CLINCH RIVER

BREEDER REACTOR PROJECT

PRELIMINARY SAFETY ANALYSIS REPORT

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PROJECT MANAGEMENT CORPORATION

TABLE OF CONTENTS

Amend. 68
May 1982

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Amend. 68
May 1982

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Amend. 68
May 1982

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Amend. 68
May 1982

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Amend. 68
May 1982

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

PSAR Appendix C

SAFETY RELATED RELIABILITY PROGRAM

Table of Contents

Table of Contents (Cont'd)

List of Tables

List of Figures

C.1.0 Introduction

C.1.1 Program Objectives

This appendix provides a description of the objectives, scope, method of implementation and current status of the CRBRP Reliability Program. The basic objective for this program is to provide additional assurance (beyond the normal design process) that the probability of exceeding the radiological release guidelines defined in 10CFR100* is acceptably low. The focus of the program is on those safety related systems which act to prevent accidents which result in potential radiological release.

Licensing requirements and associated Regulatory Guides currently in use on thermal reactors are directed towards the goal of prevention of significant radiological release. Where those requirements and guides are applicable to LMFBR's, they are being applied to CRBRP. The basic design of the safety related systems in CRBRP therefore provides a level of protection against radiological release comparable to that provided in thermal reactors. Features of the safety related systems in CRBRP however differ in some respects from those in equivalent thermal reactor systems. In view of these differences, it was considered prudent to devote additional effort to the design, development testing, fabrication, shipping, installation, operation and maintenance of the safety related systems for CRBRP. The CRBRP Reliability Program is one of the principal vehicles for the application of this additional effort.

Radiological release guidelines are specified in 10CFR100* in terms of the potential biological doses received by individuals located at the boundaries of the exclusion area and low population zone. A broad interpretation of the Reliability Program objectives would involve a reliability evaluation of systems having an effect on accidental radioactive dose at the appropriate boundary. It is important to note however that event chains postulated for significant radioactive doses at the appropriate boundary involve the loss of coolable geometry in components and assemblies containing radioactive species. The program objective can therefore be conservatively restated as one of preventing the loss of coolable geometry in components and assemblies containing radioactive species. This more conservative program objective was adopted to gain the important advantage of being able to focus the Reliability Program resources on the more important safety related systems.

C.1.2 Reliability Program Focus

All significant quantities of radiological species in CRBRP are housed in one of six locations. These are (a) the ex-vessel storage tank, (b) the ex-vessel transfer machine, (c) the primary cold traps, (d) the radwaste system, (e) the primary coolant and (f) the reactor core. Each of

*10CFR100 defines whole-body and thyroid dose guidelines while equivalent guidelines for lung and bone doses are used as defined by NRC guidance received in the letter from Denise to Caffey dated May 6, 1976.

these potential sources for release of radiological species was evaluated during the initial stages of planning the Reliability Program. The objective for this evaluation was to determine where the Reliability Program resources should be applied in order to maximize the benefit from the program. As a result of this evaluation, it was determined that the focus of program activities should be on prevention of loss of coolable geometry in the reactor core. Rationale backing this conclusion are summarized in the following paragraphs.

Ex-Vessel Storage Tank (EVST)

Fuel assemblies within the EVST are stored in a sub-critical configuration in sodium filled pots. The centerline spacing of adjacent fuel assemblies is in excess of 9 inches. The combination of this centerline spacing and the additional structural barriers provided by the core component pots effectively precludes any possibility of fuel failure propagation within the EVST.

Heat transfer from the stored fuel assemblies to the cooling sodium within the EVST will normally be accomplished by forced convection provided by two redundant cooling loops. In the event that both forced circulation loops should be unavailable, a third independent and diverse loop is provided to maintain acceptable temperatures within the EVST. This loop utilizes natural circulation for heat transfer from the source to the sink and has no external power requirements. The EVST is also equipped with a guard vessel which prevents lowering of the sodium level to a point where cooling of the stored fuel array would be impaired.

Based upon these considerations, it was concluded that no credible mechanism existed whereby a major portion of fission product inventory of the stored fuel in the EVST could be released to the atmosphere of the reactor service building.

Ex-Vessel Transfer Machine (EVTM)

Fuel is transported from the reactor to the EVST in the Ex-Vessel Transfer Machine (EVTM). During transportation, fuel is housed in a sodium filled core component pot within a sealed compartment. Redundant seals are provided where they cannot be reached by sodium. The EVTM has been designed such that, even if all the sodium were to leak from the core component pot and allow fuel cladding melting, the seals will maintain their function (see Section 15.7.3.1 of the PSAR). Reactor Service Building exhaust filtering provides margin to accommodate releases in the event both seals failed after a release of fission gas into the EVTM.

Primary Cold Traps

Each cold trap consists of an economizer and a crystallizer tank. Primary sodium impurities, including fission products released to the coolant from failed fuel pins, are condensed and deposited on collector sites in the crystallizer. The cold trap is located within an inerted steel lined cell.

For the purpose of assessing the potential magnitude of a release of radioactive species from the cold trap, a rupture of the crystallizer tank was assumed followed by a sodium fire. The radioactive inventory in the cold trap was assumed to be that resulting from 15 years operation with 0.5 percent failed fuel. Leakage from the reactor containment building (RCB) to the confinement annulus was based upon a very conservative estimate of the RCB overpressure. The mitigating effect that the confinement annulus has on leakage to the atmosphere was neglected. Resulting irradiation doses were calculated for the site boundary location and a number of downwind locations. Results from this analysis (provided in Section 15.7.2.7 of the PSAR) indicated that large margins existed between the potential doses and the applicable guideline values. It was concluded that a malfunction of the cold trap system would not result in a violation of the 10CFR100 and equivalent guidelines previously outlined.

Radwaste System

The liquid radwaste system utilizes components such as evaporators, demineralizers and filters whose performance has been demonstrated in LWR's. Operating procedures and tests will assure that the system is performing as designed and within technical specifications.

Analysis has been performed for a postulated failure of a tank containing the largest inventory of radioactivity in the liquid radwaste system, i.e., the radwaste collection tank. This analysis is provided in Section 15.7.2.5 of the PSAR. An analysis of the effects and consequences of the event has been performed assuming no credit for the cell floor drains or operator actions. Postulated gaseous and liquid releases associated with this tank failure have been shown to be well within specified limits.

The gaseous radwaste system utilizes components such as cryostills and charcoal absorber beds which process and purify reactor cover gas and, as necessary, gas from inerted cells. Selected tests are to be performed during scheduled plant outage periods to ensure that components are performing consistently within specifications.

Analyses have been performed for postulated component failures for equipment which could contain significant inventories of gaseous radwaste. Design features for the CRBRP include permissible leak rate containment specifications and testing provisions, as necessary, to achieve off-site consequences in compliance with Federal guidelines. Preliminary analyses provided in Section 15.7.2.4 of the PSAR indicate that off-site consequences of postulated events for the gaseous radwaste system will be in conformance with specified limits.

Primary Coolant

The primary coolant will become radioactive from activation of the sodium and from release of radioisotopes from fuel pins in the core. A program has been established to assure the integrity of the primary coolant boundary (see Section 1.6 of the PSAR, Reference 2). A sodium leak detection system is provided to detect small leaks so that operator action can be taken to limit leakage. In addition, inert atmosphere, cell liners and the containment isolation system limit the consequences of postulated leaks to well below the specified limits (see Section 15.6.1.4 of the PSAR).

Reactor Core

Fuel located within the core represents a major inventory of radioactive species. Prevention of the release of radioactive species from the core must be accomplished by means of the reliable operation of the appropriate safety related systems. This reasoning led to the emphasis in the Reliability Program being placed on those systems, the malfunctions of which could lead to a loss of coolable core geometry. Loss of coolable core geometry is believed to occur following cladding melting. For the purposes of the Reliability Program evaluation it has been conservatively assumed that loss of coolable geometry will occur at the onset of coolant boiling.

Postulated events which could lead to the loss of coolable core geometry can be divided into three categories. These are (a) events which result from the failure to shutdown power generation within the core when required, (b) events which result in a failure to remove the residual heat from the core in its shutdown condition and (c) fuel failure propagation. The systems designed to perform functions which would prevent these failures are the Reactor Shutdown Systems (RSS) and the Shutdown Heat Removal Systems (SHRS). The focus of the Reliability Program activities is therefore on reliability enhancement and verification of these systems (RSS and SHRS). Interfacing equipment and systems are included in the scope of the program when their malfunction could result in a safety related malfunction of either the RSS or the SHRS. Fuel failure propagation evaluations presented in Section 15.4 of the PSAR eliminate consideration of that failure mode as a potential initiator of significant radiological release.

The RSS is comprised of a primary shutdown system and a secondary shutdown system. As a safeguard against common cause failures, these systems differ substantially both in design and mode of operation of electronic and mechanical components. Major segments of the Reliability Program are devoted to the primary and secondary shutdown systems.

Shutdown heat removal capability is provided via four redundant heat removal paths. Three of these paths utilize the three heat transport loops. The normal short term heat sink for these loops during reactor shutdown is the turbine generator condenser. In the event of failure of this heat sink, a backup heat sink is provided. The backup heat sink utilizes steam release to the atmosphere and an auxiliary feedwater system to provide an initial high capacity heat sink coupled with protected air cooled condenser heat exchangers for long term heat rejection. The protected air cooled condenser heat exchangers are also used during normal long term shutdown.

The fourth shutdown heat removal path is via the Direct Heat Removal Service (DHRS). The DHRS makes use of the sodium overflow-makeup system to extract hot sodium from the reactor vessel and return cold sodium. Circulation of sodium through the core is achieved by means of forced circulation in the primary loops. Heat extraction from the sodium overflow-makeup loop is achieved via a heat exchanger located in the sodium makeup line. This heat exchanger is coupled to the EVST NaK cooling loops. Heat sink capability in this system is supplied by the EVST air cooled heat exchangers.

C.1.3 Program Design

The design of the CRBRP Reliability Program has been dictated by a number of key requirements and constraints. Some of these requirements and constraints would be common to any Reliability Program while others are unique to the CRBRP. The following paragraphs (a) identify some of the more important factors considered in the design of the program and (b) indicate how these factors influenced the selection of program features.

C.1.3.1 Design Integration

A basic ground rule set prior to the initiation of design work on the Reliability Program was that the primary objective for the program would be reliability enhancement in the RSS and SHRS. The intent of this ground rule was to ensure a direct integration of the Reliability Program and the component/system design activities. The most readily visible program feature stemming from this integration are the component level qualitative reliability assessments and the system level Reliability Design Support Documents. These documents are produced by the appropriate Design Engineering organization for items listed on the Reliability Related Components List (defined in Section C.1.4). The document is subject to approval by the Reliability organization. The requirement for the Reliability Design Support Document has the effect of ensuring direct Reliability Engineering involvement in the design process.

Reliability verification was set as a very important second objective. Reliability verification is achieved by a combination of component and system feature tests run under both design conditions and overload conditions coupled with qualitative reliability analyses at both the component and system levels and quantitative analysis at the RSS and SHRS levels.

C.1.3.2 Qualitative Reliability Analysis

The initial step in the qualitative reliability analysis is a preliminary total system Failure Mode and Effects Analysis (FMEA) for both the RSS and SHRS. Results from this analysis are used as a means of providing an initial identification of those system features having a significant impact on the overall system reliability.

Refinement of the system level FMEA is then achieved by rebuilding it from the component level up. The basic building block used in this process is the component level FMEA produced as a part of the component reliability qualitative assessments. This procedure for refining the system level FMEA was adopted as a means of assuring that the technology used in the design of many CRBRP components is reflected in an accurate and balanced manner in the reliability evaluations. Examples of this new technology are the high temperature design rules used in the design of outlet plenum and hot leg components and the irradiation effects (swelling, creep and ductility loss) technology used in the design of core components. Application of this technology is handled by specialists who are experts in their particular field. By requiring that the system level FMEA be reconstructed using FMEA's produced at the component level, the program assures that all necessary specialists, especially those who are experts in these specialized areas, are involved in the production of the FMEA building blocks. This process minimizes the potential for failure mode omission in areas of specialist knowledge.

At the component level, the failure mode criticality and probability ratings (detined in Section C.2.1) are related only to that portion of the RSS or SHRS directly impacted by the failure. The component designer does not make final judgments relative to the total system response to the failure of his component. This restriction is imposed to assure that component level failure mode impacts are not distorted by judgments based on an inadequate understanding of the system design.

The FMEA's contained in the component level qualitative reliability assessments are used by the system designers and reliability engineers to build system level qualitative assessments. In using the component level FMEA's to assess the system level effects, the system designer working with the reliability engineer reviews each component level failure mode and may modify its criticality and probability ratings based upon his knowledge of the total system response to the postulated failure. Typical of the factors considered in this reevaluation are system redundancy and the potential for common cause failures. The system level qualitative assessment is continuously updated as the component level input data are updated. The component level data are updated as the component proceeds through the various stages of design, fabrication, etc. System level FMEA's are used to guide the application of Reliability Program resources.

In performing the system level qualitative reliability analysis, special attention is paid to any failure mode or initiating event which has the potential to produce concurrent failure of more than one element of a system or more than one system. Failures in this category are termed common cause failures. Some of the measures adopted in the Reliability Program to provide protection against this type of failure include (a) imposing a requirement for diversity in the design of the RSS and SHRS, (b) requiring that essential safety related systems be redundant and have excess capacity and (c) performing evaluations and recommending corrective action to mitigate the consequences of any feature of a system or interfacing component which has potential susceptibility to common cause failures.

C.1.3.3 Quantitative Reliability Analysis

Quantitative reliability analysis plays an important role in the CRBRP Reliability Program. Its primary uses are (a) as a tool for the evaluation of systems (b) as a means for evaluating random independent failure modes, (c) as a decision aid for selecting between alternative designs, (d) as a guide for the design of the testing and analysis program and (e) as the basis for sensitivity studies to evaluate the range of unreliability due to uncertainties. As part of these evaluations, a top level system failure probability is calculated.

It is important to note that all the primary uses for the numerical reliability analyses are as aids in decision making. The analyses are not intended to demonstrate compliance with a top level system failure rate. The decision not to set a numerical failure probability requirement for the RSS and SHRS is a reflection of the current developmental nature of numerical reliability analysis in the field of nuclear safety systems.

An update of the reference (3) Preliminary Reliability Prediction for CRBRP SHRS will be available in January 1983. This will be the final SHRS reliability assessment update based on failure state block diagram modeling. Subsequent quantitative assessments will be based on the SHRS fault tree model being constructed for the CRBRP Probabilistic Risk Assessment. The primary reason for basing future reliability program numerical predictions and studies on the PRA fault tree model is the potential for additional level of resolution being modeled for SHRS and the supporting systems. This level of modeling will allow more extensive studies of potential for supporting systems interactions.

C.1.3.4 Test Program Rationale

Major objectives for the test program are (a) an identification to the appropriate design group of potential failure points in the design of the components/systems, (b) a deterministic evaluation of component/system performance margins as defined by the difference between the design operating envelope and the success envelope as defined by the test and (c) where possible to generate sufficient statistical data to be able to make meaningful probabilistic predictions of the component/system performance.

Tests that support the Reliability Program can be placed in one of three categories. These are: (a) component level or system feature tests, (b) system level tests and (c) materials tests. The tests are chosen on the basis of the criticality of the failure modes identified by the FMEA.

A significant segment of the test program is devoted to component tests and system feature tests. Tests performed at this level make possible the investigation of a wide range of conditions including overload conditions up to the point where failure may occur. A major objective for these tests is the identification of any areas of the design where reliability enhancement is desirable or necessary. The tests also result in the definition of the multi-dimensional success envelope for the component or system feature. The boundaries of this envelope can be compared with the boundaries of the design envelope for the component or system feature. This comparison provides a deterministic measure of the performance margin inherent in the component/system feature design.

System level tests are specified as appropriate to evaluate wear related phenomena, identify any failure modes which are real-time dependent (dormant failures), identify failure modes related to manufacturing variations, evaluate the effects of maintenance and operating procedures and identify failure modes associated with interface features not included in the component/system feature tests. Particular emphasis in the system level tests is placed on providing as exact a simulation as possible of the actual reactor operating environment (e.g., large sodium loops are used to provide a dynamic sodium environment in the case of the mechanical control rod system tests). Accelerated life system level tests are run to beyond the design life for the critical system components in order to confirm that the system design life does not lie close to a wear dependent failure boundary. Output from the system level tests provides a deterministic confirmation of the margins between the system design and success envelopes. The schedule for the system level tests necessarily lags that for the component and system feature tests. Any system level design problem uncovered in these tests, however, can still be corrected prior to operation of the plant equipment.

C.1.4 Program Implementation Procedures

Top level Reliability Program requirements for the RSS and SHRS in CRBRP are defined in the overall plant design requirements documentation. These requirements are interpreted by the Lead Reactor Manufacturer (LRM) in consultation with the CRBRP Project Office (PO) and then placed as mandatory requirements on the Reactor Manufacturers (RM's) responsible for portions of the RSS and SHRS. The LRM retains responsibility for overall coordination of the Reliability Program activities within the RM organizations. A key element of the administrative procedures set up by the LRM to assure the correct implementation of the Reliability Program activities within the RM organizations is the RM Reliability Engineering/Design Engineering Interface Definition Chart. When it is determined that interfacing functions falling under the responsibility of the A&E have a negative influence on acceptable operation of either the RSS or SHRS, then the PO will provide the direction to the LRM and A&E as necessary to reduce or eliminate this influence. Essential elements of this interface definition are illustrated in Figure C.1-1. The balance of this section is devoted to describing the interface features summarized in Figure C.1-1 and, where appropriate, providing the rationale backing the selection of the features.

An early action required of an RM involved in the implementation of the Reliability Program is a comprehensive review of the RM's internal engineering procedures. The purpose of this review is to identify all existing RM engineering procedures which must be updated to assure implementation of the

Reliability Program requirements. Modification of the engineering procedures makes compliance with the Reliability Program requirements mandatory and assures a Quality Assurance and program control overview of the program activities. Included in the listing of procedures which require modification are procedures relating to configuration control, design approval and supplier nonconformance/waiver approval. Modification of these procedures assures that Reliability organizations are involved in the approval of all aspects of the design, fabrication, shipment, installation, operation and maintenance of any item of equipment which is a part of or interfaces with the RSS or SHRS.

The procedures modifications outlined above are prepared by the RM Reliability Engineering group working with the RM Design Engineering group. In addition to the modification of existing procedures, implementation of the reliability requirements necessitates that a new procedure be generated. The new procedure requires and controls the generation and maintenance of a listing of the equipment and systems to which the Reliability Program requirements are to be applied. This listing is known as the Reliability Related Components List (RRCL). The list contains all items of equipment directly involved in the operation of the RSS and SHRS. Important interfacing, supporting systems are identified separately for appropriate reliability review.

Once the RM engineering procedure changes are in place, the Reliability Program requirements are placed on the RM Design Engineering organizations. The RM Design Engineering, Construction and Operation Organizations must then implement the Reliability Program requirements through all stages of design, procurement, fabrication, shipment, installation, operation and maintenance of the equipment. Verification of the correct implementation of the program requirements is obtained through the Quality Assurance review and audit activities. Additional verification is obtained by means of (a) a Reliability Engineering review of design review packages, waivers, nonconformance reports, etc. and (b) by the mandatory inclusion of a reliability review in the formal design reviews for each item of equipment on the Reliability Related Components List.

One of the special requirements imposed by the modified RM engineering procedures is for the production of a reliability document for each item of equipment on the RRCL. These documents are used as building blocks to construct a reliability evaluation of the total system.

Coordination of the Reliability Program output from the RM's is handled by the LRM. The LRM uses this output to assess the overall reliability of the RSS and SHRS. This assessment is used as an important indicator of the acceptability of the design of these systems.

All Reliability Program activities performed by the LRM and the RM's are subject to the direction and overview of the PO. The PO/LRM interface procedures used by the PO to direct and control the Reliability Program activities are similar in concept to those used to control the interface between the Reliability Engineering and Design Engineering groups within an RM organization. Details of the PO/LRM/RM interface are given in Figure C.1-2.

C.1.5 Appendix Content

The organization and content of the balance of this appendix are as outlined below. The intent of Sections C.2 and C.3 is to provide the background material necessary to place the subsequent Reliability Program description sections in the correct context.

Section C.2 provides a description of the analysis and testing techniques employed in the program.

Section C.3 contains a brief description of each of the systems included in the Reliability Program. The functions of the systems are described and the component parts identified. This section is provided as a convenience to eliminate the need for extensive reference to the main body of the PSAR.

Section C.4 provides the system designers' evaluation of their portions of the RSS and SHRS. Areas of system performance uncertainty are identified. A definition is provided of the Reliability Program activities necessary for the evaluation of the system performance uncertainties.

Sections C.5 and C.6 contain descriptions of the Reliability Program activities initiated to resolve the uncertainties identified in Section C.4. Results obtained to date from these activities are identified and discussed. The schedule for the production of results from activities still in progress is also discussed.

Section C.7 provides an assessment of the overall impact of the Reliability Program to date. Principal conclusions and design modifications stemming from the program activities are identified. The planned use of data from Reliability Program activities not yet completed is defined.

Addendum 1 contains a description of the test facilities for primary and secondary shutdown system tests.

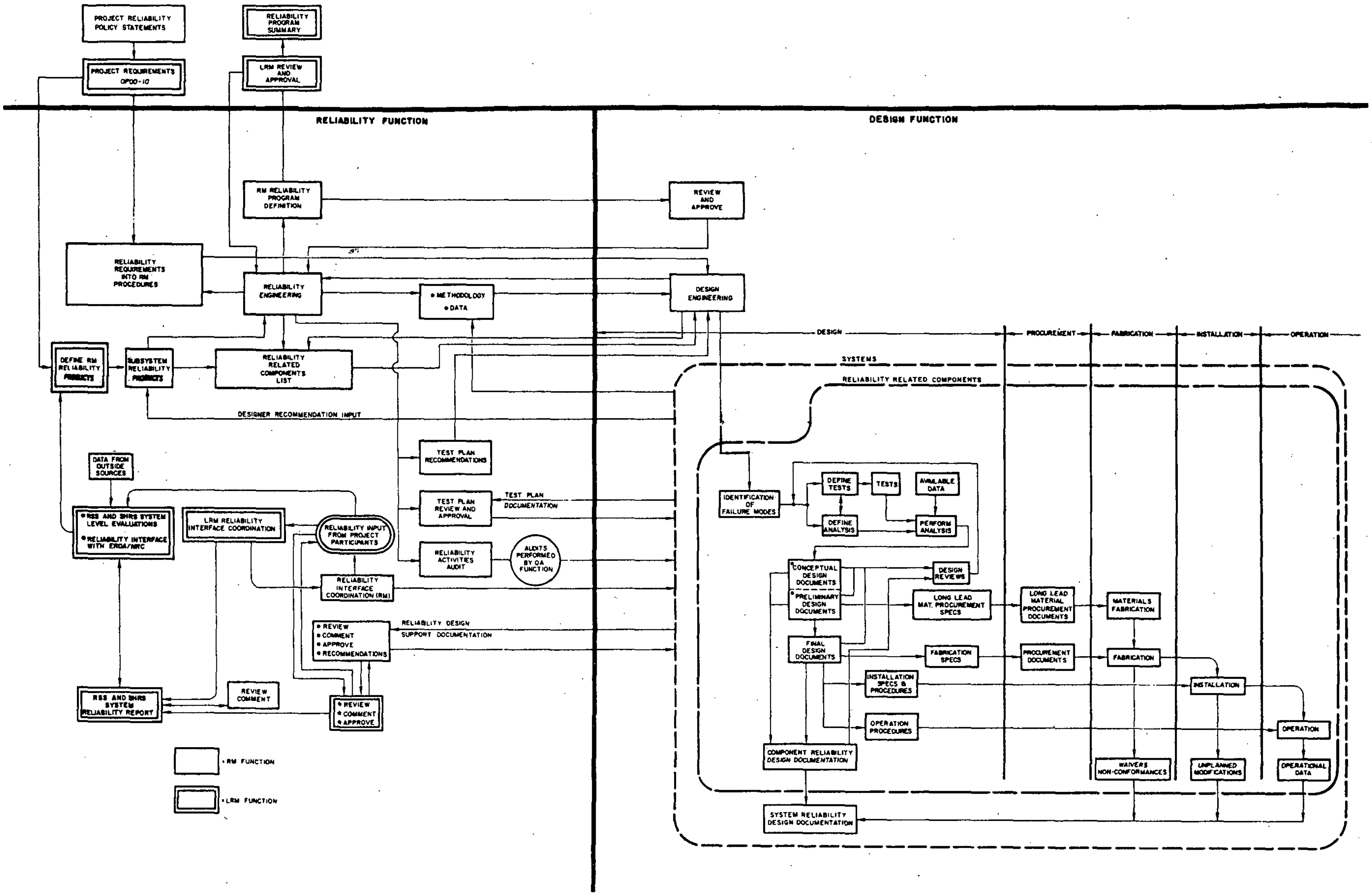

Figure C.1-1. RM Reliability Engineering/Design Engineering Interface Definition Chart

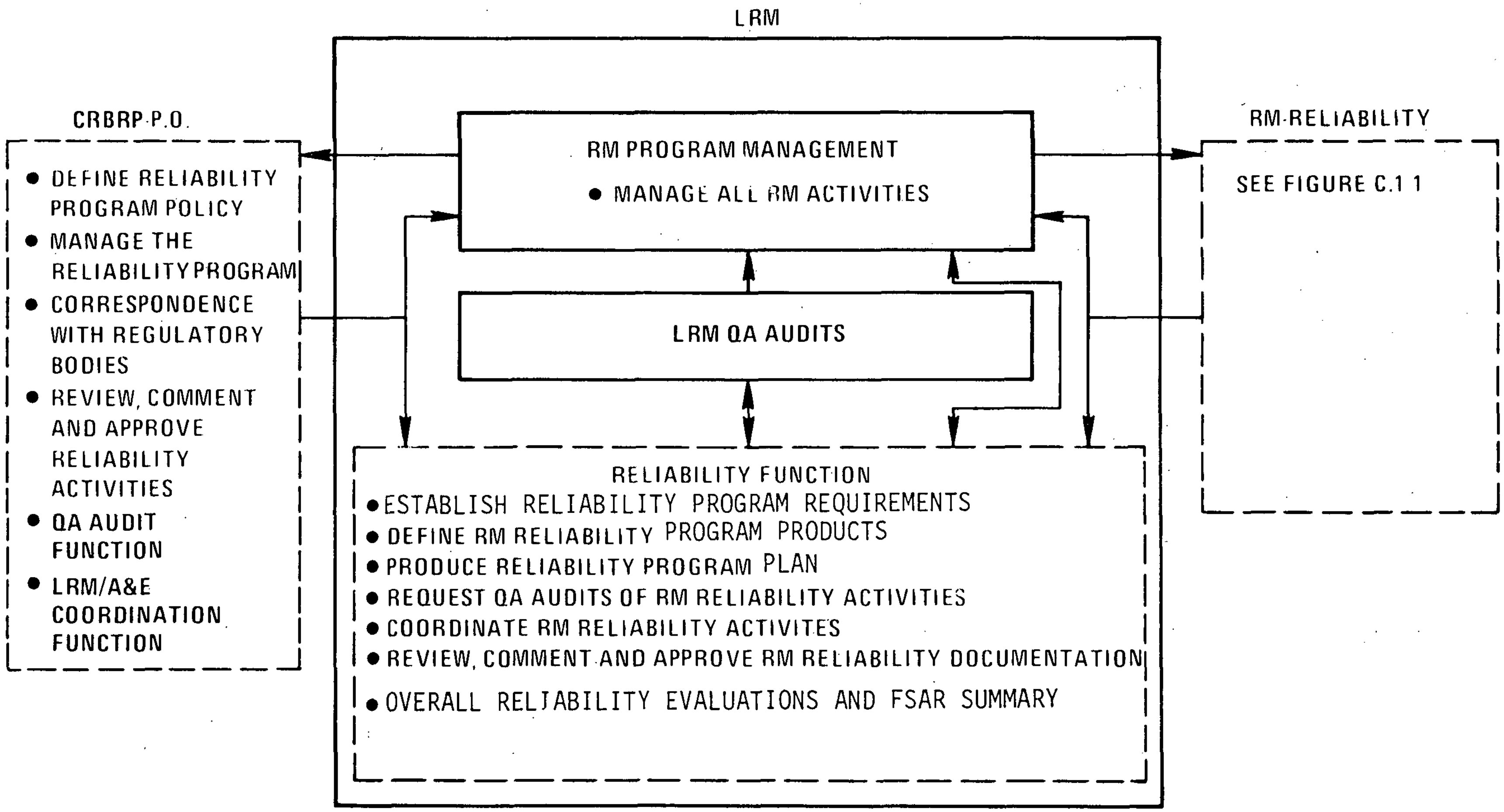

FIGURE C.1-2 PO LRM RM INTERFACE DEFINITION CHART

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Amend. 70
Aug. 1982

C.2.0 Program Guidelines

The purpose of this section is to review the process by which aspects of the RSS and SHRS having potential to degrade safety related reliability are identified and resolved. Conventional tools of reliability evaluation are being used to accomplish this task. These include Failure Modes and Effects Analysis (FMEA), common cause failure analyses (CCFA), testing and other methodology.

Figure C.2-1 shows diagramatically where reliability information is generated at each level of design and where this information is used. The remainder of this section provides a discussion of the activities shown in Figure C.2-1.

C.2.1 Component Level Evaluations

Failure Modes and Effects Analysis are the basic tool of reliability evaluation. They form the foundation upon which higher level evaluations are built. Failures critical to operational success are systematically identified and may be ranked according to both severity and probability of occurrence. These rankings are identified in Table C.2-1. Because of the technology (high temperature design, irradiation effects, etc.) involved in the design of individual components, it is essential that the component level FMEA be generated by the component design organization. To assure consistency of approach and continuity between component and system level evaluations, Reliability Engineering personnel are assigned to each component to support the evaluation. In several cases, a vendor with considerable experience in building the type of equipment under evaluation, (e.g., instrumentation and control devices, steam generator modules, etc.) was contacted to support generation of the FMEA. Typical output of the component level FMEA is:

- o A comprehensive list of failure modes
- o A list of potential causes
- o Component designers view of the failure effect and criticality
- o Initial estimate of the probability of occurrence

This output provides the initial assessment of design weaknesses and may result in immediate modifications (refer to Section C.7). It also is the first step associated with defining a test program. However, although estimates of criticality and probability of occurrence may be provided, they may be modified when aspects of redundancy and diversity are included in the system level evaluation. Because of the wide range of component types (structural members to electrical modules), the means for estimating probability of failure vary considerably. In some cases, meeting accepted code requirements may be deemed sufficient to indicate an acceptably low probability of failure. In other cases, considerable analysis may be required, especially if the failure has high criticality. Methods which are being employed to obtain failure probability estimates include stress/strength overlap, generic data and special testing designed to probe particular failure mechanisms. A further discussion of how estimates are made is provided in Section C.2.2.

All components which have the potential to impact successful operation of the RSS or SHRS are identified on a Reliability Related Components List (RRCL) produced by Reliability Engineering. An FMEA is performed for each of these components which then becomes the basis for categorizing the components according to failure mode effects. The reliability evaluation of each component is summarized in the Reliability Design Support Document at the component, component group, or system level.

Each component on the RRCL can be categorized as (a) degrading the functioning of the RSS or SHRS or (b) preventing the functioning of the RSS or SHRS. Those components on the RRCL are given a thorough review. Review of RRCL components includes all maintenance, shipping, installation and operation procedures, waivers and nonconformances as well as design documentation (specifications, drawings, design support documents, interface control data) and changes to those documents. Reliability Engineering is a participant in design reviews for all components on the RRCL.

The Reliability Design Support Document summarizes the activities performed to demonstrate achievement of reliability objectives. These reliability assessments are included as part of the equipment design support packages. The assessments are similar in character and stage of development to the other design support analyses in the package (e.g., stress, thermal/hydraulic, shielding, etc.). Reliability assessments include coverage and interpretation of all supporting development testing activities. Typical design support documents include (a) the FMEA's, (b) an assessment of critical failure modes to show design features to preclude or control the failure and (c) an assessment of common cause failure potential.

C.2.2 System Level Evaluations

System level evaluations are performed to relate detailed failure information to its impact on system performance. Just as a component designer is most qualified to assess the failure mechanisms associated with his component, the system designer must place each failure mechanism in perspective relative to overall system objectives. Although a component designer may indicate on an FMEA a high probability of failure or high criticality, when system considerations are included, these factors could change significantly. Some important considerations used to influence a change in criticality between the component and system level evaluations include:

- o Are other components which perform a similar function susceptible to the same failure mechanism?
- o Is the system in which the component is used redundant?
- o Can this failure initiate other failures that may affect the RSS or SHRS?
- o Can the component failure initiate failure of the entire RSS or SHRS?

A system viewpoint is especially important when determining if a design change is required to achieve adequate reliability. Both quantitative and qualitative evaluations are performed at the overall system level.

C.2.2.1 Numerical System/Subsystem Evaluations

Initially, a numerical evaluation is made based on random independent failure potential using component failure rate estimates. While it is recognized that random independent failure rates constitute only a part of the total failure probability, these assessments serve three important functions:

1) They provide an indication of the inherent system reliability if common cause failure potential is eliminated or controlled.

2) Components having greatest impact on predicted reliability are highlighted for priority attention in future evaluations.

3) They aid the designer as a decision-making tool for evaluating design changes.

The analytical techniques which have been applied to the system level numerical evaluations are success state, failure state and Markov modeling.

Success state or failure state modeling are techniques used to analyze a system's reliability on the basis of the system's and component's operational states. A logic block diagram is produced to display the system components and the logic associated with their configuration. From this diagram, different component failure combinations are evaluated to determine their effect on system operation. By evaluating all possible combinations of operational states of the system components that lead to successful or failed system operation, it is possible to derive an expression giving the reliability of the system. This method has had application in both the RSS and SHRS. Details are reported in References 2 and 3.

To evaluate repairs or system reconfigurations during the time of interest (e.g., a full reactor operating cycle), Markov modeling has been selectively employed. All states of the system are defined along with the transitions that can occur between states. This information is mathematically represented by a series of first order linear differential equations which define the various states and the transitions into and out of each state. This method has been used in conjunction with success state modeling in the evaluation of the RSS. It is also being evaluated for use in the assessment of the SHRS.

Component failure rate data required to support the systems evaluations is obtained from many sources. Generic data used may be divided into two broad categories, directly and indirectly applicable to the components considered. Because certain elements of the RSS and SHRS are not unique to CRBRP, data exist which can be applied with little modification. This includes portions of the SHRS which are on the water side, as well as sodium side equipment which has been used in FFTF test facilities and sodium reactors such as SEFOR and EBR-II. In the RSS, considerable data exist on roller nut type control rod drive mechanisms which are very similar to the primary system mechanisms. Further, the design of the PPS electrical equipment is very similar to that developed and tested for FFTF. These directly applicable data are being used to the fullest extent possible and are discussed further in Sections C.5 and C.6. For other components, because their designs are relatively new, no significant failure rate data have been accumulated. It is therefore often necessary to derive component failure rate estimates from lower level piece part data. Military, industrial and governmental data sources are used in these evaluations (e.g., WASH-1400, MIL-HDBK-217B, etc.). These data may be modified using accepted reliability derating factor rules or engineering judgment. When modifications to data are made, the basis is made visible by thorough documentation.

Data available from components, subsystems and systems which are like the RSS and SHRS elements are being used extensively in the early assessments of the RSS and SHRS. This approach is particularly appropriate for the electrical systems because of the large bank of data available and the established acceptability of MIL-HDBK-217B methodology.

As the results from CRBRP test programs become available, these data are used to supplement those currently available. For reasons described later, much of the CRBRP testing will not yield failure rate data directly. Information obtained from some tests will be used to calibrate analytical techniques to provide greater assurance that reliability characteristics are correctly modeled.

C.2.2.2 Qualitative System/Subsystem Evaluations

Qualitative system assessments are used to determine system adequacy. Common Cause Failures (CCF) receive special attention because of their potential to significantly degrade RSS and SHRS capability. The first step toward elimination or controlling a specific failure mechanism is identification. Once the failure mode and potential causes are identified, corrective action can be defined. Resolution may take the form of elimination by design alterations, procedural control or demonstration of an acceptably low probability of occurrence.

Component level FMEA's are the starting point for CCF assessment. They provide a thorough listing of the failure mechanisms and associated causes for the elements of the system and its interfaces. FMEA's are a source of data for determining which system elements are susceptible to failure from common causes.

Past reactor operating experience plays an important part in the failure mode identification effort. Available operating experience is thoroughly reviewed to uncover common cause initiators underlying previous reactor incidents. The bulk of experience for hardware systems designed and fabricated to meet nuclear standards and codes lies in the domain of Light Water Reactors (LWR's). This body of data serves to identify potential component failure modes, design errors, operating problems and the actions necessary to correct these deficiencies. Output of the LWR incident survey includes:

- o Review of reported incidents and identification of the information source
- o Selection of incidents having CCF potential and identification of the causative mechanism

From these considerations, a list of potential causative factors is prepared which relate to LMFBR operating conditions. These causative factors are used as the basis for an evaluation of CRBRP component and system designs. This evaluation employs logic based on specific design features. This approach provides a systematic method for reviewing each failure and the relevant system functions required to successfully mitigate the incident.

As each failure is reviewed, protection provided against such factors is identified. The visibility of potential problem areas provided by the approach being employed assures that each design area is thoroughly investigated against the potential factors for common cause failures.

C.2.3 Testing

The CRBRP test program has as its objectives:

1) To identify to the appropriate design group potential failure points in the design of the components/systems

2) To assure the system design margins are adequate to meet the design specifications under the anticipated range of operating conditions

3) To determine the design margins against identified system weaknesses with the potential to degrade RSS or SHRS performance

4) To identify unknown system weaknesses

System level reliability evaluations were used to determine required testing. Factors evaluated to determine the need for testing include:

- Severity of the failure effect
- Common cause failure potential
- Estimated probability of occurrence
- Availability of applicable data from other sources
- Availability of verified analysis techniques for system performance evaluation

A primary purpose of testing is to demonstrate the capability of critical components to perform their function over as wide a range of operating conditions as practical. In some cases, tests will be run to failure to establish margins above those defined by the operational envelope.

Design performance and most postulated failures are affected by variations in the system operating environment. The fractional factorial design of experiments approach has been used in a number of instances in planning the test program to investigate the effects of variations in system environment.

