated time or stress methods, or both, are employed. The purpose of environmental sensitivity tests is to determine the boundaries of operation when earlier tests have not incorporated various environmental conditions subsequently deemed to be significant.

Demonstration. Demonstration tests will be conducted to verify that a quantitative reliability requirement has been achieved. When demonstration tests are formulated, the test descriptions shall include formal decision criteria, definition of failure, provisions for voiding the test, and quantitative indication of hypothesis risks (i.e., probabilities associated with making incorrect decisions).

Tests other than those specified may be recommended by a subcontractor. The specification of tests by the RAM task does not relieve the subcontractor of responsibility for ensuring the reliability of the component systems covered by the contract.

A.3.12.3 Test Report

A test report shall be prepared for each test and shall contain the following information:

- title page,
- table of contents,
- summary,
- objective of test,
- equipment tested,
- test facilities and equipment,
- test procedures,
- test data,
- certification of test results,
- test evaluation, and
- conclusions and recommendations.

A.3.13 DATA COLLECTION AND TREND ANALYSES

Reliability data may be derived from data-collection programs, analyses of operational and test experience, engineering judgment, and Bayesian analysis. Provisions will be made for the collection, analyses, updating, storage, and efficient dissemination of such information for use in the design of the component system.

A.3.14 CRITICAL ITEMS

Critical items are items whose failure could affect significantly the ability of a component system to perform its function effectively or safely. The critical items list can identify all components that (1) perform critical functions, (2) are reliability sensitive, (3) have long procurement times and limited life, (4) require formal statistical qualification, and (5) are high-cost items. The critical items list will be prepared and maintained throughout the component development program for the system. QA programs, special reliability studies, special maintenance and handling considerations, and reliability improvement programs shall be implemented for critical items as necessary to ensure that each item is acceptable for its intended application.

The identification of items in the component system design believed to be critical from the standpoint of reliability or availability is an excellent way to bring the importance of reliability matters into central focus. The earliest identification may be purely qualitative, perhaps derived from the FMEA. The list is periodically updated as the design progresses, as test results become available, and as further reliability studies are performed. A critical items list is a valuable management tool allowing management to deal with the most important reliability problems. The list simply reflects the state of knowledge at a given point in time. It is one of the least-expensive reliability tasks in the project's lifetime.

A.3.15 PARTS AND MATERIALS SELECTION PROGRAM

The parts and materials selection program will ensure that the piece parts, materials, and components selected in the design process enable the component system to meet the established requirements. It also will minimize the number and types of different items used in the system. This program is particularly important in controlling critical items and maintaining standardized piece parts and designs.

The components PDR, SDD, or E-SPEC will establish criteria to control the selection and application of parts and material. The selection process should include design analysis, reliability-experience review, failure analysis, screening, cost-effectiveness studies, and an application review and approval procedure. A controlled parts and material list will be prepared and implemented so that no drawing, specification, or other design definition document may contain or use any part of material not incorporated on the list. Furthermore. a continuous effort shall be pursued to standardize the design and manufacture of component system equipment.

A.3.16 DESIGN REVIEWS

Design reviews are conducted to assess the adequacy of the design with respect to criteria and requirements and to ensure that no deficiencies exist that could adversely affect safety, performance, or RAM. The reviews should be comprehensive and critical of all pertinent aspects of systems design. Formal design reviews are planned and scheduled as an integral part of the major design review and identified in the RAM program plan. Each design review and the necessary follow-up actions and closeouts will be documented in a report. Other mechanisms of the review, including attendees, review checklists notification, and other requirements of applicable QA program requirements documents, will be employed. When practical, design reviews should be scheduled and held during conceptual, intermediate, and final stages of system design. Equipment system RAM will be addressed in all design reviews.

APPENDIX B

REFERENCES

REFERENCES

Ref. no.

1. *Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems*, ANSI/IEEE 353-1975, Institute of Electrical and Electronics Engineers, New York, 1975.

2. *Reliability Manual for LMFBRs*, Volumes 1 and 2, SRD-75-064, General Electric Co., Schenectady, New York, December 1975.

3. J. M. Harrer and J. G. Beckerley *Nuclear Power Reactor Instrumentation Systems Handbook*, Vol. 1, Chap. 11, TID-25952-P1, Office of Information Services, U.S. Department of Energy, Washington, D.C., May 1973.