Testing is performed at the component, subsystem and system level to explore failure modes of concern. Higher level testing provides maximum feedback of information concerning multiple failure modes and interface problems. RSS testing includes individual tests of the complete Primary and Secondary Control Rod Systems (drive mechanisms, driveline, absorber assembly and interface simulation). The electrical subsystem tests include essential system elements in a prototypic configuration. In the SHRS, testing above the level of individual components (e.g., steam generators, pumps, etc.) is accomplished at the plant start-up stage. Since the connecting elements (piping, wiring, etc.) are passive, component testing can provide a large portion of the information necessary to deterministically confirm system reliability. Supplemental testing and analysis is directed toward identifying and resolving potential interface induced failure modes. An example of such an activity is the piping integrity report, Reference 4. Where components, subsystem and system level testing identifies interfacing functions falling under the responsibility of the A&E which would degrade RSS or SHRS operation, then the PO will define any additional testing necessary to provide the needed level of information for use in resolving the identified degradation.

Accelerated life testing is employed to provide early feedback concerning potential failures. In the mechanical systems, this includes cyclic induced failures associated with the scram function under specified misalignments. Thermal cycling tests are performed on electrical subsystem equipment to accelerate the failure process involved in parts with latent time dependent failure mechanisms. Burn-in tests are used to screen out defective parts. Some failure mechanisms, however, cannot be investigated by performing accelerated life tests. For example, failure mechanisms related to time or operating conditions such as creep, self-welding and irradiation cannot be simulated by such tests. These failure mechanisms require separate tests, analysis or a combination of test and analysis for resolution. Time dependent failure mechanisms are evaluated whenever possible by operation of test hardware under prototypic conditions for extended periods of time. This section of the test program includes testing of complete Primary and Secondary Control Rod Systems under simulated prototypic operating conditions. In the SHRS, extended real-time testing of critical components such as the steam generator tubes will be performed.

Certain failure mechanisms will be explored by testing hardware that is not prototypic. However, this testing provides valid phenomenological information associated with these failure modes. Data obtained will be used to verify calculational models which are used to predict component behavior. Hardware and test fixtures specifically designed to explore the mechanism of concern are being constructed. Included in this category are irradiation effects, seismic induced loads and associated component interface characteristics, friction couples which influence unlatching and insertion, thermal striping and weld quality evaluation.

The impact of maintenance and operation on system reliability has also been considered in the design of the test program. Proposed CRBRP plant maintenance and operation procedures are employed whenever feasible in the tests. This includes equipment replacement activities that can be performed on both RSS and SHRS test hardware. Calibration procedures and repair actions associated with the electrical subsystem equipment are fully explored. Emphasis is placed on design feedback to reduce the potential of failure due to human factors.

Details of specific tests, rationale for those tests and expected outputs are described in Sections C.5 and C.6.

TABLE C.2-1

FAILURE RANKING CRITERIA

CRITICALITY RATING

Numbers*	Definitions
5	Failure to Perform Safety Function
4	Degradation of Safety Function
3	No Effect on Safety but Causes Unscheduled Outage
2	No Effect on Safety, Repair Deferred until Scheduled Outage
1	No Effect on Safety or Operation

PROBABILITY RATING**

3	An Off-Normal Condition Which Individually may be Expected to Occur Once or More During the Plant Lifetime
2	An Off-Normal Condition Which Individually is not Expected to Occur During the Plant Lifetime; However, When Integrated Over all Plant Components and Systems, Events in this Category may be Expected to Occur a Number of Times.
1	An Off-Normal Condition of Such Extremely Low Probability that no Event in This Category is Expected to Occur During the Plant Lifetime But Which, Nevertheless, Represent Extreme or Limiting Cases of Failures Which are Identified as Conceivable.

*Initial rankings are provided by the component designer and modified as appropriate in the system assessment.

**Alternative numbering schemes have been used on certain FMEA forms. The definitions of the categories are identical. In addition, an alternate approach which has been used is the actual estimated failure rates, obtained from the data base, manufacturer's specifications, pertinent literature, previous experience or tests.

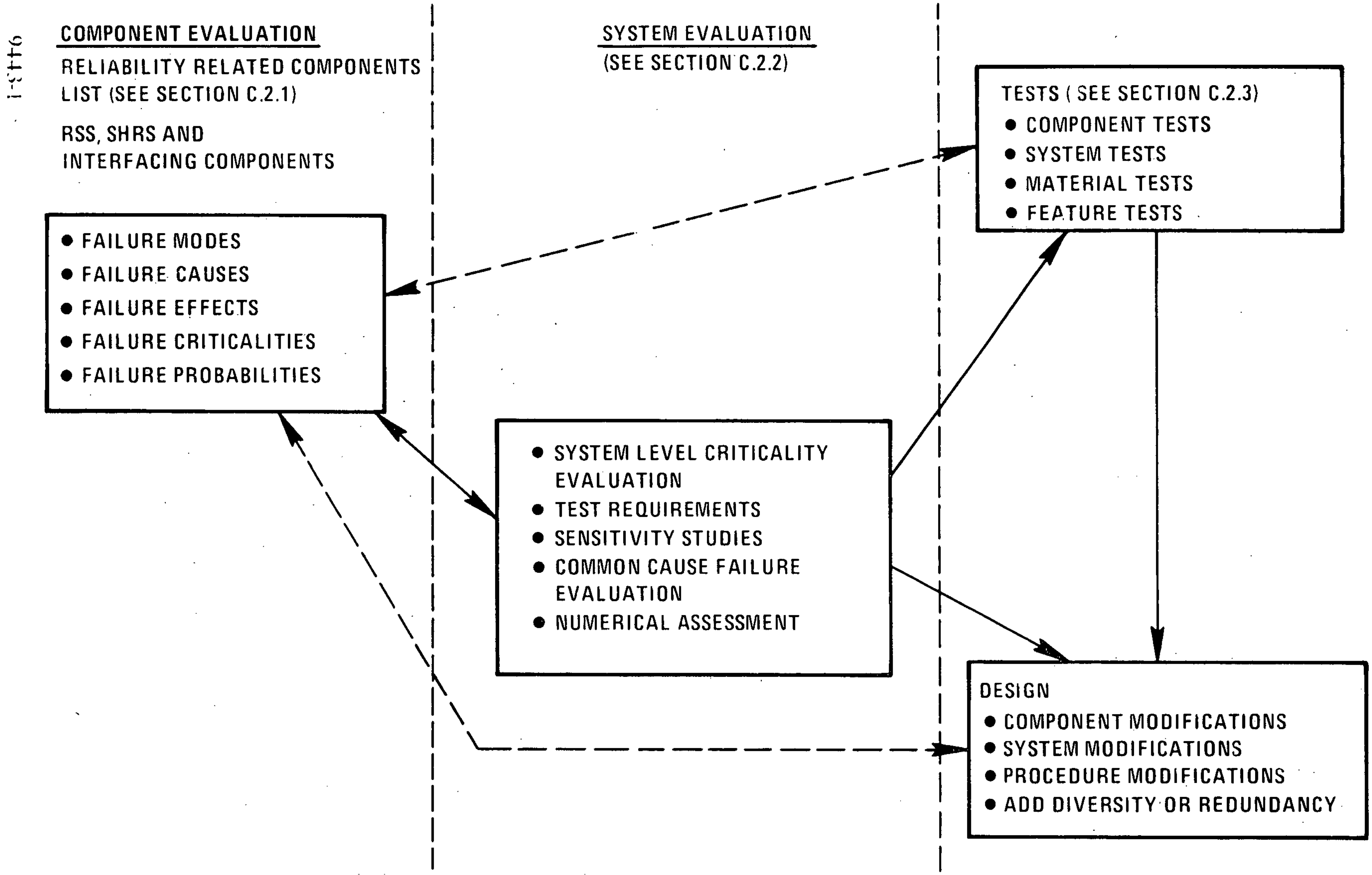

Figure C.2-1. Reliability Evaluation Activities

C.3.0 Systems Descriptions

This section provides a brief description of the functions and component parts of the systems included in the Reliability Program. This section is provided as a convenience to eliminate the need for extensive reference to the main body of the PSAR.

C.3.1 Reactor Shutdown System

C.3.1.1 Overall System Function

The Reactor Shutdown System (RSS) consists of two independent and diverse systems which are capable of shutting down the reactor without exceeding specified limits. (See Section 4.2 of the PSAR).

C.3.1.2 Design Description

The systems and components which make up the RSS are shown in Figures C.3.1-1 and C.3.1-2. A brief description of the systems and components follows:

Primary Mechanical Subsystem

The Primary Mechanical Subsystem (PMS) of the RSS includes 9 Primary Control Rod Systems (PCRS). Each PCRS consists of a Primary Control Rod Drive Mechanism (PCRDM), a Primary Control Rod Driveline (PCRD), and a Primary Control Assembly (PCA). The PCRDM is mounted on top of the reactor vessel closure head and provides mechanical actuation for insertion, withdrawal and scram functions of the control rod absorber. The PCRD connects the PCRDM with the control rod absorber. The PCRD passes through the upper internals structure. The PCA is located in the array of core assemblies and consists of a movable control rod (absorber pin bundle) and an outer duct assembly.

The PMS provides the functions of reactor startup, operational control and shutdown reactivity control. The primary function performed by the PMS which is reliability related is reactor shutdown (scram) for all conditions. Scram action is accomplished via disengagement of the roller nuts followed by downward motion of the control rod and driveline. Downward acceleration is achieved by means of the combined action of gravity and preload from the scram assist spring. All PMS functions are initiated by the primary electrical portion of RSS.

A. Primary Control Rod Drive Mechanism (PCRDM)

The PCRDMs are divided into two major sections which are described below:

The upper PCRDM assembly is an electro-mechanical actuating device which consists of a stator mounted on the outside of the motor tube and a collapsible rotor and roller nut assembly mounted inside the motor tube. The rotor assembly consists of a bearing mounted rotor tube and two pivoted segment arms. On each segment arm there are two roller nuts. When the stator is energized, the upper ends of the arms are pulled outward by the magnetic field and the lower arms are pivoted inward engaging the roller nuts with the threads of the leadscrew.

To produce a scram, the electrical power is removed from the stator causing the magnetic force field to collapse which releases the rotor segment arms. Springs separate the lower end of the arms and disengage the roller nuts from the leadscrew allowing the control rod to drop into the reactor core. A scram assist spring in the lower PCRDM is provided to supplement the gravity drop. A synchronizer bearing is provided to assure that both segment arms separate simultaneously. Anti-ejection pawls in the segment arms engage the leadscrew to prevent control rod ejection in the unlatched condition. These pawls are spring loaded allowing them to move out of engagement during downward motion of the leadscrew.

The lower PCRDM assembly consists of an extension nozzle, torque taker and tube, shield plugs, internal seal system and scram assist spring.

The extension nozzle is part of the pressure boundary and mounts the PCRDM to the intermediate rotating plug. The torque taker and torque tube constitute a torque restraint located in the space outside of the large bellows which prevents the mechanism leadscrew, bellows and PCRD from rotating. Keys on the torque taker slide in keyways in the torque tube over the full length of the stroke. The internal seal system utilizes three metallic bellows as well as conoseals to separate the rotor assembly and leadscrew from the reactor cover gas environment, precluding possible buildup of sodium frost on these components. The shield plugs provide radiation shielding for the PCRDM's and head access area.

B. Primary Control Rod Driveline (PCRD)

The PCRD consists of three concentric shafts: the driveline shaft, the disconnect actuating shaft and the position indicator rod. The driveline is the load carrying member and the outermost shaft. It connects the PCRDM leadscrew with the control rod. The disconnect actuating shaft (middle shaft) is used to disconnect the driveline from the control rod for maintenance or refueling. The innermost part is the position indicator rod which is used to verify that the control rod remains fully inserted during refueling, uncoupling and withdrawal of the driveline.

A dashpot is included in the PCRD to decelerate the driveline and control rod during the last few inches of insertion. The dashpot consists of a piston and cup with matching tapered fits. The piston is attached to the driveline shaft and the cup is supported by the shroud tube of the upper internals structure.

C. Primary Control Assembly (PCA)

The PCA consists of two major subassemblies: the outer duct assembly and the pin bundle/shaft assembly called the control rod. The outer duct assembly is hexagonal having external dimensions identical with the fuel assemblies. A handling socket is provided at the top which interfaces with the refueling equipment. Two load pads are provided at the outside to interface with adjacent core assemblies for positioning and seismic load carrying capability. A shield plug is welded to the outer duct at its lower end to provide neutron shielding. The inlet nozzle for the PCA is welded to the bottom of the shield plug and contains internal orifice plates. Two piston rings on the exterior of the nozzle prevent excessive leakage to the low pressure plenum and insure hydraulic balance for assembly holddown. The bottom end of the inlet nozzle has a discriminator post which prevents installation of the PCA in an incorrect core lattice position or installation of an incorrect assembly in a PCA position.

The control rod contains thirty-seven absorber pins, spaced on an equilateral triangular pitch. The absorber pins are sealed stainless steel tubes containing boron carbide (B_4C) neutron absorbing material. Each pin is helically wrapped with wire which maintains the pin spacing in the rod and promotes coolant mixing within the rod. The bundle of 37 pins is surrounded by a thin hexagonal inner duct which provides a coolant channel and structural support for the pins.

The control rod shaft consists of a limited motion azimuthal rotational joint, a solid shaft and a female coupling for attaching the rod to the driveline.

For further descriptive and functional details, refer to Section 4.2.3 of the PSAR.

Secondary Mechanical Subsystem

51 The Secondary Mechanical Subsystem (SMS) of the RSS includes six Secondary Control Rod Systems (SCRS's) located in row 7 of the reactor core. Each SCRS consists of a Secondary Control Rod Drive Mechanism (SCRDM), a Secondary Control Rod Driveline (SCRD), and a Secondary Control Assembly (SCA). The SCRDM is mounted on the reactor vessel closure head and axially positions the control rod and driveline. The SCRD extends through the upper internals structure and connects the SCRDM and the latch mechanism. The SCA is located in the array of core assemblies and contains the movable control rod.

The SMS provides a secondary shutdown system for off-normal conditions. As such, the SMS is independent of the PMS and is diverse in both scram function initiation and insertion assist. Scram is accomplished by unlatching of the control rod by a fraction of an inch drop of the tension rod and insertion of the control rod into the core by gravitational pull supplemented by the hydraulic force of the sodium flow. The SMS scram function is activated by the secondary electrical portion of the RSS.

A. Secondary Control Rod Drive Mechanism (SCRDM)

The SCRDM contains the mechanisms for insertion and withdrawal of the control rod. These mechanisms include the latch actuator assembly, twin leadscrews and motor. The latch actuator assembly is mounted to the top of the positioning carriage at the upper end of the driveshaft. The main components of the assembly are the pneumatic cylinder, the scram valves, the sensing tube and tension rod position indicating devices. The piston in the pneumatic cylinder is coupled to the latch tension rod. The scram valves provide pneumatic control for latch actuation.

During normal operation, pressure is applied to the bottom of the piston to hold it in the up position. Pneumatic pressure is controlled by an arrangement of poppet valves and solenoid operated pilot valves. To initiate a scram, power is cut to the solenoid valves which opens the poppet valves to vent the cylinder. This allows the tension rod to fall which releases the control rod to insert into the core. The solenoids are normally energized to prevent venting the cylinder. Venting occurs when power is cut to two of the three solenoids.

Twin leadscrews driven by an electric motor are provided in each SCRDM to raise or lower the control rod. Two idler gears from the motor pinion gear transfer torque to the leadscrews which raises and lowers the positioning carriage.

A main shaft bellows between the SCRDM housing and driveshaft and additional bellows between the driveshaft and sensing tube and between the sensing tube and tension rod protect the internals of the SCRDM from sodium vapors.

B. Secondary Control Rod Driveline (SCRD)

The SCRD contains the tension rod, sensing tube, driveshaft, driveline bellows and latch. These provide a connection between the SCRDM and the control rod in the SCA. The tension rod, sensing tube and driveshaft are concentric shafts running the length of the SCRD which move axially with respect to each other.

The tension rod connects a latch located at the lower end of the SCRD to the pneumatic actuator device. The tension rod is surrounded by the sensing tube which is used to transmit the position of the control rod coupling head (when held in position by the latch) to the position sensors in the SCRDM. The sensing tube is surrounded by the heavy-walled driveshaft which protects the sensing tube and the tension rod over their entire length.

The latch is located approximately five feet above the top of the active core region during power operation. The latch is used to grapple the coupling head and lift the control rod out of the core and to release the control rod for scram. The latch and the tension rod are the principal components in the SCRS for performing the scram release function. A short downward stroke of tension rod permits the latch grippers to move radially outward and release the control rod coupling head.

Two pairs of bellows isolate the SCRD internals and the SCRDM from the sodium vapor-argon cover gas environment below the reactor head.

C. Secondary Control Assembly (SCA)

The SCA consists of a movable control rod enclosed within a circular guide tube. The guide tube fits inside a hexagonal duct which is essentially identical to the fuel assembly ducts.

Internal flow paths are used to direct high pressure sodium flow against the hydraulic assist piston to generate the hydraulic scram assist force. Sodium flow used for scram assist is directed downwards through the circular absorber guide tube. Flow channels located in the control assembly nosepiece vent the scram assist sodium flow to the low pressure passages in the core support structure. Flow is also provided through the control rod pin bundle for cooling purposes. The bottom of the channel contains a nose piece which engages the high pressure plenum of the core support structure.

The control rod consists of a bundle of pins containing boron carbide (B_4C) as the neutron absorber. It is held in position above the core by means of the coupling head which fits into the latch of the SCRD. The control rod is free (when unlatched) inside the guide tube so that it will insert into the core by virtue of its own weight. Extra downward force is provided by hydraulic assist.

A damper mechanism is used to decelerate the descending control rod. The initial damping is provided by hydraulic dashpot action and the final portion of the descent is controlled by a hydraulic spring damper device.

For further descriptive and functional details, refer to Section 4.2.3 of the PSAR.

Electrical Subsystem

The Electrical Subsystem (ES) is part of the overall Plant Protection System. It consists of two independent and operationally diverse systems, the Primary Electrical Subsystem (PES) and Secondary Electrical Subsystem (SES) that monitor the condition of the plant and initiate scram of the primary and secondary control rods, respectively. Each system can independently initiate shutdown of the reactor. Each system has three redundant instrument channels and logic trains that provide sufficient redundancy to preclude degradation of either the PES or SES through a single failure.

The three redundant channels of each system are physically and electrically separated to assure that their independance is maintained. The ES is illustrated in Figure C.3.1-2.

Electrical piece/part requirements have been defined to assure high reliability. Most resistors and capacitors in the ES comparators, calculation units, logic and buffers are MIL-SPEC or established reliability components. Most transistors and diodes used in the comparators, calculation units, logic and buffers are qualified to Military Standard-S-19500. Most integrated circuits used are screened, inspected and tested according to Military Standard 883A, Method 5004, Level B. The vendor is also required to use Military Standard 454 as a specification for electronic module construction.

To provide added assurance against potential degradation of protection due to single failures, functional and equipment diversity have been designed into the ES. The PES responds to a different plant parameter than does the SES to provide protection against common cause failure of the sensing system. The only exception to the use of functional diversity is in subsystems which measure nuclear power. Since nuclear flux is the only parameter indicative of nuclear power that is fast enough to provide adequate protection, equipment diversity rather than functional diversity is provided in the power measurement system. Nuclear flux measurement is made in the PES using three compensated ion chambers and in the SES using three fission chambers. Section 7.2 of the PSAR includes lists of the ES protective functions and the design basis fault events and the first protective primary and secondary subsystem to respond to each event. The PES and SES instrumentation used to determine off normal conditions are also described in Section 7.2 of the PSAR.

The output signal from each of the three redundant sensors in each system is amplified and converted to a standard input signal by signal conditioning equipment. Where necessary, calculational units derive secondary variables from the sensed parameters. Where a single parameter is used in a level trip type, no calculational unit is used. Where ratio type trips are used, calculational units are used to derive the appropriate ratio. A comparator in each instrument channel outputs a trip signal when it senses that the instrument channel analog signal exceeds specified limits.

For additional diversity, the PES is configured using local coincidence logic while the SES is configured using general coincidence logic. In the case of the PES, each instrument channel outputs three redundant signals corresponding to either the reset (not trip) or trip state. Light emitting diodes and photo transistors are used to provide complete electrical isolation between redundant instrument channels and logic trains. The three redundant instrument channels are recombined as inputs to three redundant logic trains arranged in two out of three local coincidence. The 2/3 logic modules determine if two or more trip inputs are received from the subsystem comparators and then provide a trip signal to a 1/24 logic module. The 1/24 logic module outputs a trip signal if any of the 24 subsystems in a logic train have tripped. These signals deenergize primary scram circuit breaker undervoltage trip coils. The five primary scram circuit breakers are arranged so that when two or more logic trains trip, the scram circuit breakers remove power to the PCRDM's releasing the primary control rods. Manual shutdown and test capability is provided.

In the SES, each instrument channel comparator outputs a signal to the 1/16 logic corresponding to either the trip or reset state. The secondary logic system consists of the 16 protective subsystems arranged in a general 1/16 coincidence configuration. If any of the 16 channel A comparators trip, the 1/16 logic module inputs a channel A trip to the 2/3 con-
51 figuration of each of the six SCRDM solenoid operated valves. Similarly, a trip signal from channel B or channel C comparators is transmitted to the SCRDM solenoid operated valves by the 1/16 logic module. The SCRDM solenoid operated valves are arranged in a 2/3 configuration such that a trip signal from two or more logic trains vents the latch cylinder, unlatches the control rod and allows it to be forced to its shutdown position.

C.3.2 Shutdown Heat Removal System

C.3.2.1 Overall System Function

Sensible heat in the structures and sodium and core decay heat are removed from the reactor following reactor shutdown by the Shutdown Heat Removal System (SHRS). The SHRS utilizes the normal heat sinks or alternate heat sinks to dissipate sensible and decay heat and prevent loss of coolable core geometry.

Normal heat removal paths are provided through three independent loops of the Primary Heat Transport System (PHTS) which transfer heat from the reactor to three independent loops of the Intermediate Heat Transport System (IHTS). Heat is removed from the IHTS by three independent loops of the Steam Generator System (SGS) to the main condensers. Alternate redundant heat sinks are provided through the Steam Generator Auxiliary Heat Removal System (SGAHRS) and the Direct Heat Removal Service (DHRS). SGAHRS provides an alternate heat sink for the main condensers and DHRS provides an alternate heat removal path and heat sink connected directly to the PHTS.

C.3.2.2 Design Description

The systems and components which make up the SHRS are shown in Figures C.3.2-1 and C.3.2-2. A brief description of the SHRS systems and components follows:

Primary Heat Transport System

The Primary Heat Transport System (PHTS) transports heat from the reactor to the Intermediate Heat Exchangers (IHX). The three PHTS loops transport the sodium coolant from the reactor vessel to the IHX's which connect the primary and intermediate loops. The three primary loops have common flow paths through the reactor vessel, but are otherwise mechanically independent and isolated in separate PHTS cells.

Each PHTS loop contains a hot leg centrifugal sodium pump, a permanent magnet flowmeter, a cold leg check valve and an IHX. Detailed descriptions of these components are contained in Sections 5.2 and 5.3 of the PSAR.

Intermediate Heat Transport System

The Intermediate Heat Transport System (IHTS) transports heat from the PHTS to the Steam Generator System. The system consists of three essentially identical, independent cooling loops operating in parallel to circulate sodium from the tube side of the IHX through the steam generators and back to the IHX.

Each of the cooling loops contains a cold leg pump, an intermediate sodium expansion tank, a permanent magnet flowmeter and piping to transport the sodium from the IHX outlet through the superheater and the two evaporators back to the IHX inlet. A detailed description of IHTS components is contained in Section 5.4 of the PSAR.

Steam Generator System

The Steam Generator System (SGS) extracts heat from the IHTS sodium. There are three independent SGS loops. Each loop consists of three steam generator modules (two evaporators and one superheater), a steam drum, a recirculating water pump, a Sodium-Water Reaction Pressure Relief System, a Sodium Dump System, a Water Dump System and a Leak Detection System.

The main Condensate and Feedwater System supplies feedwater to the steam drums. Superheated steam produced by each of the three SGSs loops is supplied to the single turbine generator. Feedwater is returned to the three steam drums from the condenser hot well by two condensate pumps and two of three main feedwater pumps.

The Sodium-Water Reaction Pressure Relief System (SWRPRS) becomes operational only in the event of a steam tube leak large enough to cause a rapid pressure rise from a sodium-water reaction. The system provides protection from over-pressure on the sodium side of the evaporator modules, superheater modules, IHTS and IHX by the use of rupture discs on the piping adjacent to the modules. The Water Dump System accelerates blowdown of the evaporator modules through quick opening water dump valves at the inlet to each evaporator module and reduces the extent of the sodium-water reaction. The Sodium Dump System provides sodium dump capability for the IHTS and the sodium side of the evaporator and superheater modules.

The Steam Generator Leak Detection System monitors for hydrogen and oxygen in the sodium in order to identify small leaks in the steam generator modules.

Details of the SGS components and subsystems are provided in Section 5.5 of the PSAR.

Steam Generator Auxiliary Heat Removal System

The Steam Generator Auxiliary Heat Removal System (SGAHRS) provides redundant shutdown heat removal paths and heat sinks when the main condenser or main feedwater supply is unavailable. SGAHRS consists of an Auxiliary Feedwater System (AFWS), three Protected Air Cooled Condensers (PACC's) and associated piping.

AFWS contains the Protected Water Storage Tank (PWST) and three pumps. Two of the pumps having one half capacity each are electrically driven and the third is a full capacity pump driven by a steam turbine using steam from the steam drum. The AFWS draws water from the PWST and supplies feedwater to all three steam drums.

The three PACC's are connected to the steam drums and reject the heat to the atmosphere. Steam from each steam drum rises by natural circulation to a PACC where the steam is condensed. Saturated water is returned to the drum by gravity flow. Each PACC utilizes a fan to force air across condenser tubes. The PACC's are used for long term shutdown heat removal when the condensers are out of operation. SGAHRS provides short term heat rejection by a direct steam dump from the steam drums to the atmosphere through power relief valves. The expended water is replaced by the AFWS.

Details of the SGAHRS components and subsystems are provided in Section 5.6 of the PSAR.

Direct Heat Removal Service

A Direct Heat Removal Service (DHRS) is provided to remove decay heat in the remote event that all of the steam generator decay heat removal paths are not available. The DHRS dissipates reactor decay heat through the primary sodium overflow system, an overflow heat exchanger and the EVST cooling system air blast heat exchangers to the atmosphere. The plant components utilized by DHRS are the primary sodium overflow vessel, the two primary sodium makeup pumps, the overflow heat exchanger, the reactor vessel, the primary pumps and their pony motors, the EVST NaK pumps and the EVST air blast heat exchangers, as well as the piping and valves which connect these components. DHRS is shown schematically on Figure C.3.2-2. Details of DHRS are provided in Section 5.6.2 of the PSAR.

C.3.2.3 Heat Removal Operational Description

Normal shutdown heat removal is through the PHTS, IHTS, SGS and main condenser. Each of the three independent heat transport system paths are designed to remove all short term and long term decay heat from the reactor. Pony motor operation of the primary and intermediate system pumps are utilized for this mode of shutdown cooling. The PHTS, IHTS, SGS and main condenser will also provide sufficient heat removal to prevent loss of coolable core geometry following a scram with pump coastdown from full power operation with three loops at natural circulation flow.

For the short term, decay heat is to be removed from the main condenser whenever it is operational. The plant operator may initiate SGAHRS heat removal via the PACC's for long term heat removal at any time. However, due to the heat removal capacity of the PACC's either the main turbine generator condenser (normally) or short term steam venting and AFWS must function (main condenser or feedwater not operational) until the steam generator heat load drops below the heat removal capacity of the PACC's. During three loop shutdown without using the main condenser, steam venting is expected to cease within one hour after the plant trip.

The SGAHRS is designed to provide the ultimate heat sink for all postulated loss of feedwater or loss of normal heat sink incidents. Whenever the normal heat removal path is not available in the short term, activation of SGAHRS will occur automatically with both the AFW and PACC subsystems brought into service. The two subsystems will continue to function concurrently until the heat load is reduced to a level such that steam venting ceases and the PACC's will remove the entire heat load. Operator action is only required to shut off the auxiliary feedwater pumps once the venting and feedwater supply requirements are ended.

The PHTS, IHTS, SGS and SGAHRS are designed to provide decay and sensible heat removal from the reactor via natural circulation in combination with steam venting utilizing only the steam turbine driven auxiliary feedwater pump. The SGAHRS steam turbine driven auxiliary feedwater pump is sized to provide adequate short term heat removal after full power operation via one loop without recirculation pump or motor driven feedwater pump operation. The Protected Water Storage Tank capacity and PACC heat removal capability are such that the entire long term decay heat load can be carried by a combination of extended steam venting from one SGS loop and operation of one PACC with water side natural circulation and air side forced circulation. These components have been sized to assure a 30 day supply of protected water under the most severe accident conditions.

The DHRS is provided to increase the shutdown heat removal reliability by providing additional redundant and diverse shutdown heat removal capability to that provided in the three redundant heat transport system loops and SGAHRS.

The DHRS is initiated by operator action. Hot primary sodium overflows from the reactor vessel to the overflow vessel. Operation of one or more of the three primary pump pony motors provides sodium flow through the core. The primary sodium makeup pumps circulate the hot sodium through the overflow heat exchanger and back to the reactor vessel. EVST NaK removes the primary sodium heat in the overflow heat exchanger. The heated EVST NaK is pumped to the EVST NaK air blast heat exchangers where heat is transferred to the atmosphere. DHRS capacity is adequate to prevent loss of coolable core geometry assuming heat rejection capability is lost from the PHTS immediately upon shutdown from rated power and active operation of DHRS is initiated one half hour after shutdown. Operation of all three primary pumps at pony motor speed is required in this mode.

C.3.2.4 Electric Power Considerations

The sources of electric (AC) power for the SHRS are the preferred and reserve (off-site) AC power supplies and the standby (on-site) AC power supply. The standby power supply consists of two independent diesel generators and the emergency batteries and converter. Power under normal operation is needed for the primary and intermediate sodium pumps and for the steam generator recirculation pump and the main feedwater and condensate pumps.

For SHRS operation, standby power is supplied to the components of the PHTS, IHTS, SGAHRS and DHRS to assure operation in the event of loss of the main power supply. Standby power is provided to the two motor driven auxiliary feedpumps, the PACCs blowers, the pony motors for both the PHTS and IHTS pumps, the primary sodium makeup pumps, the EVST NaK and sodium pumps and the EVST air blast heat exchanger blowers. In addition, battery power is provided to the safety-related SGAHRS motor operated valves. The standby power supply is sufficient to facilitate and maintain adequate shutdown heat removal.

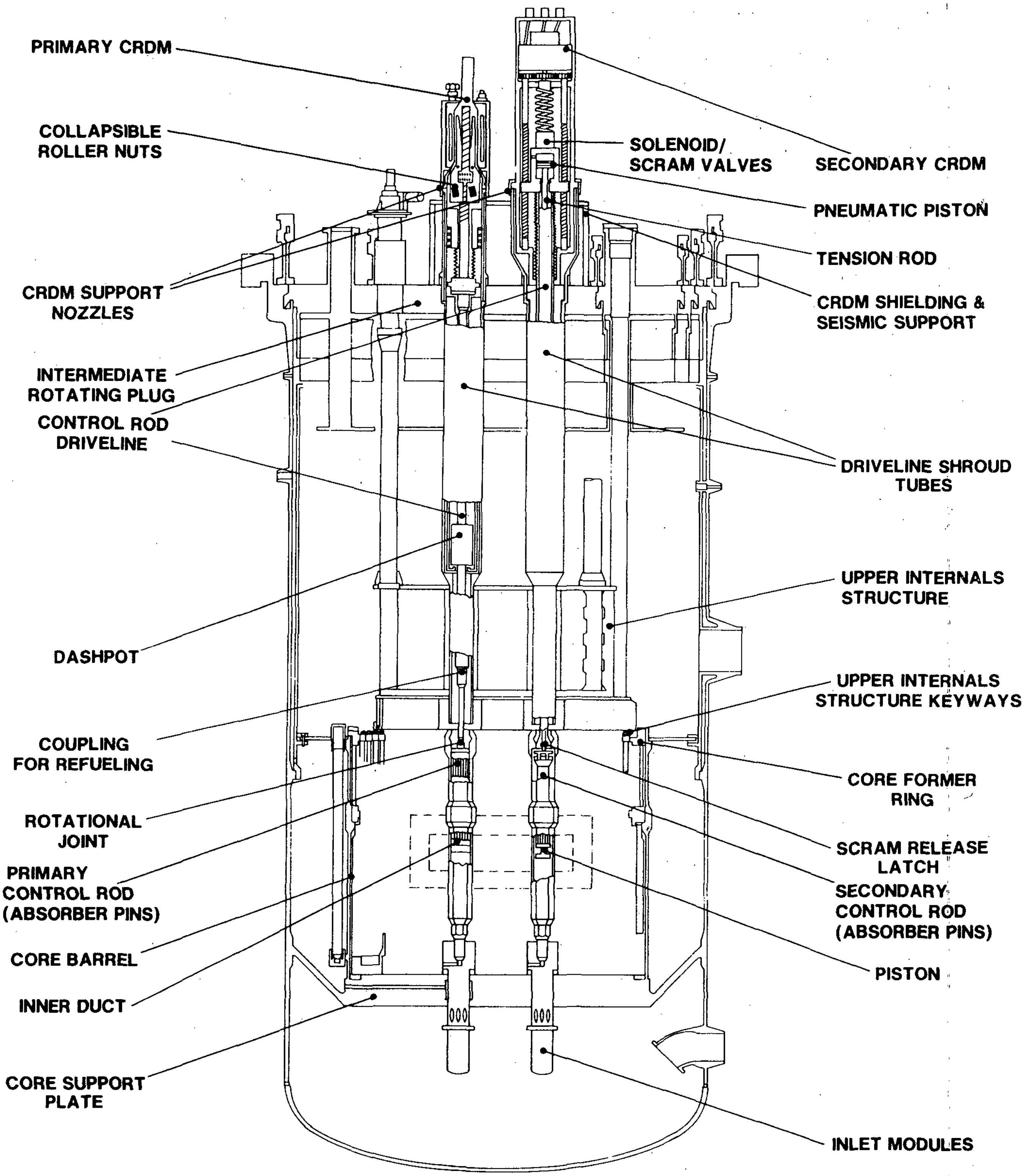

Figure C.3.1-1. Control Rod System Schematic-Reactor Elevation (Refer To Section 4.2 Of The PSAR For A Detailed Description Of The Control Rod Systems)

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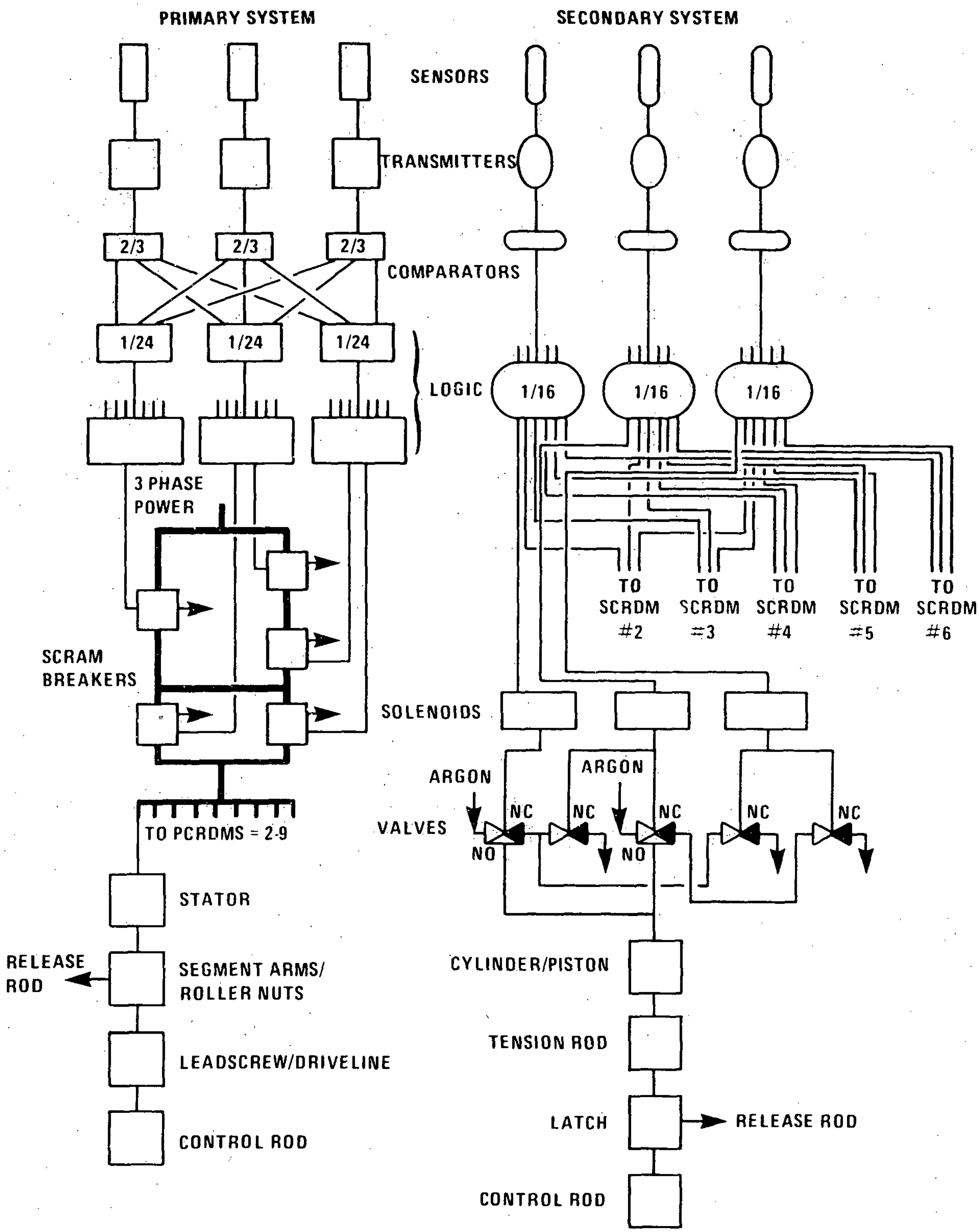

Figure C.3.1-2. Reactor Shutdown System Schematic (Refer to Section 7.2 of the PSAR for a Detailed Description of the Reactor Shutdown System)

1614-3

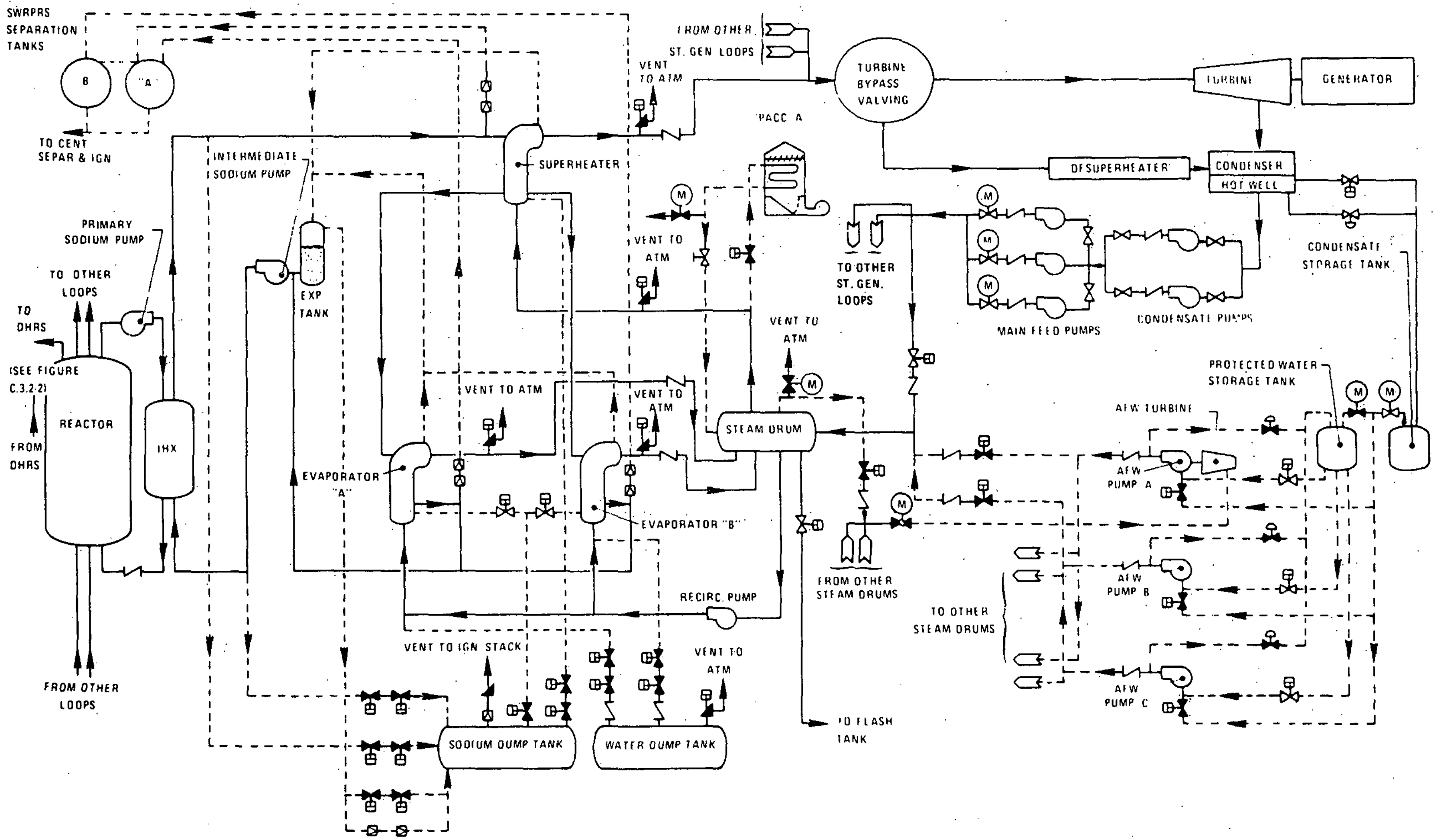

Figure C.3.2-1. Shutdown Heat Removal System/Schematic (Without DHRS) (Refer To Section 5.0 Of The PSAR For A Detailed Description Of The SHRS)

9443-11

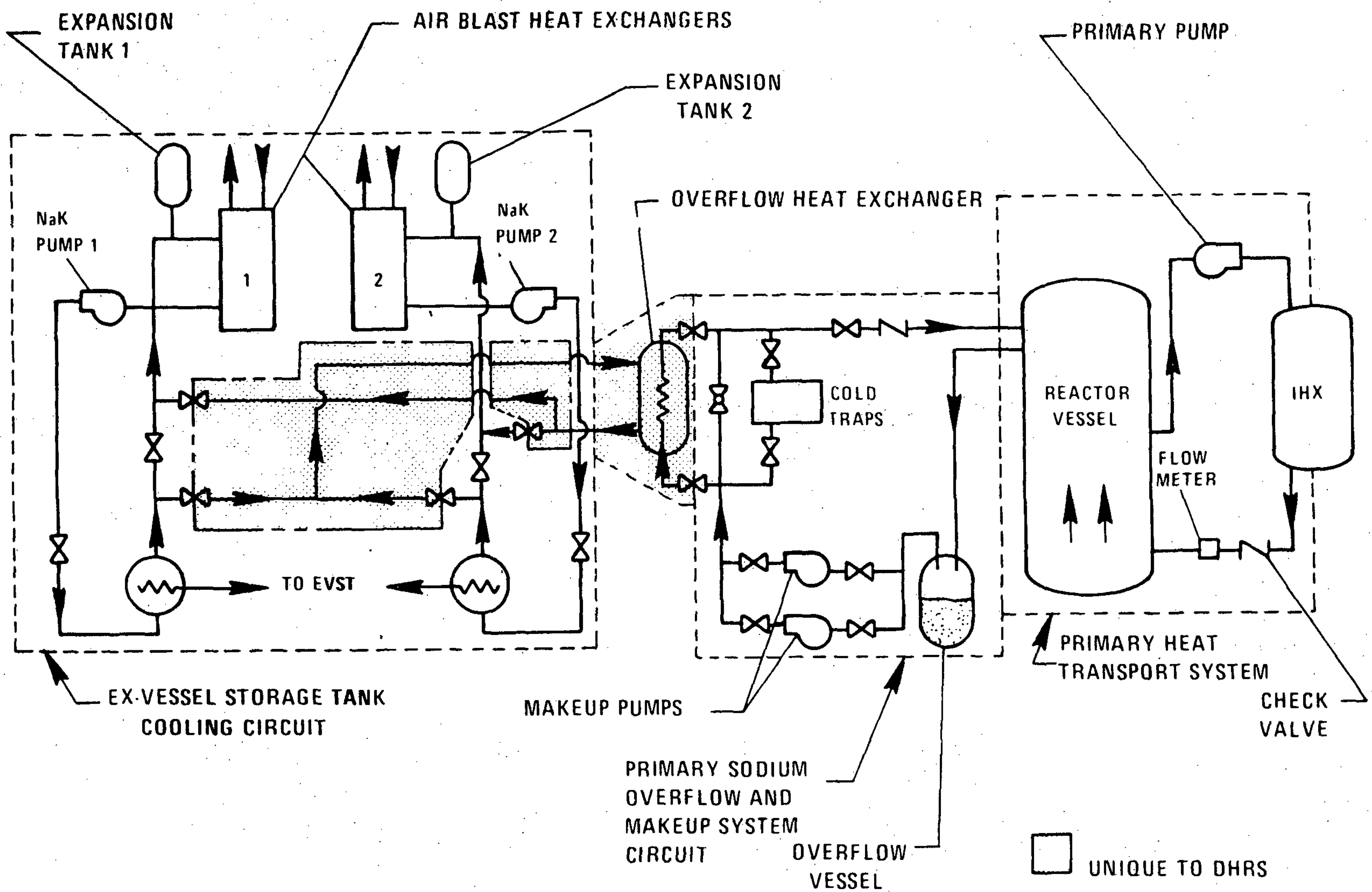

Figure C.3.2-2. The Direct Heat Removal Service (DHRS) Showing Its Relationship To Other Components And Systems (Refer To Section 5.6.2 Of The PSAR For A Detailed Description Of The DHRS)

Amend. 36
March 1977

C.4.0 Evaluation Focal Points

C.4.1 Reactor Shutdown System

This section provides the system designer's evaluation of areas of system performance uncertainty. Failure Mode and Effects Analysis (FMEA) coupled with FFTF testing and LWR operating experience were used to select the principal areas for reliability emphasis. The initial FMEA's were performed during the conceptual design stage. Identified potential scram failure modes and associated causes were correlated with available test data and analytical capabilities. Reliability emphasis was placed on credible failure modes having the greatest impact on scram reliability. Identified areas of uncertainty are cross referenced to specific tests which are described in Section C.5.

C.4.1.1 Primary Mechanical Subsystem (PMS)

This section describes the principal areas of the PMS identified as requiring reliability testing and analysis. Emphasis is placed on assessing areas which could cause failure of the PMS to perform its scram function. Common cause factors which could potentially lead to multiple PCRS failures and resultant shutdown failure of the PMS are identified for reliability emphasis. The PCRS scram function consists of the roller nut unlatching from the leadscrew and the translation of the leadscrew, driveline and control rod. Areas for reliability emphasis are identified separately for these two critical functions.

Areas Identified for Reliability Emphasis

A. Unlatching

The primary scram function of the PCRDM is to release (unlatch) the leadscrew upon loss of electrical power to the stator. The magnetic field of the stator holds the segment arms (rotor) radially outward which compresses the segment arm springs and engages the roller nuts with the leadscrew. With the removal of electrical power, the segment arm springs disengage the roller nuts and unlatch the leadscrew. PCRDM unlatching is dependent on segment arm spring forces and outward parting load forces generated at the leadscrew/roller nut interface. Forces retarding unlatching consist of the magnetic moment based on stator current decay, friction effects at the pivot pin and leadscrew due to roller nut contact, and inertia of the segment arms.

Areas for reliability emphasis to assure unlatching include investigations of: variations in friction coefficients, wear effects, manufacturing errors, internal misalignments, debris from leadscrew wear and relaxation or breakage of the segment arm springs. An analytical dynamic model is utilized to assure that adequate margins against these failure causes are included in the PCRDM design. Since FFTF testing has been highly successful and has provided a basis for analytical model verification, only prototypic PCRDM testing is considered necessary for reliability verification. PCRDM life tests beyond the design life are used to assess wear effects and to confirm operation. Tests at worst case temperature and pressure limits establish sensitivity of scram components to PCRDM environmental conditions. These tests are described in Sections C.5.1.2A and B.

Since the PCRS is required to scram during seismic events, verification of unlatching capability during seismic excitation is necessary. Relative lateral motions of the leadscrew and roller nuts, vertical acceleration and potential structural failures are the key areas for reliability evaluations. Shaker tests are planned to assess seismic performance and support analytically determined margins for seismic conditions. The PCRS seismic test is described in Section C.5.1.2I.

If PCRDM bellows leakage occurs, sodium vapor can enter the upper mechanism. Sodium vapor can affect the unlatching function by increasing friction coefficients and sodium solidification can occur in tight clearances between moving parts. A failed-bellows test will be conducted to confirm acceptability of operation with a failed bellows. The failed-bellows test is described in Section C.5.1.2B.

The PCRDM/PCRDs are given acceptance tests at the vendor prior to shipment. In addition, operational tests are performed prior to initial CRBRP startup and scram tests are performed after each refueling. These tests provide a basis for identification of manufacturing, installation and maintenance errors affecting scram performance.

Human errors could occur during maintenance operations and could adversely affect scram performance. To minimize the potential for and the effect of maintenance errors, maintenance procedures and tools will be developed in PCRS tests. Prototypic maintenance operations will be performed throughout the PCRS tests to identify any effects on system performance.

B. <u>Insertion</u>

The PCRS scram insertion function involves full stroke and partial stroke motion of the connected leadscrew, driveline and control rod. The areas where contact points and minimum clearances could affect scram insertion are: the leadscrew to PCRDM upper and lower bushings, the PCRD to lower PCRDM torque taker keyway, the PCRD shaft to the bottom of the dashpot cup, the PCRD piston to dashpot cup (over the last few inches of insertion), the control rod shaft coupling to the PCA scram arrest flange (over the last portion of insertion), the control rod wear pads to the PCA outer duct and the control rod inner duct to the PCA outer duct. In a seismic event, additional contact points may occur between the PCRD and the PCRDM shield plug and the PCRD and the driveline shroud tube. Areas for reliability focus are the effects of misalignments, seismic loadings, friction coefficient variation, wear, irradiation and manufacturing errors.

PCRS misalignments are established from manufacturing and installation tolerances and clearances between PCRS parts and interfacing reactor system components including the reactor vessel closure head, reactor vessel, core support structure, core barrel with associated core former rings of the core restraint system, core assemblies and the upper internals structure. An analytical model is utilized to evaluate PCRS performance under varying misalignments for confirmation of scram insertion performance. Analysis of the interaction loads resulting from control rod system misalignments is a complex process however, involving three dimensional mixed structural and mechanical response of the interfacing components and the driveline/control rod assembly. Existing structural analysis tools require the application of engineering judgments to deal with mixed mechanical-structural response of complex systems. To verify these engineering judgments, test calibration of the analytical models is required. Misalignment tests of PCRS performance are utilized to confirm scram capability.

Lateral seismic accelerations leads to a "rattling" effect on the driveline with impulsive drag forces resulting from impact of the driveline/control rod with the surrounding structures. The frequency and magnitude of the impact forces are influenced by fluid coupling between the driveline and guiding structure, squeeze film fluid effects at impact and dynamic friction coefficients. PCRS testing under conditions of simulated seismic excitation will establish the magnitude of these effects and permit calibration of the seismic scram insertion analysis. The PCRS dynamic seismic friction test is described in Section C.5.1.2C, and the PCRS seismic test is described in Section C.5.1.2.I.

Lateral loads on core assembly outer duct load pads during a seismic event could lead to control assembly duct deformation or increased PCRS misalignments. The above core load pads are located in a region where substantial irradiation induced ductility loss is anticipated. Brittle fracture of the load pads must therefore be considered as a potential failure mode. A duct crushing test in support of CRBRP core assemblies has been completed. Analyses of this test, which showed no brittle failure of irradiated ducts under loading conditions prototypic of CRBRP seismic loads, will be used to confirm PCA design margins. The duct crushing test is described in Section C.5.1.2L.

Wear effects between moving parts can lead to changes in scram speed as a result of changes in effective friction coefficients and clearances. Galling of sliding surfaces can lead to significant friction increases and to seizing of moving parts. Wear effects can best be evaluated by tests under prototypic conditions. PCRS testing in sodium loops is planned to evaluate wear effects on system performance. Testing exceeding the design basis service life (number of scrams, feet of travel) will be performed to establish lifetime margin relative to wear effects. Tests to investigate wear effects are described in Sections C.5.1.2A and B.

Control assembly outer duct galling was observed in FFTF testing as a result of forced contact (beyond design basis) between the movable pin bundle wear pads and the outer duct. The pattern of galling marks observed was consistent with a torsional loading transmitted from the CRDM to the control assembly absorber section. A rotational joint has been included in the PCA design to minimize PCRDM torque transmission and the resultant inner/outer duct contact. Testing to verify rotational joint performance in sodium has been satisfactorily completed. The rotational joint test is described in Section C.5.1.2F.

Irradiation effects on PCRS scram performance must be considered in the PCA. Irradiation could degrade scram performance by reducing control rod to outer duct clearances either as a direct effect of irradiation induced swelling or as indirect effects of duct bowing. Reduction in clearances resulting from failures of component parts due to ductility loss or inner duct distortion from pin bowing or pin ruptures must also be considered. Bowing of the inner and outer ducts results from thermal and flux gradients across the ducts leading to differential irradiation swelling combined with creep effects from interactions with adjacent assemblies. Section 4.2.3 of the PSAR provides a detailed discussion of duct bowing. Differential bowing between the inner and outer ducts could, if the bowing magnitude were sufficiently large, lead to duct to duct contact with resultant increase in drag forces retarding scram insertion. CRBRP programs to verify swelling and creep correlations used for bowing analyses are underway. These programs together with operational data from other reactors (FFTF, EBR-II, etc.) will provide a basis for establishing the magnitude of duct bowing. Analyses have been conducted to assure that design envelope duct bows do not result in significant drag forces and that margins exist against scram failure. A duct bowing test using prototypic ducts has established scram limiting duct bows and determine duct bowing margins.

Absorber pin ruptures could impact scram performance due to reactivity loss from B_4C washout at open cladding areas or due to inner duct deformation from pin failure gas pressure pulses. Absorber pins are designed not to fail and analyzed using conservative deterministic cladding criteria. Washout test data for B_4C pellets exposed to flowing sodium must be evaluated. This evaluation is described in Section C.5.1.1. Reliability emphasis is placed on pin rupture effects of mechanical deformations that result from sudden release of pin internal pressure. Tests have been performed to determine inner duct deformation (ballooning effect) from pin failure pressure pulses to envelope worst case effects of pin rupture. These tests have shown that pin ruptures do not result in significant deformations and have a negligible impact on scram performance. The pin rupture tests are described in Section C.5.1.2J.

Temperature and flux gradients across an absorber pin produce pin bowing. Due to dominance of the temperature gradient with higher temperatures at the interior side of the pin bundle, the bow is nominally inward. With wire wrap point load constraints, local outward deflections of the pins will occur. This outward deflection coupled with pin swelling can close pin to inner duct clearances and result in an outward pressure on the inner duct. The inner duct is necessarily a thin wall member. It could therefore deflect outwards under the action of pin bundle/duct interaction loads. Pin deflection effects on the inner duct could have an adverse impact on scram performance due to a reduction in duct to duct clearances. Analytical predictions of pin to pin and pin bundle to duct interactions are made. Data are available on this type of interaction behavior from FFTF fuel pin testing. While not prototypic, this provides additional support to the analysis for the current design. The behavior of the pin bundle is characterized by a mixture of structural and mechanical response to the applied loading. Models using existing structural analysis tools are however subject to uncertainties. A pin compaction test has been conducted to determine inter-pin loads, pin to duct loads and pin bundle compressibility to envelope the inner duct deformation that might result from pin bowing. Testing described in Section C.5.1.2G has provided the data required to define the pin bundle-duct interaction analysis.

The impact of the driveline/control rod on the PCA scram arrest flange must be evaluated to verify that a brittle fracture of the irradiated PCA outer duct will not occur. Transmitted and reflected (from core support structure) stress waves can lead to a stress buildup and brittle failure of the irradiated duct becomes a potential failure mode. The reason for concern with this failure mode is that potential chips or duct distortion from the duct fracture could retard scram insertion. To support analyses in this area, duct impact testing was conducted to minimize analytical uncertainties and to provide test confirmation that brittle fracture will not occur. The duct impact tests are described in Section C.5.1.2K.

The previously identified PCA component testing will provide data at an early date which is directed at specific areas of reliability emphasis for feedback into final PCA design. Based on preliminary analyses, testing is anticipated to confirm a design lifetime of two years. To obtain direct irradiation behavior data to confirm PCA lifetime capability, irradiation testing of a PCA in FFTF is planned. Post irradiation analysis will provide direct data on duct bowing, pin pressures, irradiation induced swelling, etc. prior to extended power operation in CRBRP.

Manufacturing, maintenance and procedural errors could affect scram insertion through factors such as internal misalignments of the assembled components, incorrectly assembled joints or materials errors. These factors could result in increased insertion drag forces resulting in slowed scram insertion. Vendor acceptance tests and development tests on prototype and plant manufacturing units will be performed. These tests will make maximum practical use of common materials for both test and plant units.

C. Interfacing Components

Interfacing component failures can impact PMS scram performance by increased misalignments, temperature effects and flow changes. To identify failures, failure detection capability and effects on PMS performance, analysis of interfacing component failure modes and their effects are performed. This analysis together with PCRS performance evaluations against identified failure modes is directed at reliability enhancement.

C.4.1.2 Secondary Mechanical Subsystem (SMS)

The SMS has been evaluated from a reliability standpoint and the continuing reliability efforts will concentrate on the safety related functions, i.e., the unlatching and insertion of negative reactivity into the core (scram). This section describes those features of the SCRS where design and reliability efforts are emphasized.

Areas Identified For Reliability Emphasis

Each of the three components of the SCRS has a function which is necessary for successful scram performance. The SCRDM scram function is to release the pneumatic holding pressure thereby allowing the tension rod to fall. The SCRD function is to allow the tension rod to drop a fraction of an inch to open the gripper fingers. The functions required to assure successful scram are control valve and piston/cylinder operation, tension rod translation, latch release and control rod insertion. Each of these is discussed pertaining to factors involved in the SCRS design and environment and areas of expected reliability activity.

A. Control Valve, Piston/Cylinder Operation

A pneumatic actuator, connected by the tension rod to a gripper device latched to the control rod, is vented when electrical power is cut off to at least two of the three solenoid operated control valves. Venting of the actuator allows the tension rod to drop unlatching the gripper device from the control rod coupling head.

Reliability Program activities on the control valves center on eliminating any potential for jamming, sticking or slow operation. The possible long term hold periods (up to one year between operations) could result in valve degradation. Mechanical distortion caused by thermal effects or shock impact in the valve assembly could cause binding forces in the pilot valves, solenoids or main valves. Deposition of particulates in the pressurizing gas could also lead to binding as well as to port and/or vent blockage. Thermal degradation of valve seat material or the presence of gas contaminants could jam or delay the operation of the valves and armatures. Variations in friction coefficients, wear effects on the valves, manufacturing errors and internal misalignments could impact proper valve operation. The effects of galling and wear and the potential sodium vapor effects (caused by bellows failure) on clearances are areas of reliability emphasis.

Tests are planned for the valve/cylinder assembly to provide proof-of-principle and are described in Section C.5.2.2C. Life tests (see Section C.5.2.2F) will be performed to confirm operational performance beyond the design life of the valve/cylinder assembly. Analysis will be performed to investigate manufacturing variations and to assess variations in wear and friction effects. A failed-bellows test of a prototypic SCRDM/SCRD (described in Section C.5.2.2G) will confirm acceptable operation in a possible sodium vapor environment.

B. Tension Rod Translation

The translation of the tension rod, which connects the actuator piston to the latch, under conditions of a deformed driveline is an area of uncertainty requiring additional testing and analysis. Distortion of the driveline tubes surrounding the tension rod is capable of introducing friction forces which can retard the motion of the tension rod. Tension rod drop of a fraction of an inch is sufficient to permit unlatching of the control rod, however, simultaneous binding of the driveshaft and sensing sleeve on the tension rod from abnormal thermal bowing effects or from excessive external loadings applied to the driveshaft could retard or prevent tension rod motion. The effects of fabrication tolerances and straightness of the rod and two surrounding tubes on tension rod translation are also needed to evaluate its reliability. The effects of bowing will be evaluated to determine displacements of SCRD component parts.

C. Latch Release

Reliable operation of the gripper fingers is essential for reliable scram performance of the SCRS. The latch is therefore the subject of a substantial segment of the SCRS reliability program.

The gripper fingers in contact with the coupling head form a latch to hold the control rod in the ready position. Potential self-welding between the gripper fingers and the coupling head could prevent insertion of the control rod. Solid material diffusion in liquid sodium (a function of sodium temperature, contact time and pressure, mating surface conditions, cleanliness, and the mating materials) may promote self-welding. This could also result from mechanical adherence of the rubbing parts as the end result of galling.

Confirmation of latch performance will be achieved by means of verification tests. The choice of latch and interfacing cam surface materials has been based on analysis of material interactions in sodium. Verification testing will include prototypic tests in sodium to assess material interactions and to demonstrate performance. These tests are described in Section C.5.2.2A. Testing to determine the effects of the long-term hold periods under prototypic environmental conditions will be used to confirm functioning. In addition, accelerated latch life testing will be performed to verify that galling and repeated latching/unlatching do not degrade unlatch performance and that margins beyond design life exist. Latch scram testing is described in Section C.5.2.2D.

Evaluation of the test results will be factored into the design and fabrication of the SCRS latch and interfacing components. If test results indicate potential for problems or if performance margins were not confirmed, corrective design action will be initiated.

D. Control Rod Insertion

The guide tube and outer duct of the SCA together form a channel that guides the control rod during its insertion into the core. Reliability activity in the area of control rod insertion focuses on assuring adequate clearances between the rod and its cylindrical guide tube. Hang up of the control rod in the guide tube or slow insertion may be caused by increased friction resulting from excessive channel distortion. Channel distortion can result from thermal bowing effects, irradiation swelling and/or creep effects, control rod pin bowing or ruptures, manufacturing errors or seismic loading effects on the SCA or on interfacing components. Other reliability activities focus on the hydraulic assist feature and the overall hydraulic characteristics of control rod insertion. Distortion effects of the hydraulic assist feature or particulate deposition in close clearance areas could affect the insertion of the control rod. Slowed control rod insertion could result from wear effects between the control rod and guide tube. Galling of sliding surfaces could lead to significant friction increases and/or seizing of moving parts.

Significant emphasis is placed on analyzing and testing the SCRS to determine the overall impact of distortions on control rod insertion. Analysis will be performed to determine the thermal bowing of the control rod, the irradiation swelling of the hydraulic assist piston, the irradiation and thermal bowing of the outer duct and guide tube, the irradiation creep and swelling of the guide tube cross section and the deformation of guide tube and control rod under seismic loadings. Results of these analyses will be used to determine potential control rod/guide tube contact points and to evaluate potential frictional forces. Results will be factored into SCRS testing. An analytical scram insertion model will be used to evaluate SCRS performance.

Verification tests (see Section C.5.2.2J) will provide proof-of-principle for the hydraulic assist and control rod insertion. Guide tube deformation tests will be used to determine the effects on rod insertion. These tests are described in Section C.5.2.2H. Guide tube distortion beyond the maximum calculated value will confirm that performance margin exists. SCRS life tests will be used to provide wear data under prototypic environmental conditions.

E. Interfacing Components

The successful scram function of the SMS could be affected by the reactor components which interface with the SCRS's. Interfacing components could potentially apply loads to the SCRS or allow displacements of SCRS components beyond design envelope misalignments which could prevent scram. Examples of components which are in these two categories are the upper internals structure, the reactor closure head, fuel assemblies and the core support structure. Analysis of each interfacing component to determine its failure modes and their effects (FMEA) is used to identify areas where adverse effects could exist. Analyses and test results will be used to provide substantiation that interfacing components are not potential scram failure initiators. Where the analyses indicate potential initiators, the component design will be modified to remove or minimize the potential.

C.4.1.3 Electrical Subsystem (ES)

The systems and equipment covered in this section comprise electronic and electrical signal conditioning equipment with associated cabling, instrumentation and switchgear needed to operate the mechanical shutdown subsystems.

System design features included in the CRBRP ES are similar to those widely used in LWR's. These equipments are implemented using piece/parts which have been proven in military programs. The equipment designs for many of the electronic subsystems, while based on designs for FFTF, have not been proven in an operating environment. As a consequence, reliability analyses and test programs are aimed at providing the same confidence in operational reliability as now exists for similar equipment in LWR's.

To evaluate the reliability of the operation of the ES, the ES is subdivided into three major areas of interest: overall subsystem, instrumentation sensors, and electronic components and subsystems. These areas are discussed in turn. The principal considerations affecting reliability are reviewed along with the resulting conclusions concerning any additional needs for analysis and testing.

A. Overall Subsystem

The Plant Protection System (PPS) design has a close similarity to systems used in Light Water Reactors for which there is an extensive background of standards, regulatory guides and licensing practice aimed at improving safety. The basis for the PPS design, the standards used and the supporting analysis are described in Chapter 7 of the PSAR and are at least as stringent as those applicable to PWRs. The use of these standards, coupled with the similarity of CRBRP and LWR designs for the ES, is a major factor contributing to the program goal of achieving a level of reliability in each of the ES subsystems for CRBRP comparable to that achieved in LWR systems.

Reliability is assured by a combination of design procedures, tests and system reviews which ensure that the requirements of the standards have been adequately met both within the ES subsystems themselves and with relation to other interfacing systems and equipment.

Assurance of reliability in design features within the ES has been met by a combination of studies of failure modes and effects (in order to determine the results of single failures) and of common causative factors which could result in total system failures.

The industry standards referenced in Table 7.1 of the PSAR provide for the reliable operation of the ES equipment under accident conditions by placing specific requirements for separation, environmental qualification and testing. For instance, in the case of separation of ES from others, full compliance with Regulatory Guide 1.75 is required in all relevant system design descriptions. This has been implemented in the case of the ES by specially designed buffer circuits, by requirements for appropriate cable and tray separation and finally by the use of separate upper and lower cable spreading rooms for the primary and secondary electrical subsystem cabling respectively.

The activities described previously are directed at assuring that reliability is designed into the ES. The effectiveness of these design measures is assessed in the ES reliability assessment. This assessment is conducted using the techniques described in Section C.2. Particular attention is directed to the reliability evaluation of many ES interfaces with external components. The ES reliability evaluation is summarized in the ES Reliability Design Support Document.

Given the use of existing proven industry standards and design and reporting procedures that ensures their effective implementation, difference remains between CRBRP protection systems and those currently licensed for LWRs. The difference relates to the design of the protection logic systems. Although these systems are based on the FFTF design, no overall system operating experience exists for this equipment. To provide the required operating experience for the CRBRP system, the Reliability Program plans long-term testing of a complete Electrical Subsystem. A description of this test is contained in Section C.5.3.2B.

B. Instrumentation Sensors

Instrumentation sensors to be used in the ES are based on designs in which there is extensive previous experience from either Light Water Reactors or other sodium systems such as EBR-II, Fermi-I and SEFOR. For instance, in the case of the Power/Flow trips on which reliability interest has been concentrated, there are four different types of sensors involved: Neutron Flux Ion Chambers, Neutron Flux Fission Counters, Electromagnetic Flow Meters, and Sodium Differential Pressure Meters. The two types of neutron flux sensors are similar in both construction and functional application to sensors used in Light Water Reactors. Their reliability characteristics are consequently well understood and can be factored into the overall system design by means of accepted and proven redundancy concepts.

The electromagnetic flowmeters are based on instruments in which operating experience exists in EBR-II and Fermi and operational sodium test loops. The design utilized electrodes connected to the outside of pipes and permanent magnets located again outside the pipes. The simplicity of these sensors provides inherent high reliability.

In the case of differential pressure sensors, the similarity of the instrument to those used for similar functions in operating sodium test loops provides assurance that their failure characteristics are well understood.

In view of these considerations, it was concluded that an adequate background of relevant experience existed on the sensors to support their reliable operation in the CRBRP ES application. This conclusion also applied to the sensors which initiate the shutdown heat removal system. These sensors are similar to those now in operation in similar applications in the industry.

C. Electrical Components and Subsystems

The CRBRP ES design was based on a modification of the design prepared for the FFTF project. A reliability enhancement study carried out early in the program indicated what improvements could be most effectively achieved by means of a component reliability program. This component reliability activity has taken the form of rigorous comprehensive specs which include extensive use of MIL Specs and a component test program.

The component test program has two principal series. First, vendor thermal screening and functional tests will be used to detect any design or manufacturing deficiencies in the modified FFTF components. Second, extended life tests will provide a high confidence level in the long-term reliability of the components.

C.4.2 Shutdown Heat Removal System

This section describes the areas of the Shutdown Heat Removal System (SHRS) where testing and analysis have been identified as desirable to support the adequacy of SHRS reliability. These areas relate to uncertainties associated with specific components and have been identified after an evaluation of the overall system. Included are separate sections on the PHTS, IHTS, SGS and SGAHRS, and DHRS.

Failure Mode and Effects Analysis, numerical reliability predictions for conceptual and preliminary design configurations and designer experience with both sodium and water/steam systems and components were used to select the initial areas for reliability attention. At the initial stage in the Reliability Program, major development test programs existed in the steam generator systems and coolant boundary areas of the heat removal systems. These areas were considered for reliability emphasis since defined tests will provide information which could impact the reliability of the SHRS. The initial FMEAs and reliability assessments were performed during the conceptual and preliminary design phase. The failure modes and failure consequences and simplified systems reliability models were used to determine relative criticality of failure modes. During the design detail phases, the FMEAs and CCFAs are upgraded to reflect design maturity and changes. These evaluations confirm the appropriateness of ongoing heat transport system component development tests. Identified areas of uncertainty are cross-referenced to specific tests which are described in Section C.6.

C.4.2.1 Primary Heat Transport System (PHTS)

Areas Identified for Reliability Emphasis

The CRBRP PHTS design basis and operational environment are similar to those of FFTF. The primary pump and IHX designs as well as piping layout are areas of major difference. FFTF experience in design, fabrication, shipping, installation, inspection and operation will be utilized in the CRBRP reliability evaluations and in final design implementation.

One area of criticality to PHTS function during shutdown heat removal identified for reliability emphasis is the structural integrity of the primary coolant boundary. The FFTF experience will be significant to assessing the reliability adequacy of this boundary and identifying appropriate activities for assuring its installed integrity. Retention of the primary system coolant inventory has critical importance to transporting heat from the core. Coolant boundary integrity is also important to the successful operation of DHRS since some piping or vessel leaks may lower sodium levels below the sodium overflow level which would terminate DHRS removal of heat from the reactor vessel. Loss of primary system coolant inventory is limited by guard vessels and elevated loop piping provided to maintain independence of primary loops. Leaks in one PHTS loop will not affect inventory in the other two PHTS loops. Test programs have been directed toward assuring adequacy of base material (SS304, SS316 and Inconel 718) structural properties and the welded joint design adequacy. Much of this information is being developed under on-going technology programs described in Sections C.6.1.2H and L. Present programs may not provide sufficient information on weld joint reliability and thermal fatigue at locations where sodium streams with widely differing temperatures mix. Testing in these areas is described in Section C.6.1.2A.

Pipe hangers and snubbers impose loadings on the piping and represent potential failure mode initiators for the primary sodium boundary. Analyses of seismic response and expansion characteristics assuming failed hangers and snubbers are being performed. Testing to qualify the hangers and snubbers will be performed. The testing is described in Section C.6.1.2B.

The PHTS sodium leak detection system is a fundamental line of defense in the assurance of the primary coolant boundary integrity. Development programs are in place as described in Section C.6.1.2D which will provide diverse sodium leak detection methods and equipment with appropriate levels of sensitivity.

The PHTS pumps provide forced circulation and are important contributors to the overall reliability of the SHRS. Depending on the time after scram that the DHRS may be activated, operation of one or more of the primary pumps at pony motor speed is critical to the operation of the DHRS. Low speed pump tests have been specified. The primary pump development program includes tests on pony motor operation and will provide information on pump bearing wear characteristics at pony motor speeds. These tests are described in Section C.6.1.2F.

The main heat transport system is designed to provide natural circulation heat removal capability in all three loops. Testing is planned to confirm operation in this mode and is described in Section C.6.1.2G.

C.4.2.2 Intermediate Heat Transport System (IHTS)

Areas Identified for Reliability Emphasis

The functional requirements for the IHTS and its hardware characteristics are similar to the PHTS. Therefore, PHTS materials properties testing, leak detection testing and sodium pump testing are applicable to IHTS reliability assurance activities. The impact of intermediate system sodium leaks introduces new variables for attention. The ambient air environment and the material property differences in the transition welds to the SGS and the extensive length of piping runs are key areas of difference between the IHTS and PHTS. The ambient air environment for the IHTS introduces an increased level of corrosion potential around a small sodium leak. Sodium leak detection testing must therefore be directed towards sodium to air leakage. The materials property testing for the PHTS, however, is applicable to IHTS reliability assessment.

The IHTS connections to the steam generator introduce two unique areas of structural design. The transition weld joint at the piping connections to steam generator modules and the mixing tee joints which tie the modules in one loop back to a single pipe are areas with potential for loss of coolant boundary integrity. Development tests are underway for these two areas to investigate their potential for being a point of coolant boundary failure. These tests are described in Section C.6.2.2.

C.4.2.3 Steam Generator System (SGS) and Steam Generator Auxiliary Heat Removal System (SGAHRS)

Areas Identified for Reliability Emphasis

The steam generator systems have common elements in both the normal shutdown heat removal mode, which uses the main steam piping and condenser as a heat sink, and the auxiliary heat removal mode which uses SGAHRS to provide steam venting and PACCs as heat sinks.

There are nine steam generator modules of common design, any one of which is adequate to remove shutdown heat. The designs potential for common cause failures in the modules and their associated systems, and steam generator coolant boundary integrity is a primary focus of reliability activities. Steam generator module tests are described in Section C.6.3.2A.

A shell-side hydraulic model test is providing information on the potential for tube or tube sheet vibration in addition to shell-side flow distribution. The "few tube" model tests provided information about tube expansion during thermal transients. The potential for thermally damaging the steam generator tubes as a result of departure from nucleate boiling (DNB) is also being experimentally investigated within the steam generator development programs by exposing tubes to severe DNB conditions. Descriptions of the steam generator prototype test and "few tube" test are provided in Section C.6.3.2A.

The leak detection system has the potential for improving the availability of steam generator modules for shutdown heat removal. This system is therefore of interest to reliability. The leak detection system signals that hydrogen or oxygen is present in the intermediate system sodium. The operator would take action to isolate the water/steam side and may take action to dump the sodium from the affected loop. Such action would remove the loop from heat removal capability. Early action by the operator may preserve the sodium inventory by isolating the water/steam side. The early action may retain the loop for heat removal through the unaffected modules. Testing has been defined in support of leak detection function and is described in Section C.6.3.2B.

The burst discs in the SGS which isolate the SWRPRS from the SGS are receiving major attention since they introduce a common cause failure potential for the three main heat transport systems. Inadvertent rupture of one pair of these discs in each loop would eliminate redundancy in the SHRS (only the DHRS would then be available). The SGS development program is conducting tests to demonstrate operation of the burst discs within the design specification limit pressures. The testing for burst discs is described in Section C.6.3.2C.

The shutdown heat removal function requires the integrity and operation of the steam piping, main steam line valves, turbine bypass valves, steam generator modules and steam drums. All of these components include levels of redundancy during shutdown heat removal. Light Water Reactor and conventional steam plant experience and data as well as acceptance tests will be used to assure that adequate SHRS reliability can be established without special testing directed toward these components.