4. W. G. Ireson *Reliability Handbook*, McGraw Hill, New York, 1966.

5. E. O. Coidier "Reliability Growth in Real Life," pp. 458-69 in *Proceedings Annual Symposium on Reliability*, Boston, Massachusetts, January 16-18, 1968, Institute of Electrical and Electronics Engineers, Inc., New York, 1968.

6. E. F. Bjoro "Establishing and Defining the Reliability Engineering Program," *Reliability Engineering*, Chap. 2, ed. P. H. Zarger, American Society for Quality Control, Milwaukee, Wisconsin, 1968.

7. *Military Handbook, Reliability Prediction of Electronic Equipment*, MIL-HDBK-217B, U.S. Department of Defense, Washington, D.C., September 1974.

8. *Military Standard, Maintainability Demonstration*, MIL-STD-471A, U.S. Department of Defense, Washington, D.C., March 1973.

9. *Military Standard, Reliability Prediction*, MIL-STD-756A, U.S. Department of Defense, Washington, D.C., May 1963.

10. *Military Standard, Reliability Tests Exponential Distribution,* MIL-STD-731B, U.S. Department of Defense, Washington, D.C., November 1967.

11. *Military Standard, Reliability Program for Systems and Equipment Development and Production*, MIL-STD-785A, U.S. Department of Defense, Washington, D.C., March 1969.

12. *Guide to the Collection and Presentation of Electrical, Electronic, and Sensing Component Reliability Data for Nuclear Power Generating Stations*, IEEE Std 500, 1977, Institute of Electrical and Electronics Engineers, New York, 1977.

13. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, WASH-1400 (NUREG-75/104), U.S. Nuclear Regulatory Commission, October 1975. Available from National Technical Information Service, Springfield, Virginia 22161.

14. C. Lipson and N. J. Sheth, *Statistical Design and Analysis of Engineering Experiments,* McGraw-Hill, New York, 1973.

15. O. Locks *Reliability, Maintainability, and Availability Assessment*, Hayden Book Company, Inc., Hasbronck Heights, New Jersey, 1978.

16. *Quality Assurance Program Manual (QAPM) for the Consolidated Fuel Reprocessing Program*, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, April 1979.

17. *Component Failure-Rate Data with Potential Application to the Hot Experimental Facility*, DPST-CFRP-80-113, E. I. du Pont de Nemours & Company, Savannah River Laboratory, Aiken, South Carolina, December 1980.

18. R. E. Barlow and F. Proschan, *Statistical Theory of Reliability and Life Testing Probability Models*, published by To Begin With, Silver Spring, Maryland, 1975.

19. *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*, NUREG/CR-2300, draft, September 28, 1981. Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, D.C.

20. A. S. Goldman and T. B. Slattery, *Maintainability*, John Wiley and Sons, Inc., New York, 1964.

21. *Fault Tree Handbook*, NUREG-0492, U.S. Nuclear Regulatory Commission, Washington, DC, 1981.

22. M. J. Haire and E. H. Gift, *Reliability and Maintainability Data Acquisition in Equipment Development Tests*, ORNL/TM-8525, Oak Ridge, Tennessee, May 1983.

23. M. J. Haire and E. H. Gift, “A Guide for Reliability and Maintainability Data Acquisition,” pp. 377-384 in *Risk Analysis in the Private Sector,* Plenum Press, New York, 1985.

24. J. G. Maltese et al., *The Availability of Reprocessing Plants That Use Various Maintenance Concepts*, ORNL/Sub/82-384031, Oak Ridge, Tennessee, August 1983.

RELATED REFERENCES

1. 10 CFR 50, Appendix A, “General Design Criteria for Nuclear Power Plants,” GDC 1, “Quality Standards and Records.”

2. DOE 5480.30, ¶ 8.c.(2), Quality Standards.

3. 10 CFR 50, Appendix A, “General Design Criteria for Nuclear Power Plants,” GDCs 18, 32, 36, 39, 42, and 45 with respect to designing to permit inspection.

4. DOE 5480.30, ¶s 8.d.(2)(b); 8.d.(1)(d); 8.d.(6)(d); 8.c.(8); and 8.d.(6)(e) with respect to designing to permit inspection.

5. 10 CFR 50, Appendix A, “General Design Criteria for Nuclear Power Plants,” GDCs 18, 32, 37, 40, 43, and 46 with respect to designing to permit testing.

6. DOE 5480.30, ¶s 8.d.(2)(b); 8.d.(1)(d); and 8.c.(8) with respect to designing to permit testing.

7. DOE 1324.2A, “Records Disposition”

NOTE: Prior to RAM, ensure that the systems are designed appropriately and can be inspected and tested.