C.4.2.4 Direct Heat Removal Service (DHRS)

Areas Identified for Reliability Emphasis

The DHRS incorporates two primary coolant flow paths. An inner loop transfers heat from the core to the outlet plenum via circulation in the PHTS. Heat rejection from the outlet plenum is accomplished via injection of cold sodium into the outlet plenum via the makeup nozzle and extraction of hot sodium via the overflow nozzle. An essential element for the successful operation of this system is the effective heat transfer between sodium circulating in the two paths. This heat transfer takes place by means of mixing of sodium from the two circulation loops in the outlet plenum. The effectiveness of this mixing mechanism has been demonstrated in the 1/21 scale water tests performed at ARD. Further confirmation has been obtained from the 1/4 scale water tests conducted in the Integral Reactor Flow Model at HEDL.

The DHRS uses the components of the primary sodium service system and the EVST cooling system. The DHRS introduces only the overflow heat exchanger and additional valves. The integrity of primary piping and other elements of the DHRS coolant boundary will be supported by the materials testing programs identified for the primary coolant boundary in Section C.6.1.2. The performance of DHRS will be supported by information from flow testing of the reactor vessel outlet plenum described in Section C.6.1.2A. Other testing includes performance testing of active pumps and valves; design verification testing of the air blast heat exchangers and manufacturer acceptance testing of the overflow heat exchanger and the air blast heat exchangers. The air blast heat exhangers are similar to the FFTF air blast heat exchangers and their reliability will be supported by testing done for the FFTF components.

C.4.2.5 Interfacing Systems

Areas Identified for Reliability Emphasis

The SHRS has the capability of functioning in the natural circulation mode in the primary, intermediate and steam/water loops. The requirement for electrical power is that the battery supply be available to operate control instrumentation in the SGAHRS. The components of the power supply are of conventional design, and generic reliability data are available to support their reliability.

C.5.0 Reactor Shutdown System Evaluation

A program element essential to meeting the objective of reliability enhancement is the timely feedback of data from the program activities to the plant equipment design, fabrication, installation and operation activities. In the case of analytical assessments, this is achieved by requiring that the reliability assessments be a part of the design support package for each component which is part of the RSS. Assuring timely feedback of data from the test program, however, requires careful planning since in many instances test articles cannot be made available before a number of the design and fabrication processes have been completed. In recognition of this problem, the schedule for the Reliability Program test activities has been coupled to that for the plant component design, fabrication, installation and operation activities. All test activities will provide data in advance of operation of the plant units. The testing schedule is such that positive response is possible for the elimination from the plant equipment of any unacceptable features uncovered in the test program.

The analysis of the RSS includes: (a) qualitative analyses (FMEAs and CCFAs) which identify potential random independent and common cause failures, (b) evaluations of failure consequences, (c) numerical reliability predictions of potential failure modes to supplement design analyses, (d) evaluation of test results to provide input to failure resolutions, (e) evaluations of design changes or updated details for impact on failure modes, (f) continuing evaluations of critical dimensions or processes through manufacturing and installation to minimize potential errors and (g) assessments of interfacing components potential failure modes and consequences.

RSS analysis utilizes the preliminary FMEA as a starting point for further analysis as well as test definition. Based on this FMEA, failures having common cause potential for scram failure of more than one control rod are identified. Priority is then given to the resolution of the common cause failures in both analysis and test efforts. Each failure mode is analyzed to determine design margins or design features which protect against the failure mode. Evaluations of test results are also factored into the failure mode analyses. If marginal or inadequate protection against the failure mode is indicated, the system level consequences of the failure are evaluated to determine need for additional protection. This process is used to assure acceptably low likelihood for the failure, to determine acceptable consequences of the failure or to identify design changes for reliability enhancement.

Initial FMEAs were utilized in the preliminary design reviews of RSS components. Periodic updates of the FMEAs reflect new analyses, test data, design improvements, etc. to show that failure modes are precluded or their effects are nullified. Each failure mode identified is being addressed to ensure that it will not impact RSS reliability. Material and process specifications and installation and operation procedures are being evaluated from a reliability viewpoint. Design changes, manufacturing waivers and nonconformances are also evaluated as appropriate to ensure RSS reliability.

C.5.1 Primary Mechanical Subsystem Evaluation

C.5.1.1 Analysis

Analytical models for the unlatching and scram insertion functions have been developed to assess PCRS reliability. The impact of design changes or more detailed component design features are assessed using these models. Included in PCRS evaluations are updates of control rod system misalignments resulting from interfacing component design changes or updates of reactor system installation details. Design changes not directly impacting unlatching or insertion analyses are assessed to assure negligible impact on the shutdown systems.

Development of the analytical model to predict pin lifetime behavior and scram performance characteristics is closely allied to the test program. Data from the control assembly tests, are vital to this model development which will be used in the reliability and design analyses.

The reliability analysis and test evaluations will be summarized in the PMS Reliability Design Support Document. FMEAs for each PCRS component are prepared for component design reviews. Updates of the component FMEAs are to be prepared to support significant component milestones (e.g., final design, test program completion). The PMS Reliability Design Support Documents will be prepared to encompass the entire, completed series of PMS reliability analyses and testing activities.

Table C.5-1 provides a summary of the principal PCRS scram failure modes identified from qualitative analyses. Actions to evaluate failure modes includes assessments of design features, testing and supporting analyses. These principal areas are detailed in Table C.5-1. Comments are given in the last column of the table to elaborate on the identified areas for failure mode resolution. Preliminary design analyses indicate acceptable scram performance for each of the identified areas. The reliability efforts are directed at resolution of uncertainties in the design analyses and experimental test confirmation of the design predictions.

Washout of B_4C from absorber pins under assumed failed cladding conditions has been evaluated. The predicted total loss of B_4C from one or two pins results in only a few percent loss in control rod reactivity worth. Washout test data for B_4C pellets exposed to flowing sodium indicated low B_4C loss rates. Therefore, loss of B_4C from pin failure is not considered to be a significant failure mode.

Numerical Assessments

Numerical analyses have been performed to determine (a) the unlatching performance for FFTF test units to obtain an indication of the PCRDM unlatching reliability, (b) the PCRDM time to unlatch and (c) the PCRS time to insert in order to assess the PCRS probability to meet design requirements for negative reactivity insertion. These analyses assist identification of potential problem areas for further design, reliability evaluation and testing emphasis. Summaries of these analyses are given below and overall conclusions are given in Section C.7.1.1.

A. Unlatching Performance for FFTF Test Units

The FFTF CRDM is essentially the same design as the CRBRP PCRDM except for minor sizing differences to meet CRBRP load requirements and small changes to the segment arm springs and leadscrew bushings to enhance the scram reliability. The failure modes challenged in the integral CRDM unlatching test included those associated with part failures, friction coefficients, galling, design or manufacturing errors, leadscrew chips and misalignments. On the basis of the design and manufacturing similarity between the FFTF and CRBRP CRDM's, the FFTF test data provides a valid indication of CRBRP unlatching reliability. No failures have been found in 3513 FFTF test scrams of the test unit. This compares with the 750 scram events included in duty cycle for the CRBRP CRDM.

B. Unlatching Performance for CRBRP PCRDM

An analytical unlatching model of a CRDM was developed to predict the CRBRP unlatching time and the standard deviation for the unlatching time. The analytical model includes variables associated with the stator field decay time, segment arm springs, friction coefficients and loading conditions of the CRDM and leadscrew.

To get an accurate representation of the stator field decay, FFTF motor test data were used along with FFTF Environmental Life Test data. These data were used to calibrate the stator current decay equation. A single decay equation was fitted to the mean of all test data for field decay. Standard deviations were obtained by analyzing the spread of test data compared to the mean curve. Variations in the field decay due to temperature and critical current (two or three phase operation) were encompassed by the standard deviation. This procedure led to a conservative standard deviation as the FFTF test variations in input current and stator coolant flow lead to a broader distribution than expected for fixed plant operating conditions for these variables.

Mean friction coefficients based on material couples tests were adjusted to improve agreement between calculation and test results for FFTF unlatching tests. Friction coefficient distributions were defined using data obtained from material couples tests. The model and data were then used to predict FFTF unlatching test results. Predicted unlatching times compared well with test results. The predicted standard deviation was, however, considerably larger than that obtained from testing.

The unlatching model was then updated to CRBRP PCRDM design parameters which included preliminary electric current decay data from PCRDM motor test data. This procedure changed the mean field decay curve but the standard deviations from FFTF tests were retained as a conservative envelope since the test results covered a broader range of operating conditions.

The PCRDM model was used to aid assessments of scram time failure modes associated with the springs, stator and CRDM friction. Analysis predicted a mean time to unlatch of 0.089 seconds with a standard deviation of 0.010 seconds. This unlatch time was combined with the scram insertion times (see Paragraph C below) to provide a comparison with overall scram time requirements. Since this analysis was completed, a design change was implemented to reduce stator wire diameters (increasing resistance) and thus decreasing the unlatching time.

C. <u>Scram Insertion With Design Basis Misalignments</u>

This analysis was performed to assess insertion reliability against potential failure modes associated with variability of misalignments within the design envelope, sliding friction coefficients, flow parameters and scram spring constants. Distributions were assigned to these variables which were then Monte Carlo sampled to perform probabilistic analysis. The scram spring force and misalignment distributions utilized for this analysis were based on the design specified tolerances for the PCRS and interface components. For individual parts, uniform probability distributions over the maximum drawing tolerances were assumed for each gap. This assumption of uniform distributions is conservative compared to asymmetrical gamma distributions (pealed towards smaller gap size) typically found for manufactured parts as it leads to greater probability at the extreme tolerance limits. Since most parts contributing to these misalignments have 100 percent dimensional inspection requirements, there is a very low probability of a part exceeding drawing tolerances.

These distributions are then combined for all parts, leading to the overall misalignment at a given elevation. The resulting distributions at a given elevation approaches a truncated normal distribution. The extreme tails of the distribution are, however, included in the analysis for added conservatism. The flow parameter distribution utilized uncertainties obtained from the FFTF control assembly flow test. This test was run in water with a prototypic control assembly. The data was then correlated to flowing sodium conditions. From this, a friction factor was derived. The percent error based about the mean value was used to define uncertainties. Friction coefficients and associated standard deviations used for gamma distributions were obtained from material couples friction and wear tests performed under Base Technology programs.

These analyses yield the probability of achieving the design requirements for scram insertion speed. Combining the unlatching time and insertion time analyses for the time from start of stator field decay to insertion of 1$ of reactivity yielded a mean time of 0.338 seconds and standard deviation of 0.012 seconds. These results indicate a normal scram probability of >0.999 (per challenge) satisfying the scram time requirements under operation within the design basis and no structural failures.

C.5.1.2 Testing

PCRS tests have been planned to determine possible design deficiencies and investigate postulated failure modes. Testing is maximized under those operating conditions postulated to cause failure, especially where it is desired to supplement current data to determine design margins against potential failure.

Manufacturing processes have been considered throughout the test program planning. Included in this planning are:

1) Plant unit specifications are used for all prototype procurements to assure resolution of potential fabrication problems. No prototype exceptions have been permitted for the PCRDM/PCRDs. For the prototype PCAs to be used in sodium loop testing, the only exceptions are non-prototypic pin internals (no B_4C) and changes to material standards (ASME standards substituted for RDT standards) for absorber pin cladding and minor non-wear limited parts. Fabrication, inspection, and acceptance test specifications are the same for prototype and plant units.

2) Simultaneous material procurements have been made for prototype and plant unit PCRDM/PCRDs. Potential plant unit failure resulting from material variability should be minimized as material deficiencies are expected to be identified in the prototype tests.

3) Acceptance tests for each unit will be performed by the PCRDM/PCRD vendor prior to shipment. These tests will include functional tests of the PCRDM to compare performance with acceptance requirements.

To minimize potential failures resulting from installation and operation, the following activities are planned:

1) Prototypic installation employing plant installation tools and procedures will be used throughout the PCRS test program.

2) Prototypic testing of all planned PCRS maintenance operations employing plant maintenance tools and procedures will be used to search for human factors or design errors which could lead to scram failure.

3) CRBRP startup tests will include functional and scram tests to verify shutdown performance prior to criticality and during power ascent.

4) CRBRP scram tests will be performed after every reactor refueling prior to approach to criticality.

5) Normal shutdowns will be completed by a scram test of control rods. After control rods are inserted sufficiently to shut down the reactor, the rods will be scrammed to complete insertion to test scram performance.

The following paragraphs identify the individual tests and discuss the engineering features of each test. The feedback to the plant equipment development program is identified together with the options available for responding to the test data. A description of the test facilities to implement these tests is included in Addendum 1.

A. <u>PCRS Prototype Design Test</u>

The PCRS Prototype Design Test includes four parts: the PCRDM Accelerated Unlatching Life Test, the PCRS Prototype Design Test, the Disconnect Actuating Tool (DAT) Test and the Maintenance Equipment Tests. In the unlatching test, the PCRDM will be operated beyond the design life of unlatch and travel to assure margins against wear related failures and to eliminate design defects. In this test, operating environment extremes such as mechanism misalignment, temperature and pressure will be increased beyond design basis conditions to evaluate design margins. The PCRS Prototype Design Test is a complete control rod system (PCRDM/PCRD/PCA) test in a sodium environment. PCRDM and PCRS performance data such as unlatching time and scram insertion time will be used to assure that design specifications are satisfied under design basis operating conditions of misalignment, sodium flow rates and temperatures. The DAT and Maintenance Equipment Tests provide data which will be used to thoroughly evaluate the maintenance procedures on prototypic equipment under plant type operating conditions. These tests are to identify weaknesses in the equipment design and the maintenance procedures as well as to evaluate any maintenance related failures.

Results from this test are available for the period of early 1978 through late 1980. The PCRDM/PCRD Final Design Review was held in October 1978, and data from the CRDM Accelerated Unlatching Life Test was available for this design review. By mid 1978, manufacture of all prototype PCRDM/PCRDs was completed. Fabrication of the plant units progressing in parallel with the testing. Both the test and plant units fabrication will be completed in late 1980. The overlap of testing and fabrication has permitted PCRDM/PCRD design changes, identified as desirable from the test program, to be incorporated into the plant units. Design changes based on test results have been made to facilitate installation and maintenance. Normal operation and safety-related performance has exceeded design requirements.

B. PCRS System Level Test

The System Level Test has elements concentrating on different aspects of PCRS performance.

Part I is the Real Time Test of a prototype PCRDM/PCRD and prototype PCAs. Representative hold times (inactive periods during which the control rod is not moved) are interspersed throughout the accelerated operations. The operating profiles of a Row 4 corner control rod are simulated at an accelerated rate of cyclic operation because rods at these positions are not used for daily power control and experience periods of inactivity during normal reactor operation. Besides providing additional data to assure manufacturing variations do not affect design margins against potential wear related failures, the hold times generate data to confirm that potential time related failure mechanisms such as self-welding are not significant. Scram times and other performance data are used to confirm that design specifications are satisfied and to assure the reliable operation throughout the test.

Part II is the Failed Bellows Test and consists of operating a prototype PCRS for one year with an intentionally failed bellows to determine potential related failure modes for PCRDM unlatching and PCRS insertion. Bellows failure will expose parts normally in an argon environment to sodium vapor. Scram release time and wear will be monitored to evaluate design performance and margins under failed bellows conditions. By observing areas of sodium buildup or extreme wear, potential failure mechanisms resulting from a failed bellows will be identified.

The PCRS flow vibration test, Part III of the system level test program, utilizes accerlerometers on the PCRD and shroud tube in the area of the dashpot cup and on the PCA outer duct to monitor flow vibration effects. These data, together with past sodium test examinations of all test components, are used to verify acceptability of the PCRS design relative to flow vibration effects.

Results from these tests will be available so that any plant unit modifications can be implemented prior to their shipment to the site. All reliability testing will be completed prior to initial startup testing in CRBRP. Test results can be factored into the PCA final design, scheduled for completion in late 1981.

The PCRS System Level Test facilities have been designed for testing at the extremes of the design operating conditions and beyond to induce failures and thus determine design margins to assure reliable performance. Maintenance equipment including a simulated maintenance pit will be used in the system level tests.

C. PCRS Dynamic Seismic Friction Test

This test provides two pieces of information essential to the accurate prediction of control rod scram insertion performance during a seismic event. These are (a) the effect of fluid coupling on the lateral translational behavior of a driveline and control assembly within their respective guide members and (b) the effective coefficient of friction between the interacting components under conditions of short duration contact. Effect (a) is of importance because it dictates the number and magnitude of the lateral impulsive forces generated as seismic excitation causes the driveline and control assembly to "rattle" within their guide members. The frictional component of these loads acts to retard scram insertion, hence their number and magnitude reflects directly on the seismic scram insertion prediction. Effect (b) must be evaluated in order to reduce present conservatism in the friction assumptions used to convert the lateral impulsive loads into axial loads opposing scram insertion. During the brief period of lateral impact loading, it is possible that squeeze film sodium lubrication will decrease the effective friction coefficient.

The test provides data on the translational behavior and impact load behavior of simulated rod/guide tube features when subjected to seismic excitation in a fluid environment. The impact load-time histories obtained are used to calibrate analytical models to assure the correct representation of entrained fluid effects. Drop times are to be measured. These data, together with the impact load-time histories has been used to determine the effective coefficient of friction under squeeze film lubrication conditions.

Results from this test were obtained in the period early 1977 through early 1980. Most of the test results were available prior to the PCRDM/PCRD Final Design Review in 1978. Friction coefficients from the test have been combined with normal impact forces from seismic analyses to show that PCRS seismic scram speed requirements are satisfied.

D. PCRS Friction Couples Test

Data will be generated by these tests is used to evaluate friction and resultant drag forces that will be encountered during PCRS operation. The materials used in the PCRS design have been carefully selected, especially in the areas where contact during operation is anticipated. These tests provide friction data on the material couples under varying conditions of contact force, temperature, environment (liquid sodium, argon-sodium vapor and argon), length of contact surface and time between operations. The maximum friction developed under these conditions has been incorporated into scram speed analyses an analytical model to confirm design margins.

The test material samples consist of a pin and plate. These samples are placed in a facility capable of providing reciprocating motion and recording friction over the range of conditions specified.

Results from these tests are currently available. These data are utilized available for both the PCRDM/PCRD and the PCA Final Designs.

E. Control Assembly Hydraulic Test (Flow Test)

This test generates flow, vibration and pressure drop data to characterize the hydraulic performance of a prototype PCA. These data are required to assure that adequate design margin against control rod flotation is available. Flow induced vibration will also be investigated to check the rod bundle response to flow turbulence up to 150 percent of nominal flow. The test facility will be a circulating water loop with the required flow and pressure drop instrumentation.

Results from this test are being utilized in the PCA final design evaluations.

F. Control Assembly Rotational Joint Test

The purpose of the Rotational Joint Test was to verify the performance of the rotational joint under expected operating environments. The objective of the test was to measure the torque transmitted through the joint under prototypic temperatures and loads. In addition, the effect of scram impact dynamic loads, misalignment of input and output shafts and sodium soak were determined. Finally, the effectiveness of the rotational joint in reducing duct wear was determined by purposely inducing wear pad to duct contact and cycling the rod until approximately six times the goal lifetime travel is achieved. Wear pad to duct contact was reestablished after every half lifetime of travel. Data generated by these tests demonstrated the effectiveness of the rotational joint to minimize control assembly wear.

G. Primary Control Assembly Pin Bundle Compaction Test

Data generated by this test is used to calibrate the pin bowing analysis. Pre-bowed pins were compressed to the configuration required by the control rod inner duct. The forces necessary to compact the pins to the bundle dimensions will be measured and recorded to determine pin contact loads with the duct and with other pins. These data are combined with analysis to establish potential outward deformation of the control rod inner duct as a result of forces due to pin bowing. Results from this test are available for incorporation into final PCA design efforts.

H. Control Assembly - Drag Force for Bowed Duct Test

Control rod duct bowing resulting from irradiation and thermal gradients is a potential common cause failure. To assure that adequate design margins exist to eliminate this source of failure, drag load measurements during insertion and withdrawal were made under various bow conditions and environments. Prototype ducts were bowed in a test facility where the bow, inner to outer duct orientation, flow rates and radial misalignments between a simulated lower driveline and the outer duct were varied and recorded. The bow configurations that can cause insertion failure due to excessive drag forces were determined and the margin between failure and worst-case design conditions were established. This test also showed that the three dimensional mechanical/structural interactions between the driveline/control rod and associated bushing/outer duct under misaligned conditions can be adequately evaluated by two dimensional analyses. Effects of the rotational joint in the control rod shaft (which reduces both lateral and rotational contact loads between the control rod and outer duct) were included in the measured drag forces. Measured drag forces from this test have shown that duct bowing causes negligible drag forces for duct bowing exceeding worst-case design predictions. Bowing does not induce large retarding forces until the design criteria limit of forced three point contact between the control rod and outer duct is exceeded.

Results from this test will be produced from early 1977 through early 1978. Data will be incorporated into final PCA design efforts.

I. PCRS Seismic Test

To provide data that will confirm design margins against scram failure during an OBE or SSE, a prototype PCRS will be mounted in a test fixture coupled to eight vibration generators in a water environment simulating sodium levels. The unlatch time will be measured and recorded with various vibratory inputs. The PCRDM will be mounted on a three-dimensional shaker table to evaluate the unlatching performance. The shaker table, together with an additional five lateral shakers, are planned for evaluation of scram insertion performance. The data will be assessed to discover design deficiencies and establish design margins. This test is primarily oriented toward providing unlatching and scram insertion data for verification of analysis methods. Sinusoidal inputs typical of the acceleration levels under OBE and SSE conditions will be utilized for these tests. Results from this test will be available by late 1979. At this time, the plant unit PCRDM/PCRDs will have been completed and will be ready for shipment. Any need for modifications can delay shipment since site installation does not occur until late 1981.

J. Pin Rupture Test

Pressure pulses from absorber pin rupture could result in sufficient inner control rod duct deformation to cause a scram failure. Data generated by this test are combined with analysis to confirm design margins are adequate against this postulated failure mechanism. Pins at different locations in the pin bundle were intentionally faulted and ruptured in prototypic ducts to obtain data such as pressure pulse magnitude, duration, pin plenum pressure decay and duct deformation. The resulting duct deformations have been found to be small and pin ruptures have negligible potential for causing a scram failure.

K. Duct Impact Test

A PCRS scram is terminated by impact of the driveline and scram arrest flange at velocities less than 14 inches/sec with the scram arrest flange welded to the PCA outer duct. Since the PCA duct loses ductility from irradiation, impact tests on irradiated ducts are planned to assess the potential for brittle fracture due to scram impact loads. Impact tests in support of the FFTF program were performed without failure on an irradiated EBR-II control rod thimble at ambient temperature conditions (75°F). Tensile data generated at temperatures (1000°F-1400°F) higher than the irradiation temperature (700°F) have shown a reduction in ductility which can be lower than the ambient temperature ductility. Since CRBRP control rod ducts can be impacted at up to 1000°F during scram operation after being irradiated at lower temperatures, impact test data are required to confirm scram impact acceptability.

The Duct Impact Test simulated scram impact by dropping known weights from varying heights on an irradiated EBR-II duct. The test included impact loads resulting in stresses well in excess of stress conditions expected in PCA ducts. Tensile test data from the ducts were also obtained to assist post analysis of the test and extrapolation to PCA conditions. This test will be used to define design margins against PCA duct failure due to scram impact. Results from this test are currently available and are being used to evaluate PCA design impact.

L. Duct Crushing Test

The purpose of the Duct Crushing Test is to investigate the failure mode of a highly irradiated hexagonal duct segment when subjected to lateral loading similar to that experienced by the above core load pads on CRBRP during seismic excitation. Material used in these tests is taken from EBR-II control rod thimbles previously irradiated to a fluence of approximately 1×10^{23} total fluence and between 4 and 5.7×10^{22} fast fluence. The material is in the form of hexagonal duct sections, similar in profile to the CRBRP core duct profile. The test material therefore incorporates the features which introduce uncertainty into the duct crush strength analysis. These are (a) a much reduced ductility with the attendant potential for brittle fracture, (b) strain concentrations at the duct corners and (c) plane strain bending stresses (the available ductility data on irradiated stainless steels have been obtained from tests in which the stresses were uniformly tensile).

Sections of an irradiated EBR-II SS304 duct were loaded in a transverse direction between two jaws to simulate in-service seismic loading. In addition, tensile and bending test specimens were machined from the duct to provide basic materials data for use in analytical predictions of duct response to transverse loading for subsequent comparison with test data. Temperature and strain rate were varied over a range consistent with expected CRBRP conditions to determine if any combination of these parameters would lead to a brittle fracture. Test temperatures were chosen to be higher than the average irradiation temperature of the duct, since the results of the prior EBR-II duct evaluation indicated a decrease in material ductility with an increase in test temperature above the irradiation temperature. Results from this test are currently available and are being used to evaluate PCA duct design.

C.5.2 Secondary Mechanical Subsystem Evaluation

C.5.2.1 Analysis

A summary of the principal SCRS scram failure modes identified from qualitative analyses is provided in Table C.5-2. The areas of testing, design features to mitigate consequences or prevent the failure, and supporting analyses which are important to failure mode resolution are referenced in Table C.5-2. Identification and evaluation of these failure modes have provided guidance for the appropriate corrective or preventive actions to minimize the impact on SCRS scram function. Further efforts are directed at resolution of uncertainties in the design analyses and at experimental test calibration of the design prediction methods.

Numerical Assessments

Available data indicate that the frequency of spurious scrams is highest at the beginning of operation of a reactor and decreases thereafter because of a learning process. The number of scrams which a reactor will see through its lifetime can therefore be estimated by the use of a mathematical model which takes into account this learning process. The current reliability assessment of the SCRS design using this model is that the design is adequate in terms of safety-related reliability.

C.5.2.2 Testing

The testing of the SCRS and its components is orientated to design verification; i.e., a determination of the capability of the design to meet its functional requirements. Data resulting from the design verification tests will also be analyzed from a reliability viewpoint, and reliability deductions will be made as the data permits.

The following paragraphs identify the individual tests and discuss the engineering features of each test. A description of test facilities for these tests is included in Addendum 1.

A. Latch Real Time Test

This test permitted evaluation of self-welding in this critical component early in the development cycle. Environmental conditions for the test were more severe than those predicted for the latch in reactor service.

The test articles were subjected to less vibration, a constant force, a higher and more stable sodium temperature and a longer time between scrams than will occur in the reactor environment. This provided accelerated testing of the potential for the self-weld mechanism. This test allowed the latch test units to remain dormant in the latched condition for a full year. A dead weight was hung from the latch to simulate the gravitational and hydraulic loads of full power operation. To achieve a baseline for assessing the impact of the dormant period, friction coefficient were determined prior to the start of the dormant period.

This test was successfully completed in January, 1980. There was no evidence of self-welding or bonding. From the initial evaluation of the results of this test, including a range of coefficients of friction value, it can be inferred that the SCRS latch system of the configuration and materials tested will unlatch in a prototypic environment after prolonged exposure to high purity, high temperature sodium.

B. Latch Scram Test

The Latch Scram Test demonstrated the performance of the latch assembly under normal and overstress operating conditions. The test also determined the extent of wear between the contacting surfaces of the latch assembly as a function of the number of operating scram cycles. Two latch units were tested in the final configuration in the test, and other units are being tested in the system test. Data from this latch test did not identify any latch failure modes and established the latch cyclic life capability as being well beyond the design life.

Latch/collet assemblies were tested in liquid sodium with operating temperatures ranging from 400°F to 1050°F. Each test unit was examined before and after testing to assess the condition and degree of degradation. During the tests, all externally monitored parameters were checked for out-of-limit conditions to provide a continuous assessment of test rig and latch performance. Latch scram test #1 was successfully completed in early August 1979, after being subjected to 1987 total scram cycles, a number equivalent to approximately five times the latch service life. Analysis of test data, primarily coefficient of friction values, indicated no significant effect on latch performance of wear due to repeated scram cycles. Distributional characteristics of the data when compared with the specified coefficient of friction limits were favorable. Post-test examination of the parts did not reveal significant wear at any of the critical interfaces.

Latch scram test #2, using a different test unit, was successfully completed in mid-September 1979, after accumulating 3795 total scram releases. This number corresponds to approximately ten times the latch service life. Nothing observed during the course of testing, or as a result of analysis of the coefficient of friction data indicates any significant affect of wear on scram performance. Latch release occurred in all cases within the lower third of the specified range for coefficient of friction.

C. Driveline Lower Bellows Test

The primary objectives of these component level tests were to assess bellows design adequacy and to obtain information on component life in a prototypic environment. The tests reproduced the bellows motion involved in scram actuation and recoupling. Test items were fully prototypic of the CRBRP SCRS design in all aspects, including configuration, material construction, dimensions and clearances.

Two sets of bellows were each tested in three phases. Phase I simulated refueling conditions, Phase II simulated full power conditions, and Phase III was the life test. Each set of bellows was cycled more than 3600 times, equivalent to ten times the design life. Based on the successful tests of both items it has been inferred that the bellows design is adequate and that lifetime characteristics are satisfactory.

D. Pneumatic Valve/Cylinder Test

Both cyclic and real time failure mechanisms are being evaluated in a prototypic environment in this test. Units tested are cycled to several times the design life or to failure, whichever comes first to provide failure information and prototypic component performance data.

Pneumatic Valve/Cylinder Assemblies are being tested in two phases as follows:

1. Cyclic Testing - One assembly was cycled at approximately two-hour intervals until 900 cycles (five design service lifetimes) were completed. A cycle consisted of ten consecutive poppet valve checkout cycles followed by a scram cycle. Scram time, valve poppet opening times, cylinder leak rate, and valve temperatures were recorded at periodic intervals.

   This test of Valve/Cylinder #1 was successfully completed in March 1980. The test objectives were achieved and no safety-related failures were encountered. Nothing observed during the course of the test would have affected the ability of the valve to operate reliably from a safety (scram) viewpoint in a prototypic environment. Reliability analysis of the test data indicated adequate operating and design life margins. Analyses of valve/cylinder scram time to provide distributional characteristics showed a high probability of the valve to support the SCRS scram time requirement.

2. Real-Time Testing - A second assembly will be held in the operating mode for about 12 months. At the end of the hold period, the test article will be test cycled 900 times or to failure, whichever occurs first. The valve poppet opening time, cylinder leak rate, and temperature will be recorded at intervals during the cyclic portion of the test. Scram time at the end of the operational hold testing will be measured. Upon conclusion of the test, the resulting data will be analyzed and conclusions drawn regarding operating and design life margins, standby reliability and performance reliability (i.e., the ability to meet specified scram time requirements). Checkout of this assembly commenced in October 1980.

E. SCRS Failed Bellows-Extended Limits Test

This test is intended to evaluate the capability of the design to meet its functional requirements for periods up to 11 months under adverse operating conditions associated with failed bellows. The main shaft bellows and the driveline lower bellows protect the Secondary Control Rod Drive Mechanism (SCRDM) and Secondary Control Rod Driveline (SCRD) from sodium vapor. The major concern resulting from a bellows failure is exposure of the SCRDM and SCRD internals to sodium vapor. Condensed sodium vapor between close-fitting moving parts could result in potential interferences which could, in turn, cause degradation in the performance of the latch release action. This test will be run with both the Mainshaft Bellows and the Driveline Lower Bellows deliberately faulted to simulate the expected mode and magnitude of bellows failure. The test will demonstrate the extent to which sodium vapor can diffuse through the argon cover gas, onto the surface of moving parts of the SCRDM and SCRD, and the degree to which performance may be degraded.

Except for the purposely damaged bellows, the test article will be of the plant unit design.

Testing to be performed includes characterization testing at various sodium flow rates and temperatures, system hold and scram testing, motor test, position indication test, LVDT displacement test, and pneumatic scram valve poppet movement test. Analyses of test data will be made to draw inferences concerning safety, design margin, and scram performance. The test data will also contribute to reliability assessment of the pneumatic valve/cylinder and the latch.

F. Bowed Guide Tube Bowed Test

This test will determine the amount of deformation that the guide tube can accommodate without adversely affecting scram time. Distortion of the guide tube beyond the design limit could degrade or prevent insertion of the control rod after unlatching is completed. This test will provide data regarding scram times where a control rod is interacting with a deformed guide tube. Water will be employed as the testing fluid. The guide tube bow will be incrementally increased until control rod insertion is prevented or substantially affected. A scram will be performed for each distortion increment. The hydraulic assist force, the water temperature and the argon pressures will be monitored during the test. The scram time, guide tube deformation, degree of insertion of the control rod, and the guide tube and control rod dimensions will be recorded. The results from this test will be produced in 1981 and 1982. Scram time data will be analyzed to assess to probability of exceeding maximum allowable scram times versus a given degree of bowing.

G. SCRS Prototype-1 Test

The first SCRS prototype system test (P1) was successfully completed in December 1978. The objectives of this test were to provide a proof-of-principle demonstration of the design, to identify operating characteristics and provide a basis for assessing operating margins, and to expose failure mechanisms that had not previously been predicted. The test was carried out over a wide range of temperature and flow conditions, both above and below the anticipated operating range. The Prototype 1 test article successfully completed 1570 full scram insertions, which is more than twice the 700 scrams expected of the SCRDM over the 30 year plant life.

At the end of these extensive tests, Prototype 1 was still performing within specification requirements. No safety related failure modes occurred during testing, and there was no evidence of incipient failure encountered upon post-test disassembly and inspection. The test data and the post test observations, therefore, support the conclusion that the design is sound and incorporates adequate margins for the intended use of SCRS.

The P1 test results identified several areas in which design improvements could be made to enhance fabricability, maintainability, and performance. These changes, as well as others, were included in the Prototype 2 test article.

H. SCRS Prototype-2 Test

The major objectives of the second system test, SCRS Prototype, are to verify the ability of the SCRS design to meet its functional design requirements under expected operating conditions, to identify operating margins, to evaluate design improvements incorporated as a result of the P-1 experience. Testing will be performed to verify satisfactory operating under prototypic conditions, and to determine sensitivity to variations in such operating parameters as sodium flow and temperature, control rod elavation, misalignment and scram cylinder pressure. Repetitive scram cycles will be conducted at various combinations of these parameters. Hold testing will maintain the SCRS in the ready-to-scram position at combinations of sodium flow rate and temperature of 10%/400°F and 110%/1050°F. A series of scrams will be performed before and after each hold period. Throughout the test, the pneumatic scram valve will be periodically subjected to poppet movement tests.

Data from the P-2 test will be analyzed for inferences pertinent to overall scram reliability, reliability of safety-related P-2 design changes, safety-related design margins and operating margins. Data from this test will also contribute to evaluation of critical components such as the pneumatic valve/cylinder, the latch and the bellows.

I. SCRS Prototype-3 Test

The objectives of the Prototype 3 (P-3) test are to verify the ability of the design to meet functional design requirements under design operating conditions, to identify operating margins by testing in excess of normal design operations, to expose potential failure modes which may not have been previously predicted, to evaluate the cyclic failure mechanisms in a prototypic environment and to demonstrate the ability to perform required maintenance operations.

During the course of this test, repetitive scram cycles will be conducted at a variety of sodium flow rates, sodium temperatures, and misalignments. The effect on scram performance due to these variations as well as changes in control rod elevation and pneumatic cylinder pressure will be determined. Hold testing will maintain the SCRS in the ready-to-scram position for combinations of sodium flow rate and temperature of 10%/400°F and 110%/1050°F. A series of scram cycles will be performed before and after each hold period.

Throughout the course of the test, the pneumatic scram valve will periodically undergo poppet movement tests.

The test data will be analyzed to provide inferences regarding scram capability, operating margins, and design margins. Test data will also contribute to an assessment of the pneumatic valve/cylinder, the latch, the bellows, and other safety-related components.

J. SCRS Prototype-4 Test

The objectives of the Prototype-4 (P4) test are similar to those given for P-3; This test, however, is the final system test prior to operation of the plant units and it is intended as the final checkout for the system and to demonstrate the ability to perform required maintenance operations.

The P-4 test article will be scram cycled so that all components undergo a number of scrams greater than their design service life. Testing will be performed to determine the system performance sensitivity to variations in operating parameters. The unit will also be held in the parked position for 11 months at prototypic full power conditions to expose passive-state failure modes and mechanisms.

Data from this test will be analyzed for inferences concerning system scram capability, standby reliability, design margins, and operating margins. This test data will also contribute to a reliability evaluation of the pneumatic valve/cylinder, the latch, the bellows, and any other safety related components.

C.5.3 Electrical Subsystem Evaluation

C.5.3.1 Analysis

To supplement a system level FMEA, qualitative and quantitative reliability analyses are performed on each module in the Electrical Subsystem. The qualitative analysis consists of an FMEA at the piece part level which considers identifiable failure modes of the piece parts. This analysis lists assumptions made during the analysis such as piece part failure state and the effect of the assumed failure. The FMEAs will be updated as needed to document the current status of the design.

The qualitative analysis also considers the effects of the assumed failure on other piece/parts in the circuit and whether the assumed failure has the potential to cause additional part failures or overstress conditions in the circuit and whether these failures would be safe or unsafe. The quantitative analysis, using part stress analysis techniques, is performed on a module basis. A reliability prediction of each module is being made using MIL-HDBK-217B or other data sources as appropriate. The information from the FMEA is then used in conjunction with quantitative analysis to predict the unsafe failure rate of each module.

Numerical Assessment

A current numerical assessment documented in Reference 2 includes a quantitative evaluation of the primary and secondary electrical subsystems in relation to their ability to function.

A model was developed to evaluate the reliability of the primary and secondary subsystems as they functioned under a specified set of plant operating conditions and procedures. Input data to the model consisted of component failure rates, test intervals and other parameters characteristic of ES operation. Failure rate data used was based on either detailed predictions using MIL-HDBK-217B or other reliability studies conducted for the FFTF program which are appropriate for CRBRP equipment. Other model input parameters were based on planned operating procedures.

Numerical assessments have been conducted at both the module and system level. Results from this analysis indicate that the ES is not a significant contributor to the safety-related unreliability of the plant. Data obtained from the ES test program will provide further support for the failure rates used in this assessment.

C.5.3.2 Testing

The test program for the ES equipment is made up of two basic types of tests: qualification tests and extended operations tests. Qualification tests will be performed by the vendor primarily at his facility. Qualification tests provide evidence that the as-built equipment meets the requirements of the procurement specification. Extended operations tests will be performed. These tests provide a means by which extensive operating experience can be accumulated, resulting in both reliability growth and reliability demonstration. Reliability growth results from identifying and correcting any design, fabrication or maintenance weaknesses before the equipment is installed in CRBRP.

A. Qualification Tests

The qualification tests can be classified as preproduction, production or acceptance tests. These tests are described below:

1) Preproduction Tests

Prototype modules undergo a series of tests to verify that the design meets all the requirements of the procurement specification.

The preproduction tests are implemented by first testing each prototype module so that a set of baseline data can be developed. Later test data are compared with these baseline data so that any degradation can be detected.

Each prototype is then subjected to thermal conditioning to detect any failures due to design, fabrication or workmanship problems. During this thermal conditioning, each prototype module will be subjected to 10 thermal cycles in which the temperature is varied from -30^{O}F to 150^{O}F at rates between 9^{O}F/minute and 30^{O}F/minute. The temperature is held at the high and low extremes for a minimum of 30 minutes with power applied to the modules for intervals over this range. The modules are then baked at 150^{O}F for 200 hours. These test conditions are substantially more severe than the specific design conditions for the modules.

After thermal conditioning, each prototype module will undergo functional and performance checks while subjected to worst case environments including temperature, humidity, power supply voltage and frequency, electrical noise and vibration.

These tests were completed in early 1977. Design and component changes required as a result of the prototype preproduction tests were factored into the manufacture of the production units.

2) Production Tests

After the project was satisfied that the design and manufacture of the prototype modules met all functional, performance, quality and reliability requirements, the production modules were manufactured. The production modules include plant equipment, spare equipment and equipment to be used in the extended operations test.

Each production module underwent a thermal screen consisting of a 36 hour period of power off, temperature cycles between the limits of -4^{O}F and 185^{O}F. Each module was then subjected to full functional and performance testing to verify that each module meets its requirements.

These tests were completed in mid 1977 in the case of the reliability units and in mid 1978 in the case of the plant units.

3) Acceptance Tests

The plant equipment undergoes acceptance tests in addition to the production tests. In acceptance testing, the modules are installed in their respective panels and the complete system wired together. A full set tests which verify wiring insulation strength. The equipment will be operated in this configuration for a minimum of 125 hours.

These tests were completed by the vendor in early 1980.

B. Extended Operations Tests

Extended operations tests will be performed. For these tests, the modules are connected to form a complete electrical system. Additional modules are also interconnected to simulate subsystems of the electrical system, such as additional logic trains. Configuring the modules in this manner allows data on long-term effects of operations on performance parameters to be collected. These data can be used to determine calibration and test periods and will be factored into the plant operating procedures. These long term performance measurements provide additional supporting data to confirm that the performance characteristics and propagation delays assumed in the analysis are conservative.

Maintainability information is being generated on these prototypic system configurations and can be used to confirm maintenance design plans and also as a basis for preparing maintenance procedures. Maintenance and calibration procedures from the vendor supplied manual will be followed, where appropriate, to provide assurance of their validity. Also, trouble shooting procedures from the manual will be followed when failures are detected. Problems detected from use of these procedures will be factored into the preparation of the plant operations manual.

Functional and performance tests, as listed in Table C.5-3, will be performed on the primary and secondary subsystem components. The purpose is to determine whether they complete their intended function when called upon to do so and to check if the function is completed within specified time limits. The functional tests consist of providing voltage pulses or switch closures, as appropriate, at the inputs of the test components and checking the response from the appropriate outputs. The performance test includes measurement of propagation delay. This is done by inserting voltage pulses at the inputs and checking the response of the test systems.

As a minimum, functional pulse testing will be completed on each test component once a shift. The functional tests which require input from an operator (e.g., manual trip, bypass instatement) will be performed once a week. The flux signal transmitters will be checked for signal propagation.

The propagation delay tests are performed once a shift in conjunction with the component functional tests. The propagation delay of the breaker is tested and recorded weekly. Performance tests are completed once a week on all components except the flux drawers which are checked daily. The frequency of the functional tests will be increased if the environmental parameters drift beyond specified limits.

Test Failure Reporting, Analysis and Corrective Action

A closed loop failure reporting and corrective action system has been implemented to assure that any hardware reliability problems encountered are corrected and to force reliability growth. Failures and discrepancies occurring are documented in failure/discrepancy reports. Reliability Engineering is the focal point for the failure reporting and corrective action system. The failures reported will be screened and failure analysis performed, as appropriate, to identify underlying failure mechanisms. Each identified failure mechanism will be evaluated to assess the need for corrective action and the type of correction action required.

C.5.4 Interfacing Components Evaluation

C.5.4.1 Analysis

A Reliability Design Support Document will include assessment of the failure effects of all of the RSS interfacing components and systems that appear on the Reliability Related Components List. The interfacing component assessments include FMEA's and resolution of the failure modes through design margins and system features limiting the consequences. Shutdown system performance evaluations will determine the consequences of potential interfacing component failures. Since the interfacing component failures are potential causative factors for common cause failures of the shutdown systems, interface component assessments will be given high priority. The initial reliability reports will be completed, reviewed and updated (as applicable) prior to the components' design reviews.

Through the FMEA's for interfacing components, failure modes have been identified which have the potential to degrade the combined PCRS and SCRS insertion function. Examples of these include:

1) Large and/or intermediate plug rotation with rods withdrawn

2) Secondary control assembly flow starvation

3) Upper internals structure sheds fragments from thermal striping effects

Each of these failure modes has been assessed and has associated corrective or preventive actions to preclude adverse impact on combined PCRS-SCRS reliability. The following presents examples of the results of the assessments.

Postulated rotation of either the large or intermediate rotating plugs results in misalignment of both PCRS and SCRS. Several degrees of rotation may be sufficient to influence PCRS insertion. The SCRS, being less susceptible to misalignment, requires a larger amount of plug rotation to prevent insertion. Action relevant to this failure mode consists of the incorporation of a series of mechanical locks installed prior to reactor operation and designed to resist all forces that could conceivably cause rotation including motor torque.

Hydraulic assist is used in the SCRS to accelerate the control rod downward during a scram. While the control rod will insert without the hydraulic assist, its insertion time is extended. To assure that the SCRS always operates at maximum efficiency, it is necessary to assume that the design sodium flow is available at the SCA nozzle during power operation. The required flow is assured by means of features incorporated in the design of the core support structure. Flow blockage prevention is achieved by a combination of debris barriers and auxiliary flow ports. A description of the flow blockage prevention features is provided in Section 4.2 of the PSAR.

Fragmentation of the metal surfaces of the upper internals structure could be caused by thermal striping. Metal fragments could become lodged in any control assembly duct and adversely affect the rod's ability to insert. Actions relative to this failure mode included a design change from stainless steel to Inconel 718 for upper internals structure component parts. Items such as instrument posts, chimneys and shroud tubes exposed to thermal striping conditions are being made of Inconel 718. Analyses of the upper internals have shown that margins against this failure mode are now adequate.

Each interfacing component will be analyzed in a reliability assessment as described in Section C.1.3.2. Failure modes described above would be addressed in reports associated with the reactor closure head, core support structure and upper internals structure, respectively.

TABLE C.5-1 PCRS FAILURE MODES AND RESOLUTION SUMMARY

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
PCRDM	Excessive retarding forces prevent or slow unlatching	a) Excessive friction or wear	Increased design margin	Life	Unlatching Model	Increased segment arm spring force margin
		b) Failed bellows	Purge gas	Failed Bellows		Purge gas minimizes sodium vapor in PCRDM
			Increased bellows convolutions			Bellows stress and failures reduced by increased convolutions
		c) Misalignment	Rotating plug locks		Unlatching Model	Rotating plug locks prevent accidental plug rotation
		d) Installation and Maintenance Errors		Maintenance Procedures		Maintenance tools and procedures tested in system level tests
		e) Magnetized Components		Real Time Life	Post Test Inspection	Magnetization can be checked by its effect on unlatch time
	Part failures prevent unlatching	a) Wear		Life		Testing exceeds required wear life for each CRDM
		b) Seismic	Seismic support	PCRS Seismic	Margin Analysis	Shield and Seismic Support Structure limits lateral deflection
		c) Manufacturing Errors		Prototype Unit Testing	Manufacturing	Testing of units from prototype and plant unit manufacturing sequences to identify potential manufacturing errors
PCRD	Excessive retarding forces prevent or slow insertion	a) Excessive friction or wear	Large clearances	Life	Insertion Models	Life tests exceed required wear life
		b) Seismic		Dynamic Friction	Margin Analyses	Shaker tests to obtain friction data and to calibrate seismic insertion analyses
				PCRS Seismic		
		c) Misalignment	UIS key lateral restraints	Prototype Testing	Insertion Models	Misalignment test

TABLE C.5-1 (Cont'd)

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
PCRD	Jamming of dash-pot cup or piston	a) Foreign particles	Startup filters	Life		Special core assemblies have filters for initial sodium cleanup
			Inlet module features			Inlet modules provide debris barriers and strainers
		b) Galling		Life	Test Evaluations	
		c) Flow induced vibration deformation	Shrouded PCRD	PCRS Flow Vibration	Test Evaluations	PCRS sodium loop tests provides an extended test period to evaluate vibration effects. Vibration measured in PCRS Flow vibration test phase
				IRFM		Integral Reactor Flow Model provides vibration data
PCA	Duct deformation retards or prevents insertion	a) Irradiation induced bowing	Increased clearances	Duct Bowing	Bowing Margins	Duct Bowing test to establish drag forces and failure point for varying duct bows
		b) Scram impact on irradiated duct		Duct Impact	Impact Evaluation	Completed duct impact test shows no failure even at impact loads in excess of design values
		c) Pressure pulse from pin failure distorting inner duct	Design for no failures	Pin Rupture	Test Evaluation	Pin rupture test to establish inner duct deformation for postulated pin failures
		d) Seismic loads on outer duct load pads	Heavy duct wall at pads	Duct Crushing	Crushing Margins	Test provides data support for analyses of all core assemblies
		e) Swelling and bowing of pins deforms inner duct	Pin to duct clearances	Pin Compaction	Design and Test Analyses	Test to correlate analyses for pin interactions and bundle compressibility
		f) Weld failure due to improper weld		Life, FFTF Irradiation	Post-test Inspection	Quality control during welding to prevent poor welds

TABLE C.5-1 (Cont'd)

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
PCA	Excessive retarding forces prevent or retard insertion	a) Galling or wear of outer duct	Incorporated rotational joint	Rotational Joint and Life	Post-test Evaluation	Added rotational joint with supporting test to minimize wear pad to outer duct loads
		b) Seismic		Dynamic Friction PCRS Seismic	Margin Analyses	Shaker test to obtain friction data and to calibrate seismic insertions analysis
		c) Foreign particles	Startup filters and inlet module features	Life		Life tests will simulate effects of design basis sodium impurities such as oxygen content
		d) Misalignment	Passive core restraint	Prototype Testing	Insertion Models	Passive core restraint eliminates potential for inadvertent errors in core restraint adjustments

TABLE C.5-2 SCRS FAILURE MODES AND RESOLUTION SUMMARY

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
SCRDM	Malfunction of scram valves or pneumatic actuator slows unlatching.	a) Foreign material	Cylinder piston bellows seal	Valve/cylinder	Post test inspection	Valve/cylinder will be tested beyond design life.
			Redundancy: 3 out of 5 poppets to Scram	SCRS Prototype		Valve design includes testable feature for in plant online checkout.
		b) Part failures	Redundancy: 3 out of 5 poppets required to Scram	Valve/cylinder, SCRS Prototype,	Post test inspection	Testing of component beyond design life will identify potential failure modes.
		c) Manufacturing errors		Valve/cylinder	Post Test inspection	Testing of components and system will identify potential manufacturing errors.
				SCRS Prototype		
SCRDM/SCRD	Excessive retarding forces slow unlatching.	a) Thermal effects	Large clearances to accommodate thermal effects	SCRS Prototype	SCRS structural analysis	Testing of units at prototypic temperatures to support analysis
		b) Argon contamination	Filter	Valve/Cylinder	Post test inspection	
			Buffer gas	Failed-Bellows		
		c) Excessive friction from wear, galling	Hardened wear surfaces	SCRS Prototype	Post test inspection	Testing of SCRS units will identify potential wear and galling.
			High actuation forces			Actuation forces are high and will tend to overcome friction forces

TABLE C.5-2 (Cont'd)

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
SCRDM/SCRD			Redundancy			Tension rod moves relative to sensing tube which moves relative to driveshaft.
		d) Failed bellows	Limit stops and guides	Failed bellows, SCRS Prototype	Post test inspection Structural and fatigue analysis	Components bellows test will identify cycle life
		e) Manufacturing errors		SCRS Prototype	Post test inspection	Testing of SCRS units will identify potential manufacturing errors.
		f) Misalignment	Rotating plug locks		Misalignment analysis	Rotating plug locks preventing accidental plug rotation Misalignment test will identify safety margin and complement analysis.
SCRD	Excessive retarding forces slow tension rod drop	a) Excessive friction from wear, galling	High actuation forces	Latch Scram, SCRS Prototype	SCRS structural analysis Post Test Inspection	Component and system tests will determine amount of and effect of wear
		b) Deformation of driveline (thermal, vibration)	High strength materials and heavy sections		SCRS structural analysis	
		c) Seismic	Seismic support		Seismic analysis	
		d) Misalignment	Rotational and axial guides		SCRS structural analysis	

TABLE C.5-2 (Cont'd)

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
SCRD			Guide tube and rod flexibility	Latch, SCRS Prototype	Post test inspection	
			UIS lateral key restraints			
		e) Manufacturing errors		Manufacturing	Post test inspection	Testing of components and SCRS units will identify potential manufacturing errors.
	Excessive friction slows latch release.	a) Self-welding	1718 material cam surfaces			
			Slight pivot of gripper pads break potential welds	Latch	Latch design and test report	Results of component testing show no indication of self-welding.
				SCRS Prototype		Latch and SCRS units will identify effect of self-welding if it occurs.
		b) Misalignment	Heavy cross-section driveline at latch area		SCRS structural analysis	
		c) Particulate deposition	Plant sodium cleaning system	Latch and SCRS Prototype	Post test inspection	Latch and SCRS units testing in prototypic liquid sodium will identify effect of potential particulate deposition
SCA	Duct or guide tube deformation slows insertion.	a) Irradiation induced bowing	Clearance between guide tube and control rod	Guide Tube Bowing	Design Analyses	Testing will support analysis
		b) Seismic	Heavy duct section at load pads	Guide Tube Bowing	SCRS seismic analysis	

TABLE C.5-2 (Cont'd)

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
SCA		c) Swelling and bowing of pins	Low flux at lower pin area when in parked position Stiff bundle tube		Design analyses	
	Excessive retarding forces slow insertion	a) Excessive friction from wear, galling	Hardened wear pads Hydraulic assist force Clearance	SCRS Prototype	Post test inspection Design analysis	Test will determine wear effects and operating margins
		b) Particulate deposition	Plant sodium cleaning system	SCRS Prototype	Post test inspection	Testing in prototypic sodium will identify effects of potential particulate deposition
		c) Seismic	Hydraulic assist force, adequate clearance		SCRS Seismic analysis	
		d) Irradiation swelling of control rod	Parked position raised		Scram clearance analysis	
		e) Manufacturing errors		SCRS Prototype	Manufacturing Pre and post test inspection	Testing of units will identify potential manufacturing errors.
	Loss of hydraulic assist slows insertion	a) Flow blockage or maldistribution	Geometry or flow path opening minimizes blockages Gravity drop capability		Exit flow blockage analysis	Component and SCRS flow tests will support analysis.

TABLE C.5-2 (Cont'd)

Component	Scram Failure Mechanism	General Causative Factor	Design Feature	Test Verification	Analytical Verification	Comments
SCA		b) Weld failure	Stress relievers Material selection		Design analysis	Quality control during welding to prevent poor welds.
		c) Manufacturing errors		SCRS Prototype	Manufacturing	Testing of SCRS units will identify potential manufacturing errors.

TABLE C.5-3

ELECTRICAL SUBSYSTEM MODULE FUNCTIONAL & PERFORMANCE TESTS

Component	Functional Tests	Performance Tests
Trip Comparator	o Trip/Reset Sequence o On-Line Test Sequence* o Bypass Sequence o Manual Trip Function o Setpoint Adjustment	o Trip/Reset Accuracy o Propagation Delay*
Bypass Comparator	o Bypass Permissive Sequence	o Bypass Instatement/ o Removal Accuracy
Buffer	o Signal Transmission	o Accuracy o Isolation
Calculation Units	o Signal Transmission o Potentiometer Adjustability	o Accuracy o Propagation Delay
Logic	o Logic Function	o Propagation Delay
Breaker	o Trip/Reset Function*	o Propagation Delay*
Flux Drawers	o Signal Transmission	o Accuracy o Propagation Delay

*These tests are for the primary subsystem only. All other tests are for both primary and secondary subsystems.

TABLE C.5-4

MECHANICAL SUBSYSTEM DESIGN DIVERISTY

	PCRS	SCRS
Control Assembly (CA)		
Absorber Pin	37	31
Control Rod Geometry[1]	Hexagonal	Circular
51 Number of CA[2]	9	6
Special Feature[3]	Rotational joint in control rod shaft	Latch location at top of CA
Control Rod Driveline (CRD)		
Coupling to control rod	Rigid coupling - released only during refueling	Flexible collet - rod is released at this point for scram and refueling by internal CRDM action
Connection to CRDM	CRD leadscrew to CRDM collapsible rotor roller nuts	Permanent connection to CRDM carriage which traverses only during start up and shutdown
Disconnect from control rod for refueling[4]	Manually - requires special tool	Automatic - same as scram with CRDM deactivation of collet.
Special Features[5]		Heavy CRD wall in the Upper Internal Structure and CA parting plane.

[1] As a result of the difference in control rod geometry, absorber loading and enrichment requirements and effects of transients, the control rod and absorber pin designs in the two systems are completely different.

[2] The larger number of PCA's generally provide for greater redundancy in shutdown capabilities.

[3] The PCA rotational joint eliminates CRD and control rod rotational binding.

[4] The SCRD automatic disconnect feature greatly reduces the per mechanism time for preparation for refueling

[5] The SCRD heavy wall increases the margin against scram latch tension rod drag due to gross Upper Internal Structure to SCA misalignment.

TABLE C.5-4 (Cont'd)

	PCRS	SCRS
Control Rod Drive Mechanism (CRDM)		
Type of Mechanism	Collapsible rotor roller nut	Twin ball screw with translating carriage
Driving Power[6]	High voltage, multi phase: used continuously during reactor operation	Low voltage, direct current: used only during startup and shutdown
Axial Position Sustained by:	Application of non-rotating electric field	Self-locking device in ball screw drive system
Axial Position Indication	Reed switches - full stroke (absolute) Rotor motion detection - full stroke (relative)	Reed switches - 3 positions of stroke (absolute) Rotary encoder - full stroke (absolute)
Stroke Length[7]	37"	67"
Scram Function		
Scram Release	Magnetic decay with spring assisted release of CRDM roller nuts from leadscrew.	Release of collet in CA by removal of electric power to the scram solenoid valves which vents argon pressure from the collet latch actuating cylinder in the SCRDM.
Location of 2/3 ES Logic[8]	Circuit Breakers in the Primary Rod Control Room	Solenoid valves in SCRDM
Translating Parts during Scram	Leadscrew, CRD, control rod	Control rod

[6] The type of SCRDM allows for reduced power consumption and elimination of forced cooling

[7] The additional SCRDM stroke is required to provide the automatic control rod disconnect feature for refueling

[8] The SCRDM scram solenoid valves are powered directly from the ES logic output which eliminates the need for circuit breakers which are used in the PCRDM.

TABLE C.5-4 (Cont'd)

	PCRS	SCRS
Scram Motion through Upper Internals[9]	CRD travels the full stroke	Flexible collet latch tension rod travels fraction of an inch protected inside the drive shaft
Scram Assist[10]	Spring in CRDM	Hydraulic in CA
Scram Assist Length	Initial 27 inches of insertion	Full stroke
Scram Speed versus Flow Rate	Increases with decreasing flow rate	Increases with increasing flow rate
Scram Deceleration	Hydraulic dashpot on CRD	Hydraulic damper in CA

[9] Since in the SCRS only the control rod falls the full stroke into the core and the tension rod is very flexible, the SCRS is less susceptible to failure by system misalignment.

[10] A result of the implementation of scram assist in the two systems is that they complement each other with respect to effects of flow rate on insertion speed.

TABLE C.5-5

ELECTRICAL SUBSYSTEM DESIGN DIVERSITY

	PRIMARY ES	SECONDARY ES
Instrumentation[1]		
Nuclear Flux	Compensated Ion Chambers	Fission Chambers
Sodium Coolant Flow	Primary Sodium Pump Speed	Primary Sodium Mass Flow Rate
	Intermediate Sodium Pump Speed	Intermediate Sodium Mass Flow Rate
Core Coolant Flow	Core Inlet Plenum Pressure (2 in each plenum inlet pipe)	Core Coolant Flow[2]
Auxiliary Electrical System	Primary Pump Bus Voltage	Loss of Offsite Power[3]
HTS Heat Removal Capability	Primary IHX Outlet Temperature	Evaporator Outlet Sodium Temperature
Steam & Feed Systems	Steam Mass Flow Rate	Steam Drum Level
	Feedwater Mass Flow Rate	

NOTES:

1. This listing is not complete, PSAR Table 7.2-2, PPS Design Basis Fault Events more fully shows the diversity provided in primary and secondary instrumentation.
2. Calculated as the sum of the Sodium Mass Flow Rates in each of the 3 loops.
3. Scrams Secondary Rods on loss of electric power to 2 or more HTS Buses.

TABLE C.5-5 (Cont'd)

	PRIMARY ES	SECONDARY ES
Protection System Equipment		
Calculational Units	Implemented using Integrated Circuits	Implemented using Integrated Circuits different from those used in Primary Calculational Units
Comparators	Implemented using Integrated Circuits	Implemented using discrete components
Logic Coupling	Infrared Light Emitting Diode Coupled	Direct D.C. Coupled
Logic	Local Coincidence Configuration	General Coincidence Configuration
Final Logic Actuation	Scram Breakers	Solenoid operated argon gas valves
Location of Cable Interconnection	Upper Cable Spreading Room	Lower Cable Spreading Room

C.6.0 Shutdown Heat Removal System Evaluation

The reliability activity associated with the Shutdown Heat Removal System (SHRS) is the identification of critical failure modes which includes common cause failure modes. Additionally, through feedback of reliability information and data to engineering, design changes to improve reliability can be made. Reliability analysis provides an assessment of the adequacy of the SHRS design to perform its intended functions of decay and sensible heat removal, according to established requirements. Confirmation of design adequacy will be achieved by means of development, acceptance and qualification testing, of selected key items.

To assure timely feedback of data from the test program, the schedule for test activities has been coupled to that for the plant component design, fabrication, installation and operation activities. The testing schedule is such that positive response is possible for the elimination from the plant equipment of any unacceptable features uncovered in the test program. The design and procedural utilization of data from each of the tests is identified at the conclusion of each of the test activity description sections.

C.6.1 Primary Heat Transport System (PHTS)

C.6.1.1 Analysis

Reliability evaluations are being performed on selected SHRS failure modes and components. Two significant evaluations are presented in References 3 and 4.

Reference 3 investigates the probability of loss of the total shutdown heat removal system capability. The failure criterion was assumed to be the bulk in-vessel sodium temperature exceeding 1250°F. This sodium temperature is too low to be associated with in-core sodium boiling and is associated primarily with the ability of reactor and piping structures to retain a pressure boundary and to support the core. Further mitigation is provided by the Direct Heat Removal Service (DHRS) that limits the temperature to 1140°F. Estimates of leakage and rupture of the PHTS and reactor vessel are very low, as documented in Reference 4.

Reference 4 provides an overall assessment of primary piping integrity and focuses on the design, quality assurance, stress analysis and service conditions of the primary piping in terms of the role that each plays in ensuring adequate defense against loss of piping integrity. Supplementing this approach, single point failure reliability analyses were made for the worst locations and loading conditions leading to pipe rupture. Under the assumed presence of a sizeable flaw, calculations of the growth show the critical crack size would not be reached for conservative imposition of loadings. Reference 3 and 4 together provide a total reliability assessment of both system and component features of the SHRS. Both of these documents are updated as the CRBRP Project progresses.

C.6.1.2 Testing

The currently identified testing relating to the PHTS can be divided into two major categories: (a) component performance and acceptance testing and (b) material development tests. Testing in each area has been initiated during the FFTF design phase and is continuing in support of CRBRP. A review of each of these areas is provided below.

Component Testing

Component performance and acceptance PHTS tests on the reactor vessel, primary piping, cold leg check valve, leak detectors, the IHX and the primary pumps are all contributing information in support of SHRS reliability.

A. Reactor Vessel

Component testing supporting the reactor vessel design centers on the outlet nozzles, the sodium makeup nozzle and the upper internals structure (UIS). Component tests of vessel nozzles are in progress as part of the "Validation of High Temperature Design Methods and Criteria" test program. The objectives center on design verification of creep ratchetting due to thermal transients. Strain histories will be recorded at critical nozzle locations. This work will be performed at the Creep Ratchetting Test Facility (CRTF) at ARD. Testing of nozzle attachments is being performed at ORNL in the "High Temperature Structural Design" test program. The emphasis of these tests centers on the inelastic behavior of nozzle attachments.

Numerical studies have been performed to assess the adequacy of the design for the FFTF reactor outlet nozzle. However, the design detail of the CRBRP nozzle liner will be different from FFTF and additional analysis and/or testing will be required to support the CRBRP reliability assessment. Supporting analytic studies are necessary to evaluate the effect of the thermal fluctuation. Material properties needed in this evaluation will be made available in a timely manner from planned test programs.

Prototypic 1/21 scale tests to confirm the thermal adequacy of the location of the DHRS overflow and makeup nozzles has been performed at ARD. These tests have demonstrated that thermal "short circuiting" is about 5 or 6 percent which is considerably less than the 20 percent value to which DHRS is designed. Therefore, the DHRS is conservatively designed.

The 1/21 scale model will also be used in a series of tests to establish the behavior of the outlet plenum flow field in the region of the makeup flow injection. This test is designed to assess the potential of thermal striping initiated failure.

Flow induced vibration has been considered as a potential initiator of failure in the upper internal structure. Outlet plenum flow simulation testing has been performed at HEDL which involves a 1/4 scale mock-up of the upper internals of CRBRP, termed the Integral Reactor Flow Model (IRFM). The primary function of these tests is to investigate velocity patterns, pressure drops, mixing characteristics, striping phenomena, gas entrainment and flow induced vibration in the upper internal structures. In addition, vibration tests of the instrument post, chimney and control rod shroud tube have been conducted in a 1/3 scale water model at ANL.

Experiments have been performed using 0.55 scale (Reference 5), 1/10 scale and 1/15 scale (Reference 6) models at Battelle-Columbus Laboratory and ANL in which the transient behavior of the outlet plenum following a reactor trip was simulated. These tests demonstrated that the thermal transient at the outlet nozzle is less severe if the upper internals structure has chimneys compared to one without. The addition of chimneys reduces the transient ramp rates and enhances reliability. Additionally, the 1/10 scale ANL testing has provided thermal data during simulated normal operation of the steady state temperature distributions and amplitudes and frequencies of thermal striping.

B. Primary System Piping

Flow induced vibration has been considered as a potential initiator of failure in the primary piping. A study has shown that for the velocities in the CRBRP design there is no appreciable change of natural frequency in the first natural frequency of the straight sections of primary pipe due to the effect of sodium flow. This resulted in the recommendation that the sodium flow need not be considered in the piping design.

Tests have been performed on the horizontal and vertical pipe clamps to qualify them for use with commercially available hangers and snubbers. The tests identified clamping preload requirements, temperature distribution in the clamps and Belleville spring washer compression.
47 Static and dynamic load testing were also performed. Test results will provide data to verify the design for thermal loads as well as static loads and vibrations. Procedures for piping support installation will be based on the information from these tests.

C. Check Valve

The dashpot in the cold leg check valve was subjected to several
47 performance acceptance tests. An assembly test was first performed to define the dashpot configuration in each of the other tests. Strength tests were performed to verify the integrity of the sodium pressure boundary. Thermal cycle tests assured proper dashpot movement at design temperature. Fill tests were performed to demonstrate that the dashpot will fill completely. Impact and damping tests confirmed that the dashpot met the necessary structural design requirements and provides the required
47 damping.

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D. PHTS Leak Detector System

Failure modes of the leak detection equipment can be classified as being either a failure caused by hardware-oriented malfunction or a failure stemming from lack of sufficient sodium aerosol by-products entering the detector. This second type of failure is dependent on time, temperature, moisture content and oxygen concentration in the environment for aerosol production, as well as on the convective currents between the leak and the detector. PHTS leak detectors have been examined in a series of tests to determine general trends in the performance of detectors caused by variations in environmental conditions of temperature, sodium content, humidity and oxygen concentrations. These tests have shown that leak detection equipment can be designed to detect the magnitude of the leaks specified for CRBRP. Additional verification testing is planned.

E. Intermediate Heat Exchanger

Nozzle tests have been performed on a prototype FFTF IHX inlet nozzle and centered on design verification of creep ratchetting due to normal
47 transients. These tests were conducted as part of the "Validation of High Temperature Design Methods and Criteria" test program being performed at the Creep Ratchetting Test Facility (CRTF) at ARD. Testing of nozzle attachments is also being performed at ORNL in the "High Temperature Structural Design" test program. The emphasis of these tests centers on the inelastic behavior of nozzle attachments.

The IHX has been subject to three flow tests in addition to
47 testing of the bellows and tube to tube sheet welds. An IHX 360°. model primary inlet flow test, an IHX model flow induced vibration and flow distribution test and an IHX intermediate flow distribution test have been performed. The results of the 360° model primary inlet flow test aided in determining the design and provided verification of predicted flows for the primary flow distribution shroud. The IHX model flow induced vibration and flow distribution test verified that no flow induced vibration of the tubes and baffle plates exists in the IHX. It also provided quantification of the pressure drop across the baffle spans. The IHX intermediate flow distribution test aided in the design of the ring baffle and provided verification for the predicted flow distribution in the lower hemispherical head. In addition to the flow tests, the bellows were tested to insure that the fatigue life and structural integrity will be adequate for 30 year life. Also, tests of the tube to tube sheet welds were made to identify effects and fit obtained in the forming process.

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F. Sodium Pumps

The primary and intermediate sodium pumps have major development tests scheduled which will contribute to assuring the reliability of the plant units. A prototype pump sodium test will provide confirmation of design and manufacturing. If unsatisfactory performance is encountered, the data will provide inputs for corrective action to the plant pumps. The corrective actions will be confirmed by water testing the plant units and in-plant sodium testing prior to plant full power operation.

The prototype pump will be subjected to the temperature transients for which the plant units are being designed up to the capability of the test facility. Tests will include endurance runs, thermal transients, speed transients, hydraulic performance, control response and coastdown measurements. These prototype pump sodium tests, curently planned for the time frame late 1981 to mid 1983, may impact the design of the plant units. Design and/or fabrication changes which may be identified by the prototype sodium tests would be retrofitted in final stages of fabrication of plant units. If the water tests indicated problems in the plant units, it would require retrofitting to units in fabrication prior to site delivery.

G. Natural Circulation Verification

The important design feature of natural circulation will be verified through combined computer model development and test verification. Verification of CRBRP's natural circulation capability will be provided by validation of the FORE-2M, DEMO and COBRA-IV computer codes through component test data (pressure drops, pump coastdown tests, decay heat experiments, etc.) and extensive analysis of various aspects such as IHX performance at natural circulation conditions, piping stratification effects, etc. Test and analysis will provide information to verify that natural circulation through the core, primary loops, intermediate loops and steam generators is adequate to remove core heat to the ultimate heat sink. The natural circulation decay heat removal verification plan is presented in Reference 7.

Material Testing

Numerous development programs are also in progress which contribute in a more generic way to reliability assurance of the PHTS. The areas of testing related to reliability include the following:

- Weld joints
- Corrosion effects
- Erosion effects

- Thermal fatigue

- Creep rupture and fatigue

Descriptions of the test programs and the data relative to reliability are provided in the following discussions.

H. Weld Joints

In the area of weld reliability, tests are in progress at ORNL to both develop weld procedures for transition joint welding and study the effectiveness of nondestructive testing on transition welds. Weld reliability is being investigated at ORNL as part of the "CRBRP Transition Joint Welding Program." Cr-Mo steel to stainless steel, Cr-Mo steel to alloy 800H and alloy 800H to stainless steel welds are to be investigated in this study.

Testing of weldments to be used in the design of the reactor vessel thermal liner will be performed at ORNL and ANL. 16-8-2 weld material will be tested extensively to provide data on hardness, tensile properties, creep-rupture properties, creep-fatigue properties, fatigue and metallographic composition. These data will be used to validate the use of 16-8-2 weldments.

Three additional areas of welding will be closely examined for their effect on structural integrity.

1) Material behavior including material properties in the heat affected zone

2) Non-uniformities in geometry including "weld shrinkage"

3) Weld condition including porosity, lack of fusion, cracking and sensitization

I. Corrosion Effects

Corrosion of LMFBR material is the subject of three planned test programs. Inconel 718 is being investigated under the "Component Materials Compatibility Program." Also, SS304 and SS316 are being tested as part of the "Characteristics of Corrosion Due to Leakage of Sodium from a Pipe Into Air Test Program." Although the PHTS will exist in an inert environment, corrosion rates identified in air tests will provide conservative data for leaks in the inert environment. In addition, stress corrosion cracking in SS304 is to be examined under the "Caustic Corrosion Product Assisted Fatigue Growth Program." Loading frequency and temperature will be varied in sodium environments.

J. Erosion Effects

Erosion was identified as potentially being significant in many reactor vessel structural members. Data exists which suggests that there is no noticeable erosion effect in sodium flow for velocities below 50 ft/sec. It was determined that erosion could pose a potential threat to structural integrity at higher velocities. Consequently, the core flow of CRBRP is designed conservatively so that the maximum velocity at critical locations is less than 25 ft/sec., and the maximum core sodium velocity is 50 ft/sec.

K. Thermal Fatigue

Quantification of thermal fatigue limits is necessary for reliability assessments. Characterization of material properties is being investigated under the program entitled "High Temperature Tests for Time-Dependent Characteristics of Materials in Sodium" at ARD and ANL. The testing is oriented towards assessing the adequacy of the ASME Code criteria and RDT Standards for design of critical CRBRP components in sodium environments. Tubular and plate specimens are to be tested. Specifically, thermal fatigue will be studied. Additional testing in the "High Temperature Structural Design Program" at ORNL involves the investigation of thermal ratchetting in seamless SS316 pipe.

L. Creep Rupture and Fatigue

Currently at ARD, creep tests with basic specimens and large components are being conducted along with testing of pre-exposed specimens to assess the effect of long-term environmental effects. Conservative minimum creep failure times are also used in the ASME Code, Section III - Case 1592 for high temperature design applications. When the phenomenon of fatigue occurs in high temperature environments, a creep-fatigue interaction may reduce fatigue life. The magnitude of the life reduction depends on the hold times under load in the fatigue cycle. The effect of multiaxial stress states on creep-fatigue on SS304 and SS316 is being studied at ORNL in the "High Temperature Design Program." In addition, the effect of long term exposure on creep-fatigue and multiaxial stress states are under investigation at ARD under the "Component Materials Compatibility Program." These planned test programs are adequate to support conservative reliability analysis.

Fatigue has been extensively studied. Current testing at ARD is oriented towards determining long-term effects on fatigue life by testing samples of SS316 pre-exposed to sodium. At ORNL, the "High Temperature Design Program" will provide data from investigations of fatigue at high temperatures. Currently work is being done at ANL to study low cycle fatigue behavior of SS304 and SS316 at high temperatures. Specifically, the effects on fatigue of roughness, sodium environment, aging and annealing are under investigation.

The analysis of stress rupture depends on the adequate quantification of material properties. Two programs at ORNL involve testing to determine tensile stress rupture properties in uniaxial tests. In the "High Temperature Design Program" tests, the material behavior of SS304 and SS316 will be studied. Another program at ORNL "Mechanical Properties for Structural Materials" is specifically tailored to study the material characterization of SS304 and SS316 reference heats. The heat-to-heat variations in mechanical properties is also under study in this program. The programs in progress along with existing data will be adequate for reliability data needs.

The material data development programs described under items H through L will provide the information to further qualify the materials and weld processes for the reactor vessel, PHTS piping and IHTS piping. These programs are a part of continuing material technology programs that were initiated for the FFTF program. The data are expected to identify additional margin in the structural components which have been designed on the conservative rules established by the early data and in large part embodied in ASME Code Case 1592. The reactor vessel is in fabrication from early 1976 to early 1980. The PHTS and IHTS piping spool pieces are expected to be in fabrication not earlier than 1982. The data from the materials testing programs have been scheduled to support these schedules.

C.6.2 Intermediate Heat Transport System (IHTS)

C.6.2.1 Analysis

The purpose of the IHTS reliability evaluation is to identify those features of the IHTS which have the maximum impact on system reliability and thereby to permit design action to enhance the reliability of the IHTS piping, the intermediate sodium pump, the expansion tank and the drain valves.

The FMEA for the IHTS is presented in Reference 3. Those failures of the IHTS which result in failure to remove decay heat were analyzed. Results of the FMEA indicate that there are five failure modes which can prevent or adversely affect SHRS operation. These failure modes are: (1) external leakage of sodium piping, (2) significant tube leakage in the IHX, (3) external leakage of the intermediate sodium pump, (4) external leakage of I&C penetrations and (5) external leakage of sodium drain valves. Each of these has been evaluated and does not significantly affect the SHRS function of the IHTS.

The CCFA for the IHTS and its interfaces is in preparation. The significant failure modes which have been identified are: (1) inadvertent operator action or false signals to the actuators of the dump valves, (2) loading from a seismic event and (3) extreme pressure transients.

Postulated dumping of the sodium in all three IHTS loops due to operator error or false actuator action requires the assumption of multiple failures of equipment or multiple operational errors. At least two operations on separate equipment are required to dump a single loop. Postulating this simultaneously for all three loops is not credible. It should be noted that the DHRS will adequately remove the decay heat for postulated events involving the draining of one or more loops.

The IHTS has been conservatively designed to withstand the effects of a conservatively specified earthquake. Therefore, only seismic events substantially greater than the SSE could be postulated to potentially cause failure of all three IHTS loops. Therefore, the potential for common cause failure due to loadings from seismic events is sufficiently remote. Testing of specific components is planned to verify the capability to withstand the SSE imposed loadings (see Section C.6.3.2D).

An extreme IHTS pressure transient could cause failure of the SWRPRS rupture discs.

Numerical Assessment

The quantitative assessment of the probability of failure of the IHTS was determined by inserting predicted equipment failure rates and operational parameters into a mathematical model of the system. The predicted failure rates and corresponding evaluation are presented in Reference 3. The failure probability of the IHTS equipment is low because the mission to remove reactor heat following shutdown requires only the natural circulation capability of the PHTS or the IHTS.

C.6.2.2 Testing

The currently scheduled IHTS testing included main circulation pump testing (discussed in Section C.6.1.2), transition joint development testing and mixing-tee testing.

A. Transition Joint Weld Assembly Tests

The transition joint development is directed towards obtaining information which will provide high confidence in the transition weld region of the IHTS piping. This transition weld is placed in the piping to reduce the differences in thermal expansion between materials to be joined by welding. The 2 1/4 Cr-1Mo material of the steam generator nozzle is joined to alloy 800H which is then welded to the SS316 of the IHTS piping. There are two groups of tests planned for these joints. A group of joints will be exposed to temperature and mechanical load transients more severe than those for which the plant is being designed. The tests will be run to failure and the dominant mode of failure identified. The tests will be accelerated so that failure occurs in about one year rather than the design life. In addition to these complete transition weld assembly tests, there are tests being conducted to establish the proper weld design. This work will contribute to producing weld designs that are appropriate for the transition assembly tests. The transition joint weld design will be completed in late 1978. Fabrication of all spool pieces will be completed in late 1980.

As a final proof test of the transition weld design, prototypic transition joints will be fabricated and used in the prototype steam generator test program. These joints will be exposed to the accelerated testing planned for the steam generator modules and will provide the desirable final confirmation of the transition joint assembly design adequacy.

B. Mixing-Tee Tests

The mixing tee tests were conducted to assure adequate mixing of the two sodium stream flows from each evaporator prior to returning to the intermediate system pump. The temperature difference in the two flows is normally less than 20°F, but can be large if the heat transfer process in one evaporator is interrupted from one of several malfunctions. These tests were conducted to develop a tee which will accommodate these large temperature differences without incurring thermal fatigue failures, should a standard tee design prove to be inadequate.

The initial tests were being run using an 8 inch diameter scale model of the perforated plate mixing tee currently being considered for use in the CRBRP. These tests were conducted with hot water simulating sodium. Tests conducted in water have been demonstrated to be a valid indicator of the mixing characteristics of sodium. The information gathered consisted of temperature fluctuation (amplitude, spatial distribution and frequency), pressure drop across the tee and perforated plate vibration.

The mixing tee development testing is completed. This information, coupled with other sodium mixing tests which have been reported in the literature, will be used to establish the final design.

C.6.3 Steam Generator System (SGS)

C.6.3.1 Analysis

Analysis of the SGS will consist of (1) a determination of the relative probability of occurrence of critical failure modes, (2) further refinement and verification of failure rate data, (3) evaluation of the reliability impact of repairs and (4) analysis of SGS failures that incapacitate one or more heat transport loops.

The FMEA presented in Reference 3 indicates that a potential failure mode of the SGS is a water-to-sodium leakage at the tube to tubesheet weld joints. Other failure modes with the potential to adversely affect the function of the SHRS are: (1) external leakage of the steam generator modules, (2) leakage or inadvertent rupture of the rupture discs in the SWRPRS, (3) inadvertent water dump (operator error of false signal of rupture disc burst), (4) leakage or rupture of water dump valves, (5) leakage or rupture of the sodium drain valves, (6) operator action incapacitating SG loop due to a false signal from the hydrogen leak detection system, (7) leakage, rupture, or internal failure of the steam drum, (8) external leakage or rupture of the recirculation pump, (9) external leakage or rupture of the isolation valves, (10) leakage or rupture of the power relief valves, (11) failure to close the safety valves, (12) external leakage or rupture of the steam or water piping and (13) external leakage or rupture of the instrumentation penetrations. These failures could potentially result in loss of one of the three main HTS heat removal paths, but independence of the IHTS and steam/water loops precludes loss of the other two loops. These failure modes will be addressed in the design of the equipment and the operating procedures.

A CCFA identified that one of the most significant common cause failures could be simultaneous rupture of the rupture discs in SWRPRS under seismic load. A failure of this type could result in draining of the sodium inventory from all three main heat transport loops with subsequent inability to remove heat. Reliability and design verification analysis has been conducted which shows that adequate design margin exists between the peak seismic pressure and minimum disc burst pressure.

Other significant common cause failures which could adversely affect SHRS reliability are: (1) inadvertent water dump (false signals to all three loops), (2) inadvertent closure of isolation valves (false signals to all three loops and (3) water-to-sodium leakage in steam generator modules.

The following paragraphs address measures taken to eliminate these potential common cause failure modes.

A. Inadvertent Water Dump From False Signals to all Three Loops

The water dump valves are in series, and opening requires either (1) individual manual operator switching actions of guarded switches or (2) a signal indicating SGS reaction products vent flow. Each steam generator loop has a separate Class IE logic train for automatic operation making common failure of all three loops highly improbable. Many actions in the proper paired relationship must be taken by the operator to initiate this failure mode.

B. Inadvertent Closure of Isolation Valves From False Signals to All Three Loops

Isolation valves fail open for both loss of electrical power and pneumatics. Automatic closure signals result from indication of initiation of SWRPRS. The most probable cause of isolation valve closure, a false SWRPRS signal, affects only one steam generator loop. Simultaneous failure of all three loops initiating circuitry causing closure of isolation valves in all three loops is sufficiently remote.

C. Water-to-Sodium Leakage in Steam Generator Modules Due to Excessive Thermal Cycling

Thermal cycling and severe transients produce creep-fatigue damage accumulation in the sodium-to-water boundary. The steam generator design and analysis accounts for this effect. In the event that the rate of creep-fatigue damage accumulation is greater than predicted, through-the-wall cracks in the sodium/water boundary could be generated. The occurrence of a through-the-wall crack during plant operation will be detectable. The sensitivity of the detection equipment is such that, under most cases, the leak will be detected at a level where the sodium-water reaction will not result in significant pressure surges. In certain locations, a crack could reach the through-the-wall stage such that a pressure surge occurs before the leak is detected, or before shutdown could be completed. The overpressure protection system is designed to protect the sodium-to-air boundary and IHX boundary from excessive loading from the pressure surge.

In most cases, the leakage rate will be small enough that operation for heat removal would be continued unless larger leaks developed during the required normal module shutdown and isolation. Since the initial leakage rate through cracks formed by the thermal fatigue mechanism is very small, and the probability is extremely small that the through-the-wall stage will be reached simultaneously in 2 or more locations, the loops would not fail simultaneously. This interpretation of the nature of steam generator sodium/water boundary failure is consistent with the experience on LMFBR steam generator leaks in Europe.

The CRBRP SGS is designed to mitigate the hazards associated with a sodium-water reaction as described in Section 5.5 of the PSAR.

Numerical Assessments

Quantification of steam generator system reliability has been accomplished utilizing (1) block diagrams that delineate the redundant and sequential relationships of the SGS constituents, (2) a mathematical model and (3) appropriate equipment failure rate estimates. A calculation of the random independent failure probability of the SGS has been made (Reference 3). This quantitative assessment of steam generator system reliability was used to identify key areas of the SGS requiring further attention.

C.6.3.2 Testing

There is in place a substantial development test program addressing the steam generator modules, sodium-water leak detection and protection against effects of sodium-water reaction. This program is a significant source of information for assessing SGS reliability.

A. Steam Generator Module

There are substantial materials properties and weld development programs which support the development of a reliable heat transfer surface for the steam generator module. For descriptions of the test programs see section 5.5.3.1.5.1.

B. Steam Generator Leak Detection System

The steam generator leak detection system development program includes development of instrumentation to (1) detect hydrogen in sodium and (2) detect oxygen in sodium. Programs are in place to develop the detection elements. The detection levels and decision logic for use in the system will also be established through these tests. The tests include operation of the detection system on the "Few-Tube" Test, and at the Experimental Breeder Reactor II at Idaho Falls, Idaho.

C. Burst Disc Testing

The steam generator development program is providing the information for assessing the reliability of burst discs. Tests have been conducted by the manufacturer to confirm that the as-built burst disc design will funtion within specified burst pressure tolerances for the large size discs required in CRBRP. Additional tests are being conducted in conjunction with steam generator component tests. Multiple disc assemblies similar in design to the CRBRP, are being installed in the large leak test rig. Performance of the double reverse buckling disc will be measured during these tests. Results are expected to confirm the design.

C.6.4 Steam Generator Auxiliary Heat Removal System (SGAHRS)

C.6.4.1 Analysis

The SGAHRS provides an auxiliary heat sink for the postulated loss of feedwater or loss of main heat sink. The SGAHRS evaluation will assess the reliability of the Auxiliary Feedwater System (AFWS) and the Protected Air Cooled Condensers (PACCs). The reliability of the main feedwater system and the main heat sinks was evaluated to properly assess SGAHRS.

Potential failure modes identified in Reference 3 include (1) failure of the two AFW motor driven pumps to start and take load, (2) failure of the AFW turbine driven pump to start and take load, (3) failure of the PACCs to operate (includes associated piping and valve failures), (4) failure of the AFW isolation valves to cycle open, (5) external leakage or rupture of AFW piping and valves and (6) external leakage or rupture of the PWST. These failure modes are being addressed in the design of SGAHRS equipment and will be fully resolved in the associated Reliability Design Support Document.

Common cause failures have been evaluated regardless of their probability of occurrence. Parameters considered were common processes, common design properties, common location, common handling, human error test and maintenance acts, external events and extreme environments. Common cause failures identified to date include: (1) AFW control valves fail to remain open due to miscalibration of AFW flow transmitters or I&C on the steam drum, (2) insufficient water due to PWST level miscalibration, (3) AFW isolation valves fail closed due to operator action and (4) PACCs fail due to environmental abnormalities. A major factor contributing to the reliability of the AFWS is its similarity to systems incorporated in current LWRs. The technology used in the design of the AFWS for CRBRP is essentially identical with that used in LWR AFWS design.

The following paragraphs address these potential common cause failure modes.

A. AFW Control Valve Failure

Although miscalibration of AFW control instrumentation is possible, surveillance tests, periodic maintenance activities, design redundancy and heat sink diversity make the loss of heat removal capability due to this cause improbable. The period of time during which significant AFW make-up is required is on the order of 1 to 2 hours.

B. PWST Level Miscalibration

The failure mode of insufficient water due to PWST level miscalibration has been addressed. Water can be transferred from the condensate storage tank to the PWST by gravity. Steam drum level control instrumentation consists of a two level system. Motor driven pump flow is initiated by a low level signal and the turbine driven pump flow is initiated by a low-low level signal. Redundancy and diversity provided in the design of this system make the probability of failure remote.

C. AFW Isolation Valves Failure

Inadvertant operator action isolating the AFWS has been evaluated. The main and auxiliary feedwater must be lost to prevent heat removal. A single (one of three) steam generator module is capable of meeting SHRS heat rejection needs. A multiple sequence of operator errors must occur to isolate the AFWS. A multiple switch sequence is necessary and a low drum level alarm would indicate improper action. The operator has several minutes to reopen the valve to correct the error. The probability that operator isolation of the AFW system will occur and will not be corrected is very small.

D. PACC's Failure

The potential for PACC's failure from environmental abnormalities will be evaluated as part of the continuing reliability studies. The air intake designs will be reviewed to assess the adequacy of blockage prevention. High temperature effects on components and system life will be considered. The location of components with respect to cooling or heat producing areas will be evaluated. The design will be evaluated to find those portions of the system which have natural frequency coupling, and techniques to separate natural frequencies in the three PACC's systems will be investigated.

Numerical Assessment

Quantitative evaluation of the SGAHRS reliability indicates an acceptably low probability of failure for the conceptual design. The details of the quantitative analysis are contained in Reference 3.

A sensitivity study has been made of the relative impact of uncertainty in constituent failure rates on SHRS reliability. The results showed that SGAHRS failure is not the controlling factor on SHRS reliability. Low sensitivity results from:

1) SGAHRS has internal redundancy, i.e., during short term heat removal, the turbine pump is redundant to the two motor driven feed pumps and during long-term heat removal, the PACC's are triply redundant.

2) SGAHRS is redundant to the main feedwater system and main heat sink.

3) The DHRS is redundant and diverse from the SGAHRS.

C.6.4.2 Testing

SGAHRS equipment will be subjected to acceptance testing at the equipment manufacturers.

C.6.5 Direct Heat Removal Service (DHRS)

C.6.5.1 Analysis

The DHRS utilizes equipment which is in operation during normal plant conditions. Failures of operating equipment are annunciated to the operator immediately. The only DHRS components not in continuous service are the overflow heat exchanger and its associated pipes and valving. Therefore, reliability assurance efforts are focused on this component and on assuring adequate repairability provisions for normally operating components.

DHRS is a redundant heat removal path and sink, but it does not have specific component redundancy or diversity under the maximum expected decay heat load. A DHRS system failure for maximum load capacity can result from failure of one of several components. Redundancy within the system exists after about 5 days in the air blast heat exchangers and sodium pumps due to the reduction in decay heat load. Provision is made for in-service inspection, testing and maintenance. Since most of the subsystems comprising DHRS are active during normal plant operation, they are available and are monitored. Design margins exist in all DHRS components such that minor failures can be accommodated. For example, all pumps and blowers are rated for higher than required loads and/or speeds for maximum DHRS service and can tolerate failures that degrade performance without adversely impacting total heat removal capability.

Reliability Assessment

The reliability assessment for DHRS is presented in Reference 3 and was used in developing DHRS (improved OHRS). This assessment is being updated to reflect a more flexible analytical model and is being used to identify areas for potential reliability improvement.

Evaluations have been made of the ability of the PHTS, the reactor vessel and the core support structure to sustain an in-vessel sodium temperature of 1140°F. In-vessel sodium would be over 900°F for less than 100 hours with DHRS operation. Creep rupture times exceeding 50000 hours for the reactor vessel and core support structure and 5500 hours for the PHTS were calculated for the most highly stressed conditions. These results indicate an adequate lifetime capability for the reactor system components under DHRS operating conditions.

C.6.5.2 Testing

The 1/21 scale outlet plenum model tests described in Section C.6.1.2A were used to initially evaluate DHRS nozzle locations to assure adequate mixing of the DHRS flow with the PHTS flow. Final confirmation of the thermal adequacy of the location of the CRBRP reactor vessel sodium make-up and overflow nozzles for DHRS was obtained by 1/4 scale model flow tests in the IRFM at HEDL. The DHRS operation was simulated with flows, temperatures and coolant conductivity measured at specific points in the model. Coolant and component surface temperatures were measured in the outlet plenum region and combined with loop coolant temperatures and flow measurement data to provide an analysis base. This experiment confirmed the adequacy of upper plenum mixing for DHRS. Testing is also being conducted on active pumps and valves.

C.6.6 Interfacing Systems

C.6.6.1 Analysis

Assessments are being conducted that provide treatment of all potential failure modes of SHRS interfacing systems or equipment. Preliminary numerical analyses have focused on critical systems and interfaces. Updating of these analyses is a continuing effort.

The SHRS depends upon groups of normal plant operating equipment to provide shutdown heat removal. Important interfaces are described below:

A. Plant Dependence on Electrical Power

For normal plant operation at power, the main feedwater pumps, condensate pumps, condenser circulating water, condenser vacuum pumps, steam generator circulating pumps, primary sodium pumps and intermediate sodium pumps require AC power which is provided by th normal and reserve plant electrical power systems. All sodium primary and intermediate pump pony motors, protected air cooled condenser fans, the motor driven auxiliary feed pumps, the DHRS EM pump and DHRS ABHX fans are provided with both normal and emergency electrical power. All essential instrumentation and control is powered from non-interruptable power supplies."

B. Instrumentation and Control

The reliability of the control and instrumentation involving air supplies, electrical devices, sensing equipment, etc. will be assessed. The DC and AC power subsystems are being analyzed and combined with the instrumentation and control reliability analysis.

C. Balance of Plant (BOP) Systems

One of the key interfaces is the main Condensate and Feedwater System. This system has been subjected to preliminary assessments used in current activities. An assessment to determine the reliability of this system in its role as a heat sink during SHRS operation is being conducted. The Turbine Bypass valving, the condenser and related BOP components are integrated in reliability assessment activities.

SHRS equipment is designed for reliable operation over the full range of operating environments expected within the equipment cells during normal operation. Environmental conditions beyond those specified for the cells could cause degradation of the BOP control systems. The environmental conditions of concern are temperature and chemical contaminents. The effects of these factors on BOP control system reliability is being evaluated. Design, installation and operational features and procedures for these systems will reflect the findings of the evaluations.

C.6.6.2 Testing

Testing identified for interfacing systems is comparable to that associated with current LWR practices augmented by consideration of the potential sodium contamination.

C.6.7 Common Cause Failure Analysis

Results of the preliminary system level study of common cause failures are summarized below.

A. Calibration

All calibration actions are controlled by maintenance and installation procedures. These procedures give detailed information for the calibration and verification of the checkout of each piece of equipment. In addition to accurate and periodic calibration of test equipment and test meters to national standards, calibration of critical sensors to manufacturer's specifications is periodically performed.

Examples of safeguards against inadvertent miscalibration included in the current design are (1) critical instrumentation racks will be locked with one set of keys under administrative control, (2) all valves left in the test position rather than run position after checkout will trigger a warning signal in the main control room and (3) stem lock needle valves that free wheel until a set screw is tightened will be used.

Procedures will be verified during manufacturer's checkout testing, and many of the procedures will receive trial usage in the system level reliability tests. Therefore, a miscalibration could only result from a series of systematic errors caused by the persons involved in the calibration function. The use of these controls makes the likelihood of miscalibration improbable.

B. Environmental Conditions Within Control Room(s)

Included in this category are such factors as temperature and humidity in the area as well as other factors that might be responsible for some local abnormal conditions, such as proximity to heated pipes, magnetic disturbances, etc. Items sensitive to these conditions include: (1) power supplies, (2) switchgears, (3) relays and (4) meters.

A worst-case environment is assumed in these areas and the equipment located there is qualified to operate correctly over the range of environmental conditions specified. Accordingly, as long as the area environment remains within the worst-case limits, the equipment should not be expected to fail for environmental reasons.

C. Failure of Common Air Supplies

The probability of an air supply failure can be made negligible by proper location of equipment and air piping runs. Backup air bottles are provided on safety-related systems (the turbine bypass valves are not safety-related) that must cycle during cooldown. Safety-related valves include accumulators and check valves to protect against an air leak upstream of the check valve(s). Up to ten cycles of operation are available from these backup air bottles. Additionally, to assure that proper installation has been obtained and joints are secure, over-pressure leak checks are planned.

D. Vibration Induced Effects

The components sensitive to vibration will undergo vibrational tests during development testing. Identification of undesirable response characteristics during testing will result in equipment modification so that equipment (e.g., electric equipment cabinets) delivered to the plant will not be inherently vulnerable to vibration.

E. Electrical Power Supply

Certain components in the SHRS require electrical power for proper operation. Power is supplied by the preferred and redundant reserve power lines, the redundant diesel generators and battery supported buses for certain equipment.

The diesel generators and battery supported buses are designed for or protected from the effects that could cause simultaneous failure of both preferred and redundant reserve power lines (seismic, tornado, grid blackout and out of tolerance power). The design of the diesel generators and support equipment to the requirements of IEEE-308 ensures independence of these redundant equipment. Therefore, the potential for common cause failure of necessary electrical power has been made sufficiently remote by the design features included.

Due to the critical nature of supplying power, continuing reliability emphasis will be placed on ensuring the sufficient remoteness of common cause failure as the detailed layout of components and routing of the wiring develops.

C.7.0 Program Evaluation

C.7.1 Reactor Shutdown System

C.7.1.1 Primary Control Rod System

This section summarizes the principal conclusions from analyses and tests performed in support of PCRS reliability assessment.

Analysis

Reliability assessments of the PCRS and interfacing components have verified the reliability adequacy of the system. These analyses have identified those components, features and phenomena upon which the PCRS reliability most relies and/or within which significant uncertainties exist. Supporting analyses and tests have been initiated to resolve uncertainties and establish design margins to confirm PCRS reliability. Design changes have been incorporated to enhance reliability by preventing the occurrence of certain failures or precluding the failures from having a significant impact on scram insertion. PCRS design improvements and interfacing component design features for reliability enhancement are given in Tables C.7-1 and C.7-2, respectively.

Numerical analyses performed for the PCRS have led to the following conclusions:

1) Misalignments within the design envelope resulted in low normal forces retarding scram insertion and should not significantly impact scram reliability.

2) Sufficient margins exist on normal scram sliding friction coefficients such that uncertainties on these data have a negligible effect on scram insertion. Existing LMFBR Base Technology programs will provide acceptable data for CRBRP reliability confirmation.

3) Analyses of CRBRP PCRDM unlatching show acceptable design parameters to achieve unlatching time requirements.

4) Based on analyses and applicable FFTF test data, random independent failure modes for the PCRDM have insignificant impact on scram reliability. Emphasis will be placed on resolving potential common cause failures.

Testing

Conclusions from these tests are summarized below:

A. Duct Crushing Test

The Duct Crushing Test was performed to provide data to support analyses for crushing of core assembly ducts under seismic loading conditions. This test, completed at HEDL, involved transverse loading of EBR-II irradiated ducts.

No brittle fracture was observed in any of the tests. Two bending specimens were loaded to failure. The crush tests (transverse loading) indicated duct deflection capability exceeded deflections predicted for CRBRP seismic conditions. Comparison of available tensile test data for 20 percent CW SS316 and SS304 indicates that SS316 ducts have greater deformation capability than SS304 ducts. The test conditions and loading in this test were based on radial blanket environments. Control assembly ducts have much less severe loading conditions and environments. The tests established that load pad brittle fracture is not a limiting factor in control rod system performance. The ducts can deform to a point where all control rod to duct clearances have been eliminated with no evidence of brittle fracture.

B. Duct Impact Test

The Duct Impact Test to verify the capability of the PCA ducts to accommodate scram arrest impact loads has been completed at HEDL.

In these tests, irradiated EBR-II ducts were impacted by known weights dropped from a range of heights to simulate prototypic and overload conditions. Interim and final examination of both EBR-II ducts tests revealed no failure initiation or cracking of these components. Strain measurements on the two ducts were consistent with each other and increased with increasing impact load. This observation supports the repeatability of the findings. Scanning electron fractography performed on high fluence tensile specimen fracture surfaces at equivalent duct impact strain rates and test temperatures revealed that transgranular channel fracture dominates over all impact conditions.

Results from the duct impact tests have demonstrated that the PCA ducts are not susceptible to brittle fracture under prototypic and overload scram arrest impact loading.

C. Rotational Joint Test

The rotational joint feature was introduced into the PCA design to preclude the transmission of torsional loads from the PRDM via the PCRD to the PCA control rod. It was these torsional loads which led to galling of the control rod outer duct during tests of the FFTF control rods. The rotational joint in the CRBRP control assembly is intended to limit torque transmission to a maximum value of 20 in-lb. At this level of torque transmission, the control rod/outer duct interaction loads are too low to produce galling. Test results have shown that the rotational joint feature limits the maximum breakaway torque to 17 in-lb. During normal operation, the torque transmitted by the joint is further reduced to 8 in-lb max. The tests have demonstrated that the rotational joint effectively precludes the potential for galling of the PCA ducts due to torque loading.

D. Duct Bowing Test

The duct bowing test was conducted to assure that adequate design margins exist for worst case duct bowing predictions and to confirm analytical models for predicting the effects of duct bowing.

The results of this test show that drag forces resulting from duct bowing are negligible (25 lbs. or less) prior to the design limit criterion for three point forced contact between the control rod and outer duct. Worst case design bowing predictions are much less than the design limit criterion. Analysis show that geometrical clearance evaluations can accurately (within 0.005 inch clearance) predict the three point forced contact conditions resulting in increased drag forces. Analysis methods conservatively predict the bowing drag forces. Test result show that flow and control rod velocity have negligible effects on frictional drag forces. The forced contact point occurs at or near full rod insertion with clearances increasing significantly with withdrawal such that negligible drag occurs prior to the last six inches of rod insertion. Consequently, large margins exist for bowing induced failure to shutdown the reactor from both predicted clearances to forced contact and that even after forced contact, the control rod would insert sufficiently to shutdown the reactor.

E. Pin Rupture Test

The pin rupture test was performed to determine the magnitude of control rod duct deformation resulting from potential failure of the absorber pins having high internal pressure due to helium release from B-10 neutron captures.

The test results show acceptable (0.030 inch maximum deformation) inner duct deformation for ruptures of pins containing pressures up to 5000 psi. At expected end-of-life pressures of less than 3500 psi, the duct deformations were even smaller. Ruptures of intentionally faulted pins at different locations within the pin bundle showed no indications of pin deformation as a result of the pressure pulses. These test results show that pin ruptures have negligible for causing a scram failure.

F. Pin Compaction Test

The pin bundle compact test was performed to assess bowed absorber pin interaction effects with the inner duct, pin bundle compressibility and pin to pin contact loads in order to aid verification of analytical models.

Pins prebowed to conditions exceeding design predictions were compressed to design pitch at the top and bottom end caps. Resulting bundle compressibility, pin shapes and typical pin loads were measured. The test results show that the pin bundle is sufficiently compressible that pin bowing will cause negligible deformation of the inner duct and that pin loads are acceptable.

G. Dynamic Seismic Friction Test

The dynamic friction test was performed to obtain effective friction coefficients under impact conditions typical of seismic events and to provide data to assist confirmation of analysis methods.

Geometries tested were a cylindrical rod in three bushings and a hexagon in hexagon configuration. Environments tested were air, argon, water and sodium. A shaker mounted to the test vessel provided the vibrational input at multiple acceleration levels. Measurements included rod drop times and impact load time histories at the bushings. Effective friction coefficients were obtained by simple analyses utilizing the measured impact loads and rod drop times. to check methods used for PCRS seismic scram analyses, these methods were used to predict the impact loads. Effective friction coefficients were than also obtained by utilizing the calculated impact loads with measured rod drop times. Good agreement was obtained between the friction coefficients obtained from measured and calculated impact loads.

The resulting effective friction coefficients were on the order of 0.5 or lower. Utilization of these friction coefficients for PCRS seismic scram speed analyses has shown that design requirements for seismic scram insertion are satisfied.

H. PCRS Friction Couples Tests

Pin or plate friction measurements were obtained for PCRS material couples to obtain sliding friction coefficients for use in normal scram analyses. Utilization of these friction coefficients in scram analyses has shown that scram speed requirements are satisfied even when maximum (3 level) friction coefficients are used in the analysis.

I. PCRS Prototype Design Tests

The PCRDM Accelerated Unlatching Test was performed using a prototype PCRDM/PCRD with a weight simulation for the control rod. Prototypic PCRDM argon and temperature environments were used with a water filled vessel for the PCRD dashpot function. More than twice the design basis lifetime of scrams and travel were completed by including 1868 rod drops and 35, 451 feet of travel. Conditions on nozzle temperatures, nozzle misalignment, internal CRDM pressure and stator cooling beyond the design basis were tested and showed no detrimental effect on PCRDM performance. All tests met design requirements for unlatch time, position indicator accuracy, dashpot final impact velocity and CRDM seal leak rates. Where over twice the service life had no significant effect on PCRDM performance. Post-test inspections confirmed that the testing produced no component failures, no excessive wear and no unusual or unexpected wear patterns.

Phase I of the PCRS Prototype Design Tests has been completed including 470 scrams and 5962 feet of travel. Prototype PCRS components (PCRDM/PCRD/PCA) were tested in a sodium environment under design basis conditions for temperature, flow and misalignment. Sodium exposure, wear and a 42 day hold period had no effect on PCRS performance. Performance characteristics including scram times, position indicator accuracy, dashpot seal leak rates satisfied design requirements.

Maintenance tests using a prototype Disconnect Actuating Tool (DAT) and plant maintenance tools were conducted using draft plant procedures for the tests. Control rod disconnect, installation, removal and power driveline replacements tests were performed. Procedure improvements were identified for DAT and sodium removal operations. Minor lower PCRDM design changes such as more extensive diameters and small reductions in external shielding diameters were identified to facilitate installation. These features have been included in plant units and one prototype test unit. No maintenance relation problems were identified that would affect PCRS functional or scram performance.

J. PCRS System Level Tests

Phase I for both the Real Time and Failed Bellows Tests have been completed, under prototypic conditions. The Real Time Test included 368 scrams and 6053 feet of travel while the Failed Bellows Test included 676 scrams and 9360 feet of travel. Phase I of the Failed Bellows Test was performed to characterize PCRDM performance prior to intentionally failing the bellows for Phase II of this test. Hold time tests including 35 day and 117 day (30 days at full flow conditions) hold periods under various sodium conditions were performed. For all hold time tests, scram times before and after the hold were not significantly (<0.025 seconds to full insertion) different with these time variations being typical of normal variations. Scram times and normal performance for all tests satisfied design requirements. Prototypic maintenance operations for DAT disconnects, installation and removal were performed and showed no impact on PCRS functional or scram performance.

C.7.1.2 Secondary Control Rod System

This section summarizes the conclusions of the reliability evaluations and tests performed in support of the SCRS design.

Analysis

Reliability assessments of the SCRS and interfacing components are being conducted to verify the reliability adequacy of the system. These analyses have identified those components, features and phenomena upon which the SCRS reliability most relies and/or within which significant uncertainties exist. Supporting analyses and tests have been initiated to resolve uncertainties and establish design margins to confirm SCRS reliability. Design changes have been incorporated to enhance reliability by preventing the occurrence of certain failures or precluding the failures from having a significant impact on scram insertion. SCRS design improvements and design features for reliability enhancement are given in Table C.7-3. The interfacing component failure modes and design features are listed in Table C.7-2.

Numerical analyses have been performed for the SCRS. The following conclusions have been reached:

1) Sufficient margins exist on irradiation creep deformation such that control rod duct and guide tube deformation will not exceed clearances provided and impact scram insertion.

2) Based on analyses, random independent failure modes are assessed to have negligible impact on scram reliability.

The SCRS reliability evaluation will be reviewed and updated as required throughout the SCRS development cycle as additional data is made available from testing and from the continued data search and analysis effort.

Testing

SCRS testing to date has been directed toward design verification. Four tests have been completed and two are in progress. Design tests of the damper, coil cord, position indication system and the argon system have been completed. The results from these tests were used to optimize the design of the individual component features. Tests in progress are the Latch Test and Latch Seal Test. Results of the Latch Test to date indicated that the latch as currently designed will perform the safety function.

C.7.1.3 Electrical Subsystem

Reliability assessments of the ES and interfacing components have verified the reliability adequacy of the subsystem. These analyses have identified those components, features and phenomena upon which the ES reliability most relies and/or within which significant uncertainties exist.

Numerical analyses performed for the ES have led to the following conclusions:

1) Sufficient failure rate data exists on electronic components to perform meaningful assessments of the random independent failure rate for each of the primary and secondary electrical subsystems. This data is taken from FFTF prototype, qualification and acceptance testing results as well as system and module FMEAs and a numerical module failure rate prediction (using MIL-HDBK-217B as a data source).

2) The redundancy provided in each ES is adequate to reduce random independent failure probability to an appropriate level.

3) Instrument channel monitoring provides significant reduction in dependence on sensor/electronics failure rates.

4) Components with maximum impact of reliability due to failure rate were identified for design consideration (e.g., upgraded MIL-SPEC specification and piece/part changes).

Common cause failure considerations have resulted in the specification of diverse primary and secondary electrical subsystems. Significant conclusions for the hardware implementation resulting from common cause failure considerations to date are discussed in the subsequent section.

A resulting recommendation from ES evaluation was that an extended operations test should be carried out on primary and secondary electrical subsystems. These tests will include all RSS signal conditioning and logic train subsystems.

System Reliability Enhancement Features

A number of reliability improvements over FFTF have been incorporated into the design. For example, the number of primary logic trains has been increased from 2 to 3 to add the capability for on-line testability without bypass.

Design of the FFTF equipment has undergone extensive qualification testing and environmental cycling tests for extended time periods. A reliability enhancement study of the FFTF system was performed by the equipment vendor. The reliability enhancement study determined that the most significant reliability improvement could be gained by increasing the piece/part quality levels and/or the levels to which the piece/parts are screened. Implementing changes to the CRBRP ES equipment based on this study have raised the inherent reliability of the CRBRP equipment.

Piece/part quality levels are provided by using military quality components in major portions of the ES. The use of MIL-SPEC components provides assurance of consistent quality and control during the component manufacturing process.

Preliminary analysis showed that a loss of the -15 volt input to a comparator would tend to prevent that comparator from tripping when required. Even though this single failure would not prevent a reactor scram since the three redundant comparators are powered by separate power supplies, power supply monitors were added. If -15 volt power is lost, all power to the comparator would be cut off by the power supply monitor. Since a removal of all power to the comparator propagates a trip signal on that channel (a safe failure), the effects of a loss of the -15 volt comparator input has been minimized.

The comparators have been designed to minimize the effects of failures in the setpoint circuit. The most likely failure modes for these components were determined and the comparators designed to trip (fail-safe) upon occurrence of these most probable failures.

The packaging of the modules was also modified to increase inherent reliability. Early designs of trip comparators had approximately 130 handwired connections in each module. This has been reduced to six in the present design. Reliability enhancement is realized by the fact that machined, soldered connections are more reliable than handwired connections. The reduction of wiring also minimizes the potential for human error either in initial wiring or future maintenance.

C.7.2 Shutdown Heat Removal System

This section summarizes the principal conclusions from analyses and tests performed in support of the reliability of the SHRS.

Analysis

The analysis that has been completed to date consists of the system level FMEA, system level assessments and probabilistic and structural assessments in support of definition of structural failure in the primary system. These assessments have contributed to the existing base of design information available on SHRS and have supported the identification of changes to design and development programs to enhance SHRS reliability.

References 3 and 4 provided substantial design and reliability information to support the conclusion that large pipe ruptures in the primary system resulting from crack growth due to material flaws can be made sufficiently improbable to exclude large pipe breaks from being a significant problem. The reliability evaluations identified the importance of the role of the leak detection system and quality assurance in attaining the desirable low probabilities for large pipe breaks.

Reference 3 provides the overall numerical assessment of the SHRS reliability. In the report are both a single point estimate of the probability of SHRS performing its mission and significant sensitivity evaluations. The assessment is that with proper attention to design and development activities adequate SHRS reliability can be achieved. The contribution made by DHRS is identified in the report. This finding was part of the information which supported upgrading OHRS to DHRS.

Table C.7-4 provides a list of features which address critical failure modes which have been identified. Table C.7-5 provides a summary list of interfacing systems failure modes and design features for reliability enhancement.

Testing

Many of the materials testing programs contributing information to support the design of SHRS have provided interim data that have been used in the PHTS, IHTS and steam generator system equipment design. A major output from these programs was the 2 1/4 Cr - 1 Mo constituent equations for application to the design of the steam generators.

The shell-side flow and tube vibration test (hydraulic test model) has been completed. The test demonstrated that no adverse vibration effects or flow conditions are present in the reference steam generator module design. Low amplitude (corresponding to low stress levels) vibration was present, however, it was found to have no effect on the reliability of the steam generator module.

The DNB testing for determination of corrosion effects has been completed. Preliminary findings show no evidence of accelerated corrosion or other anomolies.

The integrity of the Sodium to Water/Steam boundary of the steam generator is essential for reliable SHRS operation. The use of microfocus x-ray for 100% examination of steam generator tube-to-tube sheet welds has provided assurance that the welds are free of defects, which would lead to boundary violation.

Testing of tube-to-tube sheet weld development samples has demonstrated that the welds are of the same or greater strength than the parent materials.

LLTR tests have resulted in assurance that the main pressure relief burst discs will limit over-pressures due to sodium/water reactions and that the dual disc design will provide timely pressure relief while providing loop integrity during normal operation. These tests have also shown that multi-tube leakage is highly improbable, even following a guillotine rupture of an adjacent tube.

TABLE C.7-1

PCRS DESIGN FEATURES
FOR RELIABILITY ENHANCEMENT

Failure Mode	Design Features
Outer duct galls due to forced contact with inner duct wear pads	Rotational joint incorporated in PCA control rod shaft to limit contact loads
Slow unlatching time as a result of high friction or slow magnetic decay	Segment arm spring force increased to provide margin on friction effects Smaller stator wire used to increase resistance and decrease field decay time
Bellows leaks permitting sodium vapor in upper PCRDM	Increased number of bellows convolutions to reduce stresses and improve failure rate CRDM gas purge incorporated to minimize sodium vapor in CRDM
Duct distortions retard scram insertion	Increased inner duct to outer duct and pin to inner duct clearances to minimize duct to duct contact
PCA scram arrest flange galls due to rubbing with control rod shaft coupling	Coupling length and clearances with scram arrest flange optimized to minimize rubbing and limit contact to last 6 inches of insertion
Chips from leadscrew collect at bushings and retard insertion	Bushings chamfered to minimize effect of chips
PCRDM bushing wear affects mis-alignments or cause bellows rubbing	Bushing material changed from Niresist to Stellite to improve wear character-istics
Segment arm motion stop and segment arms deform permitting motor tube contact	Hardened segment arms and stop and increased segment arm to motor tube clearance
PCA flow blockage or orifice plate manufacturing variations affect-ing flow rates and insertion speeds	Orifice plate assembly and shield design simplified to minimize potential for manufacturing assembly errors and part breakage
Pin assembly errors affecting rod worths	Pin assembly discrimination features added to minimize erroneous assembly of pins into pin bundle and B_4C pellet enrichment in pin assembly

TABLE C.7-2

INTERFACING COMPONENT DESIGN FEATURES
FOR RELIABILITY ENHANCEMENT

Failure Mode	Design Features
Rotation of intermediate or large rotating plugs increase shutdown system misalignments	Operational mechanical lock and safety interlocks incorporated in head design to prevent inadvertent plug rotation
Debris collects in small clearance areas of control rod systems and retards insertion	Core special assemblies used prior to initial core assembly loading to eliminate debris from coolant
Flow blockages lead to core assembly overheating and potential melting	Axial debris barrier and auxiliary flow ports added to inlet modules
Failure of Upper Internals Structure (UIS) support columns leads to excessive shutdown system misalignments	Lengths of UIS keys to core barrel increased to limit tilt of UIS within capability of shutdown systems
Fragments from UIS shroud tubes lead to debris retarding scram insertion	Inconel 718 material used in UIS areas to minimize failure potential from thermal striping

TABLE C.7-3

SCRS DESIGN FEATURES FOR RELIABILITY ENHANCEMENT

Failure Mode	Design Features
Scram valves jam or stick	Control valve system redesigned with 3 solenoids operating main valves to allow periodic checkout of each electrical channel without causing scram.
Pneumatic actuator piston sticks due to galling	Dashpot type actuator mechanism design replaced by an all metal bellows type design so that the sliding seals are no longer required.
Bellows leak permitting sodium vapor in SCRDM	Lower driveline bellows between tension rod and sensing tube raised to lower head area region from above latch to lower temperature.
Pneumatic cylinder jams due to broken spring debris	Sensing tube and pneumatic cylinder assist springs eliminated.
Tension rod binds to sensing tube/driveshaft due to galling	Wear resistant guide bushings added to maintain position between sliding parts.
Tension rod binds due to lateral distortion	Increased driveline cross section to resist lateral displacement.
Collet gripper fingers self-weld to coupling head	Inconel 718 used to resist self-welding. Cam surfaces are curved to cause severing of any bonds that have developed.
Control rod duct distortion retards scram	Duct to guide tube clearance design is sufficient to minimize contact.
	"Parked" position of control rod raised to a half inch above the top of the core to reduce temperatures and fluence.

TABLE C.7-4

SHRS DESIGN FEATURES
FOR RELIABILITY ENHANCEMENT

Failure Mode	Design Feature
Primary System Leakage	Guard vessels with elevated piping reduced probability of loss of coolant inventory
Intermediate System Leakage	Three independent intermediate system loops are provided in isolated cells.
Loss of Cooling Water	Three independent steam-water heat exchanger systems are provided. Water supplies are provided to assure supply of water to one or all of the three sodium-to-steam/water heat exchanger systems.
Failure of Redundant Forced Circulation Systems	Natural circulation capability in PHTS, IHTS and steam-water system
Common Cause Failure of Independent IHTS Systems	DHRS provided to maintain core coolable geometry
Failure of Electric Motors from AC Power Loss	Battery power supply for short term forced circulation cooling redundant to natural circulation and steam turbine driven AFWS
Failure of all Feedwater Systems	DHRS provides redundancy. PACC's provide long term air cooling following initial cool down.

TABLE C.7-5

SHRS INTERFACING SYSTEMS DESIGN FEATURES FOR ENHANCEMENT OF RELIABILITY

Failure Mode	Design Features
Failure of Coolant Boundary Component Supports	Ability of piping to tolerate specified snubber and hanger failure.
Off-site AC Power Failure	Redundant diesel generators and short term battery power supplies.
Instrument Gas Supply Systems Failure	Fail-safe designs with backup bottle supply.
Operator Error	Controlled access to critical operations.
Sodium-Water Reaction System Failure	Intermediate System cells provide isolation for independent IHTS systems.
Sodium Fire in IHTS Cell Which Degrades PACC Operation	PACC airflow shuts off when Na fire residues are sensed at PACC inlet to prevent PACC fouling. Operator can override erroneous shut-off signal.

C.8.0 References to Appendix C

1. DELETED

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4. "Primary Pipe Integrity Status Report", WARD-D-0127, Westinghouse Advanced Reactors Division, Madison, PA, 15663, December, 1975.

5. E. H. Novendstern, et. al., "Outlet Plenum Flow Stratification Studies for the Clinch River Breeder Reactor Plant", ASME pub. 76-WA/HT-84, December 1976.

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9. "Reliability Prediction of Electronic Equipment", MIL-HDBK-217B, September, 1974.

ADDENDUM 1

Test Facility Descriptions

PCRS Test Facilities

This section provides a description of the test facililities used for the PCRS tests being conducted at Westinghouse ARD. Facilities described include part of the existing Westinghouse ARD Technology Laboratory Facilities and individual test facilities being built to support the program.

General Facilities

A. General Purpose Loop No. 1 (GPL-1)

The GPL-1 sodium test facility is an operational high temperature loop designed and fabricated in 1967 in accordance with Section I of the ASME Boiler and Pressure Vessel Code. This facility provides sodium to assorted test sections at temperatures to 1200°F, pressures to 300 psig and flow rates to 200 gpm.

The facility has logged more than 25,000 hours of successful operation in support of steam generator and other LMFBR component evaluation programs. The incorporated linear induction pump, piping, valving, flowmeters and data acquisition systems are fully operational.

The GPL-1 facility has a gas fired primary heat source capable of adding 1 MW thermal energy to the 1200 pound sodium inventory. Primary flow piping is fabricated from 2 inch Schedule 40 Type 304 SS.

The facility is used to supply sodium for Phase II of the Dynamic Seismic Friction Test described earlier.

B. General Purpose Loop No. 2 (GPL-2)

The GPL-2 sodium test facility is an operational high temperature loop designed and fabricated in 1969 in accordance with Section I of the ASME Boiler and Pressure Vessel Code. This facility provides sodium to assorted test sections at flow rates up to 2000 gpm, temperatures to 1200°F and pressures to 300 psig.

The facility has logged more than 18,000 hours of operation utilizing a 2000 gpm, linear induction, electromagnetic sodium pump. The primary piping system is 6 inch Schedule 40 Type 304 SS. The incorporated dump tank is charged with 27,000 pounds of sodium. With an overall test area of 15 feet x 30 feet x 55 feet, evaluation of full-scale reactor components is possible.

The GPL-2 facility has a heating capacity of 1.25 MW through a gas fired heat exchanger.

This facility is used to supply sodium at prototypic flow rates, temperatures and pressures for the PCRS System Level Tests described earlier.

C. Sodium Auxiliary Supply System (SASS)

The SASS is a high temperature medium flow rate system providing closed loop sodium circulation to each of three test sections. This system (now under construction) consists of two independent sodium pump loops. When combined with the existing GPL-2 pump loop, these loops provide the capability to vary flow rates, temperature and pressure on three different test positions.

Each of the two auxiliary pump loops contains an electromagnetic pump, a gas fired sodium heater/cooler unit and an economizer system. Each of these sodium pump loops can independently vary flow from 0 to 120 gpm and supply sodium to the test sections at temperatures up to 1100°F.

All sodium containing components are installed within metal enclosures to mitigate and contain sodium leaks. Each of these enclosures is kept at a slightly negative pressure to restrict sodium aerosols to normal work areas in the event of spillage. Instrumentation within these enclosures will monitor and alarm any changes from anticipated environmental conditions.

A sodium purification system will be placed on line as required to maintain purity oxide levels of less than 10 ppm. Determination of oxygen in sodium will be made by the equilibration method using vanadium wires. As a backup, the bypass procedure using the amalgamation method will be used.

All equipment forming the sodium boundary of the system will be designed and constructed in accordance with national codes and standards: the piping per ANSI B31.1, the heaters and pumps per ASME Section VIII and the valves per ANSI B16.34. The ancillary system will be equipped with isolation and select valves to enable GPL-2 to serve the three test sections should a malfunction affect the auxiliary system operation.

D. Argon Supply System

The argon supply system consists of a 3000 gallon cryogenic fluid tank equipped with an atmospheric vaporizer. Argon gas is piped from this storage tank to the various facilities within the laboratory.

The maximum working pressure of the system is 250 psi. The tank contains 337,200 cubic feet of argon at NTP (70°F, 14.7 psi absolute pressure). The system has a withdrawal rate varying with the ambient temperature and the length of time of withdrawal. The rate extends from a minimum of 800 cfh (constant usage in below freezing weather) to a maximum of 2500 cfh (interrupted usage during 70° weather).

A separate argon supply system similar to but of lower capacity than that described above is provided for GPL-1 because of the remote location of this facility.

Argon gas from these systems is sampled periodically for impurities such as oxygen, moisture, etc., to verify the purity of the gas being supplied to the individual tests.

The Argon Supply Facility is used to provide cover gas for GPL-2 and SASS sodium supply systems. It is also used to supply purge gas for the articles tested in these test rigs. The separate argon supply system located at GPL-1 is used to supply cover gas to GPL-1 for the Dynamic Seismic Friction Test.

E. Sodium Cleaning Facility

The sodium cleaning facility is a separate on-site all-weather facility providing equipment and processes suitable for safe removal and disposal of residual sodium from various sized sodium loop components or test articles.

The facility is equipped primarily to perform sodium removal by moist argon (steam), alcohol and deionized water rinse processes. Equipment is also available for draining sodium from components and for vacuum or inert gas drying of processed components.

The second floor of the facility is equipped with a 2 ton capacity overhead monorail and hoist system for handling and processing components before and after cleaning and also provides a general equipment storage and clean room area for the facility. The first floor features a 350 gallon liquid capacity stainless steel cleaning vessel (LCV) capable of accommodating components up to 20 feet long and 2 feet in diameter.

The Sodium Cleaning Facility will be used to clean test articles and equipment used in the Dynamic Seismic Friction Test and the PCRS System Level Tests.

F. Hydraulic Facility

The hydraulic facility at ARD is a water test facility capable of flow rates up to 5500 gpm at temperatures from 90 to 190°F and pressures up to 200 psi. The facility is comprised of the MPHL and TMHL (defined below) test loops to supply city or demineralizer water at controlled pressures, temperatures and flow rates to various test assemblies and a DAS (defined below) to accept, condition, record and analyze a variety of analog data signals.

This hydraulic facility and the remainder of the hydraulic facilities and data acquisition system described below are used for the Dynamic Seismic Friction Test, the Pin Rupture Test, the Bowed Duct Test and the Control Assembly Hydraulic Test.

G. Thermal Mixing Hydraulic Loop (TMHL)

TMHL is an open recirculation water loop with a 3000 gallon vertical storage tank, a 2000 gpm, 220 foot head centrifugal pump, 3 inch and 6 inch orifice flow meter sections and associated pipe, valving and instrumentation to provide flow and pressure control for a test section. Flow rate can be controlled and monitored from 26 to 2000 gpm within an accuracy of ± 1.0 percent of the actual flow rate and the pressure drop can be monitored from 0.27 to 100 psid within an accuracy of + 2.0 percent of the actual pressure difference. The water temperature can be controlled from 90 to 180°F. Pumping power is the source of heat input with the temperature being controlled by varying the flow rate to a secondary water-to-water heat exchanger.

H. Multi-Purpose Hydraulic Loop (MPHL)

The MPHL is an open recirculation water loop with a 1000 gallon vertical storage tank, three 2000 gpm, 220 foot head centrifugal pumps, 6 inch and 12 inch orifice flow meter sections and associated pipe, valving and instrumentation to provide flow and pressure control for a test section. The pumps can be arranged to provide maximum flow capabilities of 5500 gpm at 100 psid pump head or 2000 gpm at 200 psid pump head. The water temperature can be controlled from 90°F to 180°F. Pumping power is the source of heat input with temperature being controlled by varying the flow rate to a secondary water-to-water heat exchanger.

I. Data Acquisition System (DAS)

The DAS is located within a controlled atmosphere enclosure in the hydraulic facility. The system is designed to service various test assemblies to provide excitation, conditioning, amplification recording and analysis of data signals.

The system contains signal conditioning instrumentation for resistance bridge, piezoelectric, eddy current and LVDT types of transducers.

Data recording is performed by an FM magnetic tape and an oscillograph chart. Connectors will be provided on all transducers at the individual test area to facilitate maintenance and calibration.

A transducer patching system is used to permit maximum utilization of the signal conditioning for several test programs and to simplify system calibration. An intermediate patch system will provide quick changeover of amplifiers for scaling various levels of input signals and will provide input to the system for high-level transducer signals.

Both the transducer and intermediate patch panels will incorporate test output and input provisions to facilitate calibration and fault isolation.

A high-level patching system is used for routing conditioned signals to the appropriate recording device. The high-level patch permits routing of data to any channel of the recording instruments.

Recorded FM tape data can also be reproduced on the oscillograph or spectrum analyzer using this patching scheme.

Component Test Facilities

A. Dynamic Seismic Friction Test Facility

The Dynamic Seismic Friction Test will use a facility capable of providing (1) support for the test section, (2) a test fluid and (3) a vibration excitation. The test program is subdivided into three phases of which Phase I and III use water as the test fluid. These phases will be carried out in the Hydraulic Facility with the Thermal Mixing Hydraulic Loop described earlier as the source of controlled water flow. Phase II uses a static pool of liquid sodium as the test fluid which will be provided by GPL-1.

Other facilities needed for this test are:

1) Large reaction mass

2) Reciprocating hydraulic actuator (10,000 pound capacity) for the seismic vibration loads

3) Argon supply system for the Phase II sodium test

4) Pressure for the water test

5) Pressure vessel for the sodium test

6) Mechanical actuator for lifting the rod

Test data will be obtained by numerous instrumentation sensors such as accelerometers, displacement and pressure transducers, and strain gages. Analog signals will be conditioned, recorded and analyzed by the Data Acquisition System.

B. Pin Rupture Test Facility

The Pin Rupture Test will use a facility capable of providing (1) support for the test section, (2) a static pool of water and (3) a controlled helium pressure capable of bursting an absorber pin. The test will be located in the Hydraulic Facility described earlier.

The facilities needed for this test are:

1) Support structure

2) Test vessel

3) Helium supply system

4) Booster pump for pressurization of the pin

This test will be performed in the Multi-Purpose Hydraulic Loop facility.

C. Bowed Duct Test Facility

The Bowed Duct Test will use a facility capable of providing (1) hoisting of and support for the test section, (2) lateral forces for bowing the test section, (3) a mechanism for inserting and withdrawing the inner test section and (4) a water test fluid at controlled pressures and flow rates. The test will be performed in the Hydraulic Facility with the TMHL as the source of the water test fluid.

The test facilities needed for this test are:

1) Support structure

2) Test vessel with flexible end sections

3) Hydraulic actuator with pump, valves and piping

4) Outer duct bowing device

5) Inner duct bowing mechanism

D. PCRS Seismic Test Facility

The PCRS Seismic Tests will use a facility where a prototype PCRS may be mounted in the vertical position under prototypic support conditions. Seven electro-hydraulic shaker will be coupled to the support structure and will provide vibration inputs to the PCRS. The test facility is currently under construction.

E. Control Assembly Hydraulic (Flow) Test Facility

The Hydraulic Flow Test will use a facility capable of providing:

1) Support structure with positioning capability

2) Water loop to provide flow rates required

3) Instrumentation to record control assembly response such as pressure drop, vibration

F. Control Assembly Pin Compaction Test

The test facility will be equipped to provide:

1) Means to pre-bow the absorber pins to specified conditions.

2) Test rig to hold the bottom plate and "blossomed" pin bundle with a mechanism to compact the pin bundle to prototypic conditions.

3) Instrumentation to measure pin performance as specified.

G. Control Assembly Rotational Joint Test

The following facilities are needed:

1) Test vessel for the torque transmission tests in sodium.

2) Test vessel to complete accelerated life test in sodium.

3) Test fixture to perform impact tests.

4) Cleaning and inspection facilities to perform wear inspection.

5) Instrumentation to record specified parameters.

System Level Test Facilities

The system level test facility is composed of the features described in the remainder of this section.

A. Test Structure and Enclosure

A tall test structure supports three test control rod test sections and provides a limited area for maintenance and handling. The enclosure provides a sealed containment around the entire test structure and a ventilating system maintains a slight negative pressure within the enclosure for safety purposes.

B. Test Vessel

The test vessel houses a completely prototypic PCRS. Angular and lateral misalignments of the test articles can be accomplished as initial conditions prior to testing under a variety of sodium flow, level and temperature conditions that simulate in-plant operations. Angular and lateral misalignments are controlled by three separate vessel features.

1) Eccentric Flange Interfaces - The test article vertical centerline was offset 1 inch relative to the vessel vertical centerline. By aligning the driveline and control assembly directly under the CRDM, the test article can be installed in perfect vertical alignment. The clamping configuration permits any angular displacement position providing lateral misalignment capability within a 0 to 2 inch range allowed by eccentricity.

2) Misalignment Devices - Misalignment devices are similar in configuration to the stem and operator of a conventional nuclear grade valve. Positioning accuracy was obtained by using a worm gear drive to operate a ball screw, which in turn will cause the anti-rotated ball to translate to the desired position. The irreversible characteristic of the worm gear automatically locks the position of the ball screw nut.

3) Support/Position Plates - Simple machined guide plates were designed for both supporting and positioning the lower end of the CA and lower end of the lower shroud tube. Access to adjust or replace these plates is obtained by their close proximity to the vessel ledge ring and retained by a washer and deformed pin combination that precludes the use of threaded fasteners in sodium.

The CRD test article assembly is provided with upper and lower shroud tubes, which are prototypic in function and design to the CRBRP plant units' shroud tubes.

The upper shroud tube is mounted on a support ledge in the vessel head adapter and extends downward 213.47 inches where it forms a slip connection socket for the lower shroud tube. The vessel head adapter mounting provides capability for positioning and alignment of the shroud tubes relative to the control assembly. The upper shroud will be fabricated from Type 316 SS pipe. In the CRBRP, this shroud tube will be fabricated from Inconel 718.

The lower shroud tube is mounted in the lower shroud tube guide plate with its lower end fixed at reactor baseline elevation (-342.15 inches). From this elevation, the lower shroud tube extends upward 128.5 inches to its slip fit connection with the upper shroud tube. The lower shroud tube guide plate provides positioning and alignment of the shroud tube assembly to ensure a prototypic clearance envelope around the driveline and to maintain a sodium inlet annulus which, in conjunction with exit ports in the upper shroud tube will ensure prototypic sodium flow through the shroud tubes. The lower shroud tube will be fabricated from Inconel 718.

C. Sodium Supply System and Auxiliary Equipment

The sodium supply for the subsystems test utilizes both the GPL-2 and the SASS described earlier. Argon cover gas supply for this test is provided by the

Argon Supply System. The piping system for the test vessels includes valve flow meters and expansion tanks. Trace heaters and a control system are provided for the vessels, piping and auxiliary equipment.

D. Stator Cooling System

A closed-loop system provides cooling air to the CRDM stator during testing. The major components of the system are:

1) A large compressor, operating intermittently, to provide a static pressure of 90 psig to the closed loop

2) A cooler/dryer to cool the air to 60°F and remove moisture

3) A booster compressor (and a spare on standby) to provide the 20 psig pressure increase necessary to pump the air around the loop (water-cooled after cooler will remove the heat of compression and supply air at 110 psig and 70°F)

4) A second cooler/dryer unit to further cool the air to 60°F

5) A manifold to feed air at 100 psig and 60°F to each CRDM (the inlet line to each CRDM contains a Metal Tube rotameter flowmeter and a Cuno particulate air filter)

The system is designed to be able to provide cooling air to all three CRDMs simultaneously or in any desired combination with a constant mass flow rate.

SCRS Test Facilities

The SCRS will be tested at the GE-FBRD Breeder Test Facility (BTF) in San Jose, California which can accommodate the sodium testing units and the necessary ancillary equipment. The BTF consists primarily of the System Test Loops (4) and the Drive Test Loop (1).

A. SCRS System Test Loop Facilities

The SCRS System Test Loops (STL's) will be used for cyclic scram testing and real time testing.

The SCRS is mounted at the top of the liquid sodium vessel which is 44 feet tall and 18 inches in diameter. The vessel was built using standard 18 inch pipe with a normal wall thickness of 0.375 inches. The total internal volume of the vessel is approximately 70 cubic feet. The normal liquid sodium level is 87 inches below the top of the vessel. There are two level probes for the vessel sodium level. The probes sound an alarm whenever the sodium level falls outside the range of 62 to 112 inches from the top of the vessel.

Near the bottom of the liquid sodium vessel, a built-in socket and pressure plenum accommodates the control assembly as in the reactor core. Liquid sodium is directed into the plenum region from an EM pump. The plenum provides flow path simulation and a differential pressure in a downward direction on the control rod. The liquid sodium exits the vessel from both the bottom of the vessel and an opening in the side of the vessel beneath the sodium level through flow control valves back to the EM pump. Argon cover gas over the liquid sodium surface in the vessel is pressurized at 0 to 12 psig. Over-pressure protection is provided for all argon volumes associated with the STLs by a 4 to 15 psig adjustable pressure relief valve, 50 psig rupture disks and pressure indicators with adjustable alarm points.

The argon supply system is provided with pressure regulators and pressure relief valves at the source. To protect against failure of pressure regulators, each cover gas space associated with the STLs is protected with rupture disks.

The maximum sodium pressure during operation is expected to be $\sim$130 psig at the outlet of the EM pump. Nominal pump inlet pressure is $\sim$11 psig and the outlet pressure is $\sim$135 psig at 100% flow. The inlet pressure of the vessel is normally $\sim$117 psig at 100% flow psig and the outlet pressure is $\sim$20 psig. Nominal flow through the pump is 175 gpm at 1000°F. The return flow to the pump from the vessel is approximately 42 gpm from the side of the vessel and 133 gpm from the bottom of the vessel. The total flow is based on 71,500 lb/hr at 1000°F.

Prior to filling with sodium, the system is purged with argon. The argon filled piping and vessel are then pre-heated (with trace heaters) to a surface temperature between 350 to 400°F. Sodium in the storage tank is heated (with trace heaters) to a temperature between 250 to 300°F. The sodium fill operation begins by opening the test loop drain and isolation valves and pressurizing the sodium storage tank cover gas. As sodium enters the piping and vessel it will displace the system argon. Manual operator action to vent the vessel cover gas will maintain maximum system pressure below 25 psig during the fill operation. After the sodium fill operation is completed, the system drain and isolation valves are closed and the vessel cover gas pressure is adjusted to just above atmospheric pressure (0 to 2 psig). The system will then be uniformly heated by increasing the trace heating input along with initiation of operation (at reduced flow) of the EM pump. Heat-up rate is limited to 75°F/hr.

B. Drive Test Loop (DTL)

This facility is basically the same as the STLs except that it is smaller and its internals have been designed to accommodate component test article actuators. DTL-1 will be used exclusively for testing of the latch assembly.

C. Latch Test Rig

The latch test rig is designed to accept prototype latch assemblies and is instrumented to measure latch actuation forces, release times, applied loads and latch position. It is designed to fit into DTL-1 and STL-2, where the prototypic reactor environment (except for radiation and vibration) will be simulated.

D. Driveline Lower Bellows Test Rig

A lower driveline bellows unit consists of bellows between the driveshaft and sensing tube and bellows between the sensing tube and tension rod. The test actuator is designed to accept two prototype lower driveline bellows units. It is designed to fit into STL-2 where the prototypic bellows environment is simulated. The test actuator will cycle both bellows units through their prototypic design stroke and design cyclic lifetime.

E. Pneumatic Valve/Cylinder Test Rig

This test facility will be designed to accept the pneumatic valve/cylinder test articles. Provisions will be made to supply the rig with an uninterruptible power supply, argon pressure and instrumentation to monitor the tests. The main feature of the rig is the tension rod simulation and controlled atmosphere that enables the test articles to be subjected to conditions simulating those of the reactor. This test facility contains two test rigs and both utilize the automatic data aquisition system for test control and data recording.

F. Argon Pressure System

The low pressure argon is supplied from liquid argon tanks. It supplies the sodium service system storage tank, surge tank and equilibration device argon at approximately 50 psig. The pressure is reduced to approximately 25 psig for the test loop cover and purge gas. The environmental chamber utilized for installation and removal of test articles is also supplied by the low pressure argon system.

The high pressure system supplies approximately 300 psig argon to the environmental control system for each test SCRS. The environmental control system supply pressure is branched into three lines supplying approximately 5 psig to the SCRDM housing, 60 psig to the SCRDM driveline and 220 psig to the SCRDM latch cylinder.

G. Sodium Storage Facility

The sodium storage facility consists of two 2600 gallon storage tanks that each provide sodium for two system test loops and one drive test loop. Each of the tanks is connected to a sodium service system that consists of cold traps, plugging indicators, sodium sampling stations and means for determining the impurity level in the test loops. Cover gas is provided by the argon system and trace heaters are affixed to each tank to provide heat to melt the sodium so that it can be transferred to the test vessels.

H. Data Acquisition System

The operation of the test facilities and the articles being tested will be monitored by a data acquisition system that provides for continuous on-line data acquisition, data processing and control. The computer can gather both analog and digital data on magnetic tape or disc memories. The high speed analog input channels can take high level (1-10 volts) measurement from as many as 128 points every 10 milliseconds. These channels can be used for measuring sodium pressure, sodium flow rate, argon pressure, valve current, LVDT, load cells, surge tank level and argon flow rates. Low speed analog input channels can take 800 low level measurements at two points per second with a printer, 15 points per second for alarm scanning. These measurements can include temperature, motor current, brake current and sodium purity.

Supplement 1 to

Appendix C

Failure Mode and Effects Analysis

for

CRBRP Shutdown System

TABLE C.S. 1-1

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Reactor Vessel Sodium Level PPS Input

P/N: Plant Protection System (PPS) SDD-99

PREPARED BY: P. G. Woods

DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1	1	Level Sensor (3 units)	2 winding transformer in thimble to sense sodium level and convert it to a mV signal inversely proportional to level.	(1) Fails to low or zero output	Open circuitry in either winding	2	5/2	(1)Low or zero signal implies high sodium level which prevents comparator trip. Failure indicated by Interchannel Comparison Unit.		Failure prevents trip of 1 channel. System essentially reconfigured into 2/2. Another failure could cause thi[s] RSS not to trip.
				(2) Fails to high output	High excitation or external voltage applied	1	3/2	(2) High signal implies low sodium level. 1 PPS comparator trips. Failure indicated by interchannel comparison and PPS status board. Safe Failure.		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
	2	Sensor Power Supply	1.8 KHz current supply source for level probe	(1) Fails to low or zero current	Internal supply failure (e.g., output transformer failure, output capacitor short)	4	5/1	(1) Same as 1.1-1		
				(2) Fails to high current	Short circuit through test switch	2	3/1	(2) Same as 1.1-2 Safe Failure		
	3	Sensor Wiring	Transmits sensor signal to sensor transmitter/inverter.	(1) Fails to open circuit	Loose or severed wire	2	5/1	(1) Same as 1.1-1		
				(2) Fails to short circuit	Insulation failure	2	5/1	(2) Same as 1.1-1		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	represents criticality to redundant component (A) and criticality to system (B)

6487-1

Amend. 25
Aug. 1976

TABLE C.S.1-1

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Reactor Vessel Sodium Level PPS Input (Continued)				P/N: Plant Protection System (PPS) SDD-99				PREPARED BY: P. G. Woods		DATE
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1	4	Level Transmitter	Inverts mV signal so that increasing signal corresponds to increasing level and converts mV signal to standard PPS output	(1) Fails to low or zero current	Internal amplifier failure	4	3/1	(1) Low or zero signal implies low sodium level. 1 PPS comparator trips. Failure indicated by interchannel comparison and PPS status board. Safe failure.		Same as 1.1-2
				(2) Fails to high current	Internal failure or application of hot short circuit to transmitter output loose or severed wire	2	5/1	(2) High signal prevents channel trip on low sodium level. Failure indicated by interchannel comparison.		Same as 1.1-1
	5	Sensor Wiring	Transmits inverted signal from transmitter to control room	(1) Fails to open circuit	Loose or broken wire	2	3/1	(1) Same as 1.4-1 Safe failure.		Same as 1.1-2
				(2) Fails to short circuit	Insulation failure or external short circuit	2	3/1	(2) Same as 1.4-1 Safe failure.		Same as 1.1-2

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-2

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
PPS Sodium Flow Input	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	* CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
2	1	Permanent Magnet (1 per loop)	Creates magnetic field through which sodium flows	(1) Demagnetized	Physical shock, application of voltage or current	1	3/3	(1) Low signal in all 3 channels causes comparator trips and reactor scram.		
				(2) High field	Application of voltage or current	1	5/3	(2) Depending on magnitude, causes trip on high signal or causes loss of calibration in direction to retard trip on low flow.		
	2	Electrode (3 per loop)	Detects voltage induced by permanent magnet proportional to sodium flow	(1) Fails to low or zero output	Electrode connection to pipe loosens or is broken	2	5/1	(1) Failure would cause incorrect (low) input to comparator. Failure could cause Flux-Flow or Primary-Intermediate Flow trip, or could retard channel comparator trip for channel specific events.		
				(2) Fails to high output	Application of external source with proper characteristics to flow detector.	1	5/1	(2) Failure would cause incorrect (high) input to comparator. Failure could cause Flux-Flow or Primary-Intermediate Flow trip or could retard channel comparator trip.		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3 2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-2

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
PPS Sodium Flow Input (Continued)	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
2	3	Detector Wiring	Transmits detector signal to signal transmitter and control room.	(1) Fails to open circuit	Wire loose or severed	2	5/1	(1) Same as 2.2-1		
				(2) Fails to short circuit	Insulation failure	2	5/1	(2) Same as 2.2-1		
	4	Flow Transmitter	Amplifies and converts detector signal to standard PPS input signal.	(1) Fails to low or zero circuit	Internal failure (e.g., failed transister, capacitor)	2	5/1	(1) Same as 2.2-1		
				(2) Fails to high current	Internal failure	1	5/1	(2) Same as 2.2-2		
	5	Power Supply	Supplies 25 V. DC power for instrumentation	(1) Fails to low or zero voltage	Internal failure (e.g., short circuit, open circuit, blown fuse)	4	5/1	(1) Same as 2.2-1		
				(2) Fails to high voltage	Transformer primary winding short circuit	2	5/1	(2) Same as 2.2-2		

6487-2

TABLE C.S.1-3

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Pump Electric Power Sensor — P/N: Plant Protection System (PPS) SDD-99 — PREPARED BY: P.G. Woods — DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	* CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
3	1	Potential Transformer	Senses 13.8KV bus voltage	(1) Fails to low or zero voltage	Transformer open circuited.	2	3/1	(1) Single channel comparator trips. Indicated by inter-channel comparison Safe Failure		One channel tripped, system reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to high voltage	Primary to secondary winding short circuit or short circuit across primary winding	1	5/1	(2) Failure prevents single channel comparator trip. Indicated by periodic testing. Bus voltage would normally go to 0 in loss of power event which would trip channel comparator even with short circuit applied.		Failure prevents trip of 1 channel. System essentially reconfigured into 2/2. Safe as long as no other failures occur
	2	Wiring from Potential Transformer to UV relay rack	Transmits sensed voltage signal to under-voltage relay.	(1) Fails to open circuit	Loose or broken wire	2	3/1	(1) Same as 3.1-1 Safe failure		Same as 3.1-1
				(2) Fails to short circuit	Insulation failure	2	3/1	(2) Same as 3.1-1 Safe failure		Same as 3.1-1
	3.	Undervoltage Relay (including auxiliary relays)	Determines whether bus voltage has dropped below a given set point. Auxiliary relays provide normally open contracts.	(1) Output contact permanently open	Failed UV relay	2	3/1	(1) Same as 3.1-1 Safe failure		Same as 3.1-1
				(2) Output contact permanently shorted	Output contacts welded	2	5/1	(2) Failure prevents single channel comparator trip Indicated by periodic testing		Same as 3.1-2

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME, HOWEVER WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

Amend. 25
Aug. 1976

TABLE C.S.1-3

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Pump Electric Power Sensor				P/N: Plant Protection System (PPS) SDD-99				PREPARED BY: P. G. Woods		DATE: 9/3/74
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
3	4	Wiring from UV relay panel to control room.	Transmits open/closed contact signal to PPS	(1) Fails to open circuit.	Loose or broken	2	3/1	(1) Same as 3.1-1 Safe Failure		Same as 3.1-1
				(2) Fails to short circuit	Insulation failure	2	5/1	(2) Same as 3.3-2		Same as 3.1-2

Amend. 25
Aug. 1976

6487-2

TABLE C.S.1-4

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Compensated Ion Chamber Nuclear Input	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
4	1	Compensated Ion Chamber	Converts neutron flux measurement to electrical signal	(1) Fails to low or zero output	Deteriorating detector Loose or broken wire Loss of thermalizing graphite block.	4	5/2	(1) Failure prevents comparator trip. Indicated by Interchannel comparison.		Failure prevents trip of 1 channel. System essentially reconfigured into 2/2. Safe as long as no other failure occurs.
				(2) Fails to high output	Mechanical movement inside detector. Insulation deteriorates	2	3/2	(2) Single channel comparator trips. Interchannel comparison and PPS status board. Safe failure.		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
	2	Wiring	Transmits signal from sensor thru head compartment to transmitter	(1) Fails to open circuit	Loose or broken wire	2	5/2	(1) Same as 4.1-1		Same as 4.1-1
				(2) Fails to short circuit	Insulation failure	2	5/2	(2) Same as 4.1-1		Same as 4.1-1
	3	Compensated Ion Chamber Transmitter	Amplifies and converts detector signal to standard PPS signal	(1) Fails to low or zero voltage	Internal failure (e.g. transistor failure)	2	5/1	(1) Same as 4.1-1		Same as 4.1-1
				(2) Fails to high voltage	Internal failure (e.g. transistor failure)	1	3/1	(2) Same as 4.1-2 Safe failure.		Same as 4.1-2
	4	Compensating Voltage Power Supply	Supplies compensating voltage to ion chamber	(1) Fails to low or zero voltage	Internal failure (e.g. transformer or rectifier failure)	2	3/1	(1) Channel reads high. Same as 4.1-2 Safe failure.		Same as 4.1-2
				(2) Fails to high voltage	Transformer winding short circuit	1	5/1	(2) Channel reads low Same as 4.1-1.		Same as 4.1-1

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487 1

TABLE C.S.1-4

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS (Continued) Compensated Ion Chamber Nuclear Input	P/N Plant Protection System (PPS) SDD-99	PREPARED BY P. G. Woods	DATE 9/3/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
4	5	Low Voltage Power Supply for Nuclear Electronics	Supplies ±15 V DC	(1) Fails to low or zero voltage	Internal failure (e.g. transformer, reactifier)	4	5/1	(1) Channel reads low. Same as 4.1-1		Same as 4.1-1
				(2) Fails to high voltage	Transformer primary winding short circuit	2	3/1	(2) Same as 4.1-2 Safe Failure.		Same as 4.1-2

6487-2

Amend. 25
Aug. 1976

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OF ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

TABLE C.S.1-5

FAILURE MODE AND EFFECTS ANALYSIS CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Fission Chamber Nuclear Input
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
5	1.	Fission Chamber	Converts neutron flux measurement to electrical signal	(1) Fails to low or zero output	(1) Counter electrode or connecting wire breaks	4	5/2	(1) Failure prevents comparator trip. Indicated by Interchannel Comparison.		Failure prevents trip of 1 channel. System reconfigured into 2/2. Safe as long as no other failures occur.
				(2) Fails to high output	(2) Mechanical movement or insulation deterioration	2	3/2	(2) Single Channel Comparator trips. Indicated by Interchannel Comparison and PPS status board. Safe failure		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
	2.	High Voltage Power Supply for Fission Chamber	Provides high voltage necessary for neutron interaction in fission chamber	(1) Fails to low or zero voltage	(1) Internal failure (e.g. rectifier, fuse, or transformer failure)	4	5/1	(1) Same as 5.1-1		Same as 5.1-1
				(2) Fails to high voltage	(2) Transformer primary winding short circuit	2	3/1	(2) Same as 5.1-2		Same as 5.1-2
	3.	Wiring from Fission Chamber to Preamplifier	Transmits low level signal from detector to preamplifier	(1) Fails to open circuit	(1) Loose or broken wire	2	5/2	(1) Same as 5.1-1		Same as 5.1-1
				(2) Fails to short circuit	(2) Insulation failure	2	3/2	(2) Same as 5.1-2		Same as 5.1-2
				(3) Fails to ground	(3) Insulation failure	2	5/1	(3) Same as 5.1-1		Same as 5.1-1
	4.	Pre-amplifier	Amplifies low level signal to limit noise pick-up problems	(1) Fails to low or zero output	(1) Internal failure (e.g. resistor, transmitor)	2	5/1	(1) Same as 5.1-1 except only counting and log MSV ranges are affected		Same as 5.1-1

PROBABILITY NUMBERS	DEFINITIONS
5 4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3 2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-5

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Fission Chamber Nuclear Input (Cont.)	P/N: Plant Protection System (PPS) SDD-99	PREPARED BY: P. G. WOODS	DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
5	4.			(2) Fails to high output	(2) Internal failure (e.g. transistor)	1	3/1	(2) Same as 5.1-2 except that trip occurs only in counting and log MSV ranges.		
				(3) D.C. output fails low or to zero	(3) Internal failure (e.g. resistor, capacitor)	2	5/1	(3) Same as 5.1-1 except only power range channel is affected		
	5.	Wiring from Pre-amplifier to Nuclear Instrumentation Cabinet	Transmits signal to main nuclear instrumentation cabinet	(1) Pulse wiring fails to open circuit	(1) Loose or broken wire	2	5/1	(1) Same as 5.4-1		
				(2) Pulse wiring fails to short circuit	(2) Insulation failure	2	5/1	(2) Same as 5.4-1		
				(3) D.C. wiring fails to open circuit	(3) Loose or broken wire	2	5/1	(3) Same as 5.1-1 except only power range is affected		
				(4) D.C. Wiring fails to short circuit	(4) Insulation failure	2	5/1	(4) Same as 5.5-3		
	6.	Wide Range Counting Range Electronics	Amplifies and converts sensor signal to standard PPS input	(1) Fails to low or zero input	(1) Internal failure (e.g. transistor)	4	5/1	(1) Same as 5.1-1 but only counting range is affected		
				(2) Fails to high output	(2) Internal failure (e.g. transistor)	2	3/1	(2) Same as 5.1-2 but only counting range is affected		
	7.	Wide Range Log MSV Range Electronics	Amplifies and converts sensor signal to standard PPS input	(1) Fails to low or zero output	(1) Internal Failure (e.g. transistor)	4	5/1	(1) Same as 5.1-1 but only log MSV range is affected		
				(2) Fails to high output	(2) Internal failure (e.g. transistor)	2	3/1	(2) Same as 5.1-2 but only log MSV range is affected		
	8.	Power Supply	Provide ± 15 VDC for electronics in all 3 ranges	(1) Fails to low or zero voltage	(1) Internal failure (e.g. transformer rectifier, fuse)	4	5/1	(1) Same as 5.1-1		
				(2) Fails to high voltage	(2) Transformer primary winding short circuit	2	3/1	(2) Same as 5.1-2 safe failure		
	9.	Wiring from Nuclear Instrumentation Cabinet to Control Room	Transmit 1-5 VDC signal to PPS comparators	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 5.1-2 safe failure		
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 5.1-2 safe failure		

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-6

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Primary Loop Inlet Plenum Pressure Input	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	* CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
6	1.	Pressure Sensor (2 Per Loop)	Sensor pressure through bellows	(1) Rupture of bellows	(1) Defective or worn bellows	2	5/2	(1) Sodium will plug in cooler capillary tube line. Sensor will not respond to changes in pressure. Auctioneer selects high signal from 2 inputs. Failure may prevent trip if line plugs within normal pressure range. Indicated by Interchannel Comparison.		
				(2) Bellows fail to move freely	(2) Work or temperature hardening of bellows	2	5/2	(2) Slow or no response to changes in pressure. Failure may prevent trip. Indicated by Interchannel Comparison		
	2.	Capillary Tube	Transmits pressure from sensor to transducer	(1) Capillary tube ruptures	(1) Defective tube, wear, external force	1	3/2	(1) Loss of pressure driving signal. Auctioneer selects signal from redundant sensor. Safe failure.		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-6

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS (Cont.) Primary Loop Inlet Plenum Pressure Input				P/N Plant Protection System (PPS) SDD-99				PREPARED BY P. C. Woods		DATE
ITEM NO.	PART, ASSEMBLY OR PROCESS *NUMBER*	PART, ASSEMBLY OR PROCESS *NAME*	PART, ASSEMBLY OR PROCESS *FUNCTION*	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTER"ACINGS AND REMARKS
6	2.			(2) Capillary tube static failure	(2) Pinched tube or frozen Nak	1	5/2	(2) Sensor will not respond to changes in pressure. Same results as 6.1-2.		
	3.	Strain Gauge Transducer	Converts pressure signal to low level electric signal (resistive measurement)	(1) Fails to low or zero output	(1) Internal failure	2	3/2	(1) Auctioneer selects signal from redundant sensor. Safe failure.		
				(2) Fails to high output	(2) Crack in pressure plate	1	5/2	(2) Single comparator channel trip prevented. Failure indicated by Interchannel Comparison.		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
	4.	Wiring from Transducer to Transmitter (4 leads)	Transmits signal from transducer to transmitter	(1) Fails to zero output	(1) Broken or loose wire. Insulation failure.	2	3/1	(1) Same as 6.3-1 Safe failure.		
	5.	Statham Converter Transmitter	Converts resistive measurement to standard PPS input	(1) Fails to low or zero output	(1) Internal failure	2	3/1	(1) Same as 6.3-1 Safe failure		
				(2) Fails to high output	(2) Internal failure	1	5/1	(2) Same as 6.3-2		Same as 6.3-2
	6.	Wiring from Converter Transmitter to Control Room	Transmits signal to PPS equipment	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 6.3-1 Safe failure		
				2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 6.3-1 Safe failure		
	7.	Power Supply for Statham Converter Transmitter	Provides DC power for converter transmitter	(1) Fails to low or zero voltage	(1) Internal failure	2	3/1	(1) Same as 6.3-1 Safe failure		
				(2) Fails to high voltage	(2) Transformer winding short circuit	4	5/1	(2) Same as 6.3-2		Same as 6.3-2

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-7

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Sodium Pump Speed Input (Primary and Intermediate)
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
7	1	Pulsing Digital Tachometer (including toothed gear on pump shaft and 3 EM proximity sensors per loop)	Changing reluctance of rotating gear teeth on pump shaft is measured by EM proximity sensor and converted to electrical signal	(1) Loss of one or more gear teeth	Mechanical failure or external force	1	5/1	(1) Affected pump speed sensor will indicate low. Failure may trip channel comparator or will be indicated by interchannel comparison. Failure may prevent trip if coupled with change in corresponding loop speed (i.e., if primary speed indicates low and intermediate speed is low, comparator will not trip as it should).		
				(2) Foreign material in air gap between sensor and gear	Dirt, metal fillings buildup, short circuiting two gear teeth.	2	5/1	(2) Affected pump speed may read high or low depending on permeability of material. Results same as 7.1-1.		
				(3) EM proximity sensor fails to low or zero output	Internal failure	2	5/1	(3) Same as 7.1-1.		
				(4) EM proximity sensor fails to high output	Internal failure	1	5/1	(4) Affected pump speed sensor will indicate high. Same results as 7.1-1.		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME, HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

Amend. 25
Aug. 1976

TABLE C.S.1-7

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Sodium Pump Speed Input (Primary and	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
7	2	Wiring from sensor to transmitter	Transmit electrical signal from sensor to transmitter	(1) Fails to open circuit	Loose or broken wire	2	3/1	(1) Affected pump speed sensor will indicate zero. Single comparator channel trip. Safe failure.		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to short circuit	Insulation failure	2	3/1	(2) Same as 7.2-1		Same as 7.2-1
	3	Sodium Pump Speed Transmitter	Amplifies and converts digital speed signal to standard analog input for PPS	(1) Fails to low or zero output	Internal failure	2	5/1	(1) Same as 7.1-1		
				(2) Fails to high output	Internal failure	1	5/[illegible]	(2) Same as 7.1-4		
	4	Wiring from transmitter to control room	Transmits analog signal from transmitter to control room	(1) Fails to open circuit	Loose or broken wire	2	3	(1) Same as 7.2-1.		Same as 7.2-1
				(2) Fails to short circuit	Insulation failure	2	3/1	(2) Same as 7.2-1.		Same as 7.2-1
	5	Power Supply for Transmitter	Provides power for transmitter electronics	(1) Fails to low or zero output	Internal failure	4	5/1	(1) Same as 7.1-1		
				(2) Fails to high output	Internal failure	2	5/1	(2) Same as 7.1-4		

Amend. 25
Aug. 1976

6487-2

TABLE C.S.1-8

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Steam Mass Flow Rate Input
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	* CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
8	1.	Differential Pressure Transducer	Senses differential pressure across venturi flow tube and converts it to an electrical signal	(1) Fails to low or zero output	(1) Internal failure	2	5/2	(1) Affected sensor will indicate low steam flow. Failure may trip channel comparator or will be indicated by Interchannel Comparison. Failure may prevent comparator trip if corresponding decrease in feedwater flow occurs.		
				(2) Fails to high output	(2) Internal failure	1	5/2	(2) Affected sensor will indicate high steam flow. Results are the same as 8.1-1 except that comparator trip may be prevented if a corresponding increase in feed-water flow occurs.		
	2.	Temperature Sensor	Senses steam temp. to compen-sate steam mass flow rate	(1) Fails to low or zero output	(1) Open circuit in temp. sensor	2	5/1	(1) Same as 8.1-1.		
				(2) Fails to high output	(2) Application of hot short circuit	1	5/1	(2) Same as 8.1-2.		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-8

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Steam Mass Flow Rate Input (Cont.)	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
8	3.	Pressure Sensor	Senses steam pressure to compensate steam mass flow rate	(1) Fails to low or zero output	(1) Rupture in press. sensor	2	5/2	(1) Same as 8.1-2.		
				(2) Fails to high output	(2) Special internal failure	1	5/2	(2) Same as 8.1-1.		
	4.	Wiring From Transducer to Transmitter	Transmit transducer signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Single comparator channel trip. Indicated by Interchannel Comparison or PPS Status board. Safe failure.		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 8.4-1 Safe Failure		Same as 8.4-1
	5.	Wiring from Temp. Sensor to Transmitter	Transmits temp. signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	5/1	(1) Same as 8.1-1.		
				(2) Fails to short circuit	(2) Insulation failure	2	5/1	(2) Same as 8.1-1.		
	6.	Wiring From Pressure Sensor to Transmitter	Transmits pressure signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	5/1	(1) Same as 8.1-2.		
				(2) Fails to short circuit	(2) Insulation failure	2	5/1	(2) Same as 8.1-2.		

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-8

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Steam Mass Flow Rate Input (Cont.)
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: R. G. Woods
DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
8	7.	Steam Flow Transmitter	Compensates differential press. signal for temp. and pressure Amplifies and converts signal to standard PPS input.	(1) Fails to low or zero output	(1) Internal failure	2	5/2	(1) Same as 8.1-1.		
				(2) Fails to high output	(2) Internal failure	1	5/2	(2) Same as 8.1-2.		
	8.	Wiring From Transmitter to Control Room	Transmits differential pressure signal from transmitter to control room	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 8.4-1 safe failure.		Same as 8.4-1
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 8.4-1 safe failure.		Same as 8.4-1
	9.	Steam Flow Transmitter Power Supply	Provides power to differential pressure transmitter	(1) Fails to low or zero output	(1) Internal failure	4	5/1	(1) Same as 8.1-1.		
				(2) Fails to high output	(2) Transformer winding short circuit	2	5/1	(2) Same as 8.1-2.		

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-9

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Feedwater Mass Flow Rate Input | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE:

ITEM No.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
9	1.	Differential Pressure Transducer	Senses differential pressure across venturi flow tube and converts it to an electrical signal	(1) Fails to low or zero output	(1) Internal failure	2	5/2	(1) Affected sensor will indicate low feedwater flow. Failure may trip channel comparator or will be indicated by Interchannel Comparison. Failure may prevent comparator trip if corresponding decrease in steam flow occurs.		
				(2) Fails to high output	(2) Internal failure	1	5/2	(2) Affected sensor will indicate high feedwater flow. Results are same as 9.1-1 except that comparator trip may be prevented if a corresponding increase in steam flow occurs.		
	2.	Temperature Sensor	Senses steam temperature to compensate steam mass flow rate	(1) Fails to low or zero output	(1) Open circuit in temperature circuit	2	5/1	(1) Same as 9.1-1.		
				(2) Fails to high output	(2) Application of hot short circuit	1	5/1	(2) Same as 9.1-1.		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-9

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Feedwater Mass Flow Rate Input (Cont.) | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTIO	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
9	3.	Wiring From Tranducer to Transmitter	Transmits transducer signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Single comparator channel trip. Indicated by Interchannel Comparison and PPS Status Board. Safe failure.		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 9.3-1 safe failure.		Same as 9.3-1
	4.	Wiring From Temperature Sensor to Transmitter	Transmits temperature signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	5/1	(1) Same as 9.1-1		
				(2) Fails to short circuit	(2) Insulation failure	2	5/1	(2) Same as 9.1-1		
	5.	Feedwater Flow Rate Transmitter	Compensates differential pressure signal for temperature. Amplifies and converts signal to standard PPS input	(1) Fails to low or zero output	(1) Internal failure	2	5/1	(1) Same as 9.1-1		
				(2) Fails to high output	(2) Internal failure	1	5/1	(2) Same as 9.2-1		
	6.	Wiring from Transmitter to Control Room	Transmits differential pressure signal from transmitter to control room.	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 9.3-1 safe failure		Same as 9.3-1
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 9.3-1 safe failure		Same as 9.3-1
	7.	Transmitter Power Supply	Provides power to differential pressure transmitter	(1) Fails to low or zero output	(1) Internal failure	4	5/1	(1) Same as 9.1-1		
				(2) Fails to high output	(2) Transformer winding short circuit	2	5/1	(2) Same as 9.1-2		

6487-2

TABLE C.S.1-10

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Steam Drum Level Input	Plant Protection System (PPS)-SDD 99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	* CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
10	1	Differential Pressure Column	Used as static water column to measure differential pressure	(1) Column fails to low water level	(1) Operator maloperation (inadvertent drainage of column). Column leak	2	5/2	(1) Steam drum level appears high and prevent single comparator channel trip on low steam drum level.		Failure prevents trip of 1 channel. System essentially reconfigured into 2/2. Safe as long as no other failures occur.
	2	Differential Pressure Transducer	Senses differential pressure between static water column and steam drum level and converts it to electrical indication of steam drum level	(1) Fails to low or zero output	(1) Strain gauge failure	2	3/2	(1) Single comparator channel trip. Safe failure		One channel tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to high output	(2) Cracked strain gauge plate	1	5/2	(2) Same as 10.1-1		Same as 10.1-1
	3	Pressure Sensor	Senses steam drum pressure to compensate steam drum level	(1) Fails to low or zero output	(1) Rupture in pressure sensor	2	3/2	(1) Steam drum level appears low. Single comparator channel trip. Safe failure.		Same as 10.2-1
				(2) Fails to high output	(2) Special internal failure	1	5/2	(2) Same as 10.1-1		Same as 10.1-1

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-10

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Steam Drum Level Input (cont)	Plant Protection System (PPS)-SDD 99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
10	4	Wiring from transducer to trans-mitter	Transmits transducer signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 10.2-1 Safe failure		Same as 10.2-1
				(2) Fails to short circuit	(2) Insulation fail-ure	2	3/1	(2) Same as 10.2-1 Safe failure		Same as 10.2-1
	5	Wiring from pressure sensor to transmitter	Transmits pressure signal to transmitter	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 10.3-1 Safe failure		Same as 10.2-1
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 10.3-1 Safe failure		Same as 10.1-1
	6	Steam drum level trans-mitter	Compensates steam drum level for steam drum pressure. Amplifies and con-verts sig-nal to standard PPS input	(1) Fails to low or zero output	(1) Internal failure	2	3/1	(1) Same as 10.2-1 Safe failure		Same as 10.2-1
				(2) Fails to high output	(2) Internal failure	1	5/1	(2) Same as 10.1-1		Same as 10.1-1
	7	Wiring from transmitter to control room	Transmits steam drum level from transmitter to control room	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 10.3-1 Safe failure		Same as 10.2-1
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 10.3-1 Safe failure		Same as 10.2-1
	8	Steam drum level power supply	Provides power to transmitter electronics	(1) Fails to low or zero output	(1) Internal failure	4	3/1	(1) Same as 10.3-1 Safe failure		Same as 10.2-1
				(2) Fails to high output	(2) Transformer wind-ing short circuit	2	5/1	(2) Same as 10.1-1		Same as 10.1-1

8487-2

Amend. 25
Aug. 1976

TABLE C.S.1-11

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Comparator | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
11	1.	Primary Comparator	Compares input signal with fixed or calculated set point. When comparison is unfavorable, comparator is tripped to zero output. When comparison is favorable, output is positive (reset).	(1) Fails to tripped output	(1) Open or short circuited output or internal failure	2	3/1	(1) Comparator transmits trip signal to 1 channel of each of 3 logic trains. Failure indicated by PPS Status Board. Safe failure		One logic train tripped System reconfigured into 1/2. Unscheduled outage if another failure occurs
				(2) Fails to reset output	(2) Internal Comparator failure	1	5/1	(2) Disables 1 channel in each of 3 logic trains. Failure indicated by periodic testing.		Failure prevents trip of 1 logic train. System reconfigured into 2/2. Safe as long as no other failures occur.
	2.	Power Supply	Supplies DC voltage to comparators	(1) Fails to low or zero voltage	(1) Internal Failure (e.g. fuse, rectifier)	4	3/1	(1) Same as 11.1-1 except all 24 of A, B, or C comparators fail safe failure. Indicated by PPS Status Board.		
				(2) Fails to high voltage	(2) Transformer primary winding short circuit.	2	3/1	(2) Overvoltage monitor trips power supply off. results as 11.1-1. Safe failure		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME, HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

Amend. 25
Aug. 1976

TABLE C.S.1-11

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Primary Comparator (Continued)	Plant Protection System (PPS) SDD-99	P. G. Woods	

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
11	3.	Primary Comparator Bypass Circuit	Provides input to bypass comparator	(1) Fails to bypass (no voltage)	(1) Open bypass circuit	2	3/1	(1) No bypass of comparator. A false scram may result should another failure occur.		
				(2) Fails to unbypass (bypassing voltage inadvertently applied to comparator)	(2) Total short circuit around bypassing switches and permissives	1	5/1	(2) Failure prevents comparator trip. Failure indicated by bypass light.		

6487-2

TABLE C.S.1-12

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Comparator | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
12	1.	Secondary Comparator	Compares input signal with fixed or calculated set point. When comparison is unfavorable, comparator trips to zero output When comparison is favorable, output is positive (reset).	(1) Fails to tripped output	(1) Open or short circuited output or internal failure	2	3/1	(1) Comparator outputs trip signal to 1 of 3 general coincidence logic channels. Failure annunciated by PPS status board. Safe failure		One of 3 general coincidence logic trains tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to reset output	(2) Internal comparator failure	1	5/1 ●	(2) 1 out of 3 general coincidence logic channels for subsystem cannot trip. Failure indicated by periodic testing.		Failure prevents trip of one general coincidence logic trains. System essentially reconfigured into 2/2. Safe as long as no other failures occur.
	2.	Power Supply	Supplies DC voltage to secondary comparators	(1) Fails to low or zero voltage	(1) Internal failure (e.g. fuse or rectifier	4	3/1	(1) Same as 12.1-1 except that all comparators connected to power supply are affected. Safe failure		Same as 12.1-1
				(2) Fails to high voltage	(2) Transformer primary winding short circuit	2	3/1	(2) Overvoltage monitor trips power supply off. Results same as 12.2-1. Safe failure		Same as 12.1-1

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487 1

TABLE C.S.1-12

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Comparator (Continued)

P/N: Plant Protection Systems (PPS) SDD-99

PREPARED BY: G. Woods

DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
12										
	3.	Secondary Comparator Bypass Circuit	Provides input to bypass comparator	(1) Fails to bypass (no voltage)	(1) Open bypass circuit	2	3/1	(1) No bypass of comparator. A false scram may result should another failure occur.		Same as 12.1-1
				(2) Fails to unbypass (bypassing voltage inadvertently applied to comparator).	(2) Total short circuit around bypassing switches and permissives	1	5/1	(2) Failure prevents comparator trip. Failure indicated by bypass light.		Same as 12.1-2

TABLE C.S.1-13

STEPS: 1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Logic Train | P/N: Plant Protection System (PPS)SDD-99 | PREPARED BY: P. G. Woods | DATE: 9/3/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	* CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
13	1	Interrack wiring from comparator to primary logic	Transmits comparator output to photo transistor input	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Trip signal to 1 logic train. Indicated by PPS Status Board. Safe failure		One logic train tripped System reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 13.1-1 Safe failure		Same as 13.1-1
	2	Photo transistor	Isolates instrument channel signals before combining them in 2 of 3 logic	(1) Output fails to trip state	(1) Photo transistor failure	2	3/1	(1) Same as 13.1-1 Safe failure		Same as 13.1-1
				(2) Output fails to reset state	(2) Hot short	1	5/1	(2) Single logic train will not trip. Failure indicated by PPS monitor.		Failure prevents trip of single logic train. System essentially reconfigured into 2/2. Safe as long as no other failures occur.
	3	Wiring from phototransistor to logic trains	Transmits output of photo transistor to logic train.	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 13.1-1 Safe failure		Same as 13.1-1
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 13.1-1 Safe failure		Same as 13.1-1
	4	Primary Logic Train (includes 2/3 and 1/24 modules)	Combines comparator outputs in 2/3 logic coincidence	(1) Output fails to reset state	(1) Internal Failure	1	5/1	(1) Same as 13.2-2		Same as 13.2-2
				(2) Output fails to trip state	(2) Internal failure	2	3/1	(2) Same as 13.1-1 Safe failure		Same as 13.1-1

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represent criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-13

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Logic Train	P/N: Plant Protection System (PPS)SDD-99	PREPARED BY: P. G. Woods	DATE: 9/3/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
13	5	Primary Logic Drivers	Amplifies signal from logic train to scram breaker UV coil	(1) Fails to low or zero output	(1) Internal failure	2	3/1	(1) One channel of scram breakers trip. Failure indicated by PPS Status Board. Safe failure		Same as 13.1-1
				(2) Fails to high output	(2) Transformer winding short circuit	1	5/1	(2) Same as 13.2-2.		Same as 13.2-2
	6	Primary Logic Power Supplies	Provides necessary dc voltages for logic modules	(1) Fails to low or zero voltage	(1) Internal failure transformer, rectifier or fuse)	4	3/1	(1) Same as 13.1-1 Safe failure		Same as 13.1-1
				(2) Fails to high voltage	(2) Transformer winding short circuit	2	3/1	(2) Over voltage monitor on power supply trips voltage off. Same results as 13.1-1 Safe Failure.		Same as 13.1-1

6487-2

TABLE C.S.1-14

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Logic Train | P/N: Plant Protection System (PPS)SDD 99 | PREPARED BY: P. C. Woods | DATE: 9/3/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
14	1	Interrack writing from comparator to logic	Transmits comparator output to logic train	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Trip signal to 1 logic train. Failure indicated by PPS Status Board. Safe failure		One logic train tripped System reconfigured into 1/2. Unscheduled outage if no other failure occurs
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 14.1-1 Safe failure		Same as 14.1-1
	2	Secondary Logic Train (1/16 modules)	Combines like outputs from all 16 comparators	(1) Output fails to trip state	(1) Internal failure	2	3/1	(1) 1 logic train trips. Failure indicated by PPS Status Board. Safe Failure		Same as 14.1-1
				(2) Output fails to reset state	(2) Internal failure	1	5/1	(2) 1/16 incapable of scram. Indicated by periodic testing.		Failure prevents trip of 1 logic train. System reconfigured into 2/2. Safe as long as no other failures occur
	3	Logic driver	Amplifies necessary signal for final activation logic	(1) Fails to low or zero output	(1) Internal failure		3/1	(1) Same as 14.2-1 Safe failure		
				(2) Fails to high output	(2) Transformer winding short circuit	1	5/1	(2) Same as 14.2-2		Same as 14.2-2
	4	Secondary Logic Power Supplies	Provides necessary voltage for logic train	(1) Fails to low or zero voltage	(1) Internal failure (eg transformer, rectifier or fuse failure)	4	3/1	(1) Same as 14.2-1 Safe failure		Same as 14.1-1
				(2) Fails to high voltage	(2) Transformer winding short circuit	2	3/1	(2) Overvoltage monitor on power supply trips voltage off. Same results as 14.2-1. Safe failure.		Same as 14.1-1

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME, HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-15

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Calculational Unit | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
15	1.	Primary Calculational Unit	Derives secondary trip parameter for comparator (e.g., flux, delayed flux, flux √pressure, primary-intermediate speed, steam-feed-water flow)	(1) Fails to low or zero output	(1) Internal failure	4	5/1	(1) Failure may be safe or unsafe depending on the particular protective function considered. 1 channel affected.		
				(2) Fails to high output	(2) Internal failure	4	5/1	(2) Same as 15.1-1		
	2.	Primary Calculational Unit Power Supply	Supplies power to primary calculational units	(1) Fails to low or zero voltage	(1) Internal failure	4	5/1	(1) Failure may be safe or unsafe depending on the particular protective function considered. Failure affects all calculational units of train A, B, or C.		
				(2) Fails to high output	(2) Internal failure	2	5/1	(2) Same as 15.2-1		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

Amend. 25
Aug. 1976

TABLE C.S.1-16

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Calculational Unit | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
16	1.	Secondary Calculational Unit	Derives secondary trip parameter for comparator (e.g. modified nuclear rate, flux-total flow, primary-intermediate flow)	(1) Fails to low or zero output	(1) Internal failure	4	5/1	(1) Failure may be safe or unsafe depending on the particular protective function considered. 1 channel affected.		
				(2) Fails to high output	(2) Internal failure	4	5/1	(2) Same as 16.1-1.		
	2.	Secondary Calculational Unit Power Supply	Supplies power to secondary calculational units	(1) Fails to low or zero voltage	(1) Internal failure	4	5/1	(1) Failure may be safe or unsafe depending on the particular function considered. Failure affects all calculational units of train A, B, and C.		
				(2) Fails to high voltage	(2) Internal failure	2	5/1	(2) Same as 16.2-1		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-17

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Scram Actuation Logic | P/N: Plant Protection System (PPS) SDD-99 | PREPARED BY: P. G. Woods | DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
17	1.	Wiring from Logic Drivers to UV Relays	Transmit voltage from logic driver to UV relays	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) One breaker channel trips. Safe failure		One logic train tripped. System reconfigured into 1/2. Unscheduled outage if another failure occurs.
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 17.1-1 Safe failure		Same as 17.1-1
	2.	Manual Scram Relays	Manual interruption to voltage on UV relays	(1) Fails to deenergized position	(1) Loose or broken wire	2	3/1	(1) Same as 17.1-1 Safe failure		Same as 17.1-1
				(2) Fails in energized position	(2) Insulation failure or welding of relay contacts	2	3/1	(2) Manual scram will go to completion through redundant relays. Automatic scram not affected		
	3.	Manual Scram Switches	Permit manual scram by operator	(1) Fails in scram position	(1) Mechanical failure	2	3/3	(1) Reactor scram Safe failure		
				(2) Fails in reset position	(2) Mechanical failure	2	5/1	(2) Failed switch cannot initiate reactor scram. Redundant scram switch not affected.		
	4.	Scram Breaker Undervoltage Coil	Trip actuator for scram breaker	(1) Fails to open circuit	(1) Loose or broken wire	2	3/1	(1) Same as 17.1-1 Safe failure		
				(2) Fails to short circuit	(2) Insulation failure	2	3/1	(2) Same as 17.1-1 Safe failure		

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY. REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

Amend. 25
Aug. 1976

TABLE C.S.1-18

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Heat Transport (HTS) Shutdown Logic
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
18	1.	Auxiliary Contacts on Scram Breakers	Initiate HTS Shutdown on reactor scram	(1) Contacts fail open	(1) Poor electrical Contact	2	3/1	(1) 2/3 contact openings are required for HTS shutdown. Safe failure		
				(2) Contacts fail closed	(2) Insulation breakdown	2	5/1	(2) 1 channel cannot open. HTS Shutdown from other channel contacts.		
	2.	Shutdown Relays	Coil indicates scram breaker position	(1) Fails to de-energized position	(1) Relay coil open circuited (loose or broken wire)	2	3/1	(1) Same as 18.1-1 Safe failure		
				(2) Fails to energized position	(2) Relay blocked	2	5/1	(2) Same as 18.1-2		
	3.	HTS Breaker Trip Coils	Energizing either primary or secondary trip coil trips HTS breaker	(1) Fails to open circuit	(1) Loose or broken wire	2	5/1	(1) Coil incapable of breaker trip. Secondary coil or redundant breaker must provide trip.		
				(2) Fails to short circuit	(2) Insulation failure	2	5/1	(2) Same as 18.3-1		
	4.	Wiring from Shutdown Relay Panel to HTS Breaker Trip Coils	Transmits trip voltage signal to HTS shutdown breaker	(1) Fails to open circuit	(1) Loose or broken wire	2	5/1	(1) Same as 18.3-1		
				(2) Fails to short circuit	(2) Insulation failure	2	5/1	(2) Same as 18.3-1		

PROBABILITY NUMBERS	DEFINITIONS
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1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
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1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-18

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: HTS Shutdown Logic (Continued)				P/N: Plant Protection System (PPS) SDD-99				PREPARED BY: P. G. Woods	DATE: 9/4/74	
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY *	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
18	5.	Trip Coil Voltage Supply	Supplies tripping voltage to HTS breaker trip coils	(1) Fails to low or zero voltage	(1) Internal failure	4	5/1	(1) Same as 18.3-1		
				(2) Fails to high voltage	(2) Internal failure	2	5/1	(2) Breaker would function properly for reasonably high overvoltages. Extremely high voltages results *similar* to 18.3-1		
	6.	13.8 KV HTS Breakers	Provides HTS shutdown on per loop basis on trip of PPS scram breakers	(1) One breaker fails open	(1) Defective breaker or trip coil	2	3/3	(1) HTS prime mover coasts down. Reactor scram follows. *Safe* failure.		
				(2) One breaker fails closed	(2) Mechanical failure or blockage. Both trip coils fail open	2	5/1	(2) HTS shutdown is dependent upon redundant breaker		

6487-2

STEPS:
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3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
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FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Control Rod Drive Mechanism (CRDM) Power Train	Plant Protection System (PPS) SDD-99	P. G. Woods	9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
19	1	480 V 3φ Power Supply	Power Supply for CRDM M-G sets	(1) Fails to low or zero voltage	Fault in power distribution system	4	3/3	(1) Primary control rods will fall. Safe failure.		
				(2) Fails to high voltage	Primary winding short circuit in stepdown transformer	2	3/3	(2) Distribution system over-voltage relays would trip power supply. Same results as 19.1.1 Safe failure.		
				(3) Less than 1/2 second reduction or outage in voltage	Lightning strike or other fault which is cleared by breaker trip and reclose.	4	3/1	(3) M-G sets are designed to ride through outage with no effect. Longer outages result as in 19.1.1.		
	2	M-G Set Starter	Starts and disconnects M-G set	(1) Fails open	Failure of main electrical contacts	2	3/3	(1) M-G set coasts down. Same results as 19.1.1. Safe failure.		
				(2) Fails closed	Mechanical blockage	2	3/3	(2) No effect on plant safety, although M-G set may be damaged. Safe failure		

PROBABILITY NUMBERS	DEFINITIONS
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1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6482-1

TABLE C.S.1-19

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Control Rod Drive Mechanism (CRDM) Power Train (Continued)
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
19	3	M-G Set	Supplies voltage for CRDM operation	(1) Fails to low or zero voltage	Regulator failure and decreasing field current.	4	3/3	(1) Same as 19.1.1 Safe failure.		
				(2) Fails to high voltage	Regulator failure and increasing field current.	2	3/3	(2) Overvoltage monitor annunciates high voltage and high machine temp. CRDM operates properly until stator windings burn out and rods fall. Safe failure.		
				(3) Output frequency variation	Frequency variation to motor of M-G set	2	3/3	(3) Motor frequency variation tied to TVA system. Underfrequency relays will trip power supply if variations become significant Safe failure.		
	4	M-G Set Output Breaker	Provides overcurrent protection and disconnects M-G set.	(1) Fails open	Failure in trip mechanism	2	3/3	(1) Same as 19.1-1 Safe failure		
				(2) Fails closed	Failure in breaker mechanism	1	3/1	(2) Scram capability not affected. Equipment electrical protection and control performance affected. Safe failure.		

6687-2

TABLE C.S.1-19

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Control Rod Drive Mechanism (CRDM) Power Train (Continued)
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
19	[illegible]	Scram Breakers	Drop control rods by open circuiting power to CRDMs.	(1) Fails open	Worn trip latch or undervoltage coil fails open circuited.	2	3/3	(1) Same as 19.1.1 Safe failure		
				(2) Fails closed	Mechanical blockage	2	5/1	(2) Single scram breaker failure requires that the other two breaker trains open properly for HTS shutdown.		
				(3) Fails with long time response on opening.	Spring failure or friction buildup.	2	5/1	(3) Same as 19.5-2.		
	6	Wiring from M-G set to Control Cabinet	Transmits generated voltage to control cabinet	(1) Fails to open circuit	Loose or broken wire	2	3/3	(1) Same as 19.1-1.		
				(2) Fails to short circuit	Insulation failure	2	3/3	(2) MG output breaker trips. Same results as 19.1-1. Safe failure		
	7	3 to 6 phase transformer	Converts power for SCRS and CRDMs.	(1) Fails to low or zero voltage	Transformer failure (e.g., open windings)	2	3/3	(1) Same as 19.1-1 Safe failure		
				(2) Fails to high voltage	Primary to secondary short circuit	2	3/3	(2) Same as 19.3.2 except there is no overvoltage monitor. Failure indicated by high temp. alarms. Safe failure		

TABLE C.S.1-19

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Control Rod Drive Mechanism (CRDM) Power Train (Continued)
P/N: Plant Protection System (PPS) SDD-99
PREPARED BY: P. G. Woods
DATE: 9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
19	8	SCR Bank	Supplies DC voltage to 6 stator windings of one CRDM	(1) SCR fails to zero output	SCR fails open circuit	2	3/3	(1) Control Rod fed from affected SCR bank will drop. Scram follows. Safe failure		
				(2) SCR fails turned on	SCR or sequencer failure	2	3/1	(2) No safety effect Scram breakers can still drop rods. CRDM controller will sense this condition and stop rod motion.		
	9	Sequencer	Controls firing of SCRs to control rod speed and direction	(1) Fails so all outputs go to zero voltage	Loss of DC control power	2	3/3	(1) Same as 19.8-1 Safe failure		
				(2) Fails so that extra outputs are turned on	Misfiring output circuit	2	3/1	(2) Same as 19.8-2 Safe failure		
				(3) Runs at fast speed.	Drive motor overspeed	2	3/1	(3) If rod motion exceeds 9"/min by more than 10%, rod motion is held. Maximum mechanical speed of CRDM is 70"/min. Safe failure		

PROBABILITY NUMBERS	DEFINITIONS
5 4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
[illegible]	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME HOWEVER WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION
*A/B	Represents criticality to redundant component (A) and criticality to system (B)

6487-1

TABLE C.S.1-19

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Control Rod Drive Mechanism (CRDM) Power Train (Continued)	P/N: Plant Protection System (PPS) SDD-99	PREPARED BY: F. G. Woods	DATE: 9/4/74

ITEM NO.	PART ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
[illegible]		Wiring from Control Cabinet to CRDM	Transmits voltage from sequencer to CRDM	(1) Fails to open circuit	Loose or broken wire	2	3/3	(1) Same as 19.8-1. Safe failure as scram breakers can still drop rods.		
				(2) Fails to short circuit	Insulation failure	2	3/3	(2) Same as 19.8-1. Safe failure as scram breakers can still drop rods.		

6487 2

TABLE C.S.1-20

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
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4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
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FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
PPS Voltage Signal Buffer	Plant Protection System (PPS) SDD-99	P. G. Woods	9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY *	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
20	1	PPS Voltage Signal Buffer	Provides non-PPS output for all PPS voltage signal inputs. Buffer isolates PPS from other systems.	(1) Open circuit to buffer input	Loose or broken wire	2	5/1	(1) One PPS channel fails. Indicated by interchannel comparison.		
				(2) Short circuit to buffer input	Insulation failure	2	5/1	(2) Same as 20.1-1		
				(3) Short circuit, open circuit, or voltage or current source applied to buffer output	Various failures	2	3/1	(3) PPS is not affected. Safe failure.		
				(4) Buffer failure	Internal failure	2	5/1	(4) 1 PPS channel not properly isolated from external systems.		

PROBABILITY NUMBERS	DEFINITIONS
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CRITICALITY NUMBERS	DEFINITIONS
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6487-1

TABLE C.S.1-21

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
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FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
PPS Current Signal Buffer	Plant Protection System (PPS) SDD-99	[illegible]. G. Woods	9/4/74

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY*	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
21	1	Buffer Input Resistor	Provides voltage input to PPS buffer	(1) Buffer resistor open circuited	Resistor failure or broken lead	2	3/1	(1) PPS input signal goes to zero. Safe failure.		
				(2) Buffer resistor short circuited	Resistor or insulation failure	2	3/1	(2) PPS signal not affected. Safe failure.		
	2	PPS Input Resistor	Provides voltage input to PPS	(1) PPS resistor open circuited	Resistor failure or broken lead	2	3/1	(1) Same as 21.1-1. Safe failure.		
				(2) PPS resistor short circuited	Resistor or insulation failure	2	3/1	(2) Same as 21.1-1. Safe failure.		
	3	PPS Voltage Signal Buffer	Provides non-PPS output which isolates PPS from other systems	(1) Open circuit to buffer input	Loose or broken wire	2	3/1	(1) Same as 21.1-1. Safe failure.		
				(2) Short circuit to buffer input	Insulation failure	2	3/1	(2) Same as 21.1-2. Safe failure.		
				(3) Short circuit, open, open circuit, or voltage or current source applied to buffer output	Various failures	2	3/1	(3) Same as 21.1-2. Safe failure.		
				(4) Buffer failure	Internal failure	2	5/1	(4) 1 PPS channel not properly isolated from external systems.		

PROBABILITY NUMBERS	DEFINITIONS
5 4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3 2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
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Amend. 25
Aug. 1976

TABLE C.S.1-22

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FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept | P/N: LDSK 379114J Revision: Preliminary 8-28-74 | PREPARED BY: G. F. Wandell/T. Pitterle | DATE: July 31, 1975

ITEM NO	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1		Handling Socket	Provide lifting surface for handling tool to remove Primary Control Assembly from reactor	Contamination or debris collects on lifting shoulder.	Coolant Chemistry or cleanliness causes deposits of contamination or debris.	1	2	Unable to engage and remove the primary control assembly	Control coolant chemistry and cleanliness	Refueling grapple; coolant
				Weld to outer duct fails	Design/Quality Assurance	1	4	Control rod system misalignments increase.	Normal design and quality assurance processes.	Control rod system; welding process
			Provide positioning of the upper end of the primary control assembly	Hexagonal guide pad seizes in core restraint system	Metal self-welding; bowing of other outer ducts.	1	2	Normal refueling equipment unable to remove PCA.	Minimize friction coefficient on load pads; verify core restraint system performance	Core restraint system; refueling equipment.
				Coolant passage clogs	Debris within the assembly at manufacture.	2	1	None unless several blocked	Ensure assembly cleanliness during manufacture.	Manufacturing processes.
			Limit lower travel of the absorber assy.	Crushing of upper load pad	Seismic event	1	4	Increased drag force	Maintain heavy wall thickness at upper load pad to assure adequate strength.	Core restraint system.

PROBABILITY NUMBERS — **DEFINITIONS**

5-4 AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME.

3-2 AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES

1 AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

5 Failure of a PCRS to insert (A PCRS consists of a single PCRDM, PCRD, and PCA).
4 A slowed PCRS insertion. Partial loss of reactivity.
3 A spurious PCRS insertion or other unscheduled outage.
2 No effect on safety; repair of PCRS deferred until scheduled outage.
1 No effect on safety or operation.

6487 1

Amend. 25
Aug. 1976

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept | P/N: EDSK 379114C Revision: Preliminary 8-28-74 | PREPARED BY: G. F. Wandell/T. Pitterle | DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Breaks at scram arrest flange	Absorber assembly impact during insertion	1	5	Debris may jam primary control assy; further insertions may damage absorber assy. or other parts of primary control assembly.	Verify dashpot velocity limits by analysis and testing	PCRD dashpot
				Galling at inside diameter of scram arrest flange	Rubbing between control rod shaft and flange	2	4	Increased friction drag during last six inches of scram	Review materials couples for wear data. Consider need for hard surfacing of scram arrest flanges	Materials development testing
				Contact of coupling flange and handling socket exit chamber and inside diameter	Inadequate clearance between coupling flange and handling socket caused by large clearance between tapered shaft and scram arrest flange.	4	4	Increased insertion frictional retarding forces	Design revision to increase length of large shaft diameter to prevent contact with handling socket exit chamber	Control rod shaft
2		Outer Duct Assembly	Connects handling socket to inlet nozzle	Weld to handling socket fails	Design/Quality Assurance	1	4	Control rod system misalignments increase.	Normal design and quality assurance processes.	Control rod system; welding process
				Weld to inlet nozzle fails	Design/Quality Control	1	4	Control system misalignments increase significant misalignment effect would require total shear failure of weld which is considered incredible	Normal design and quality assurance processes.	Control rod system; welding process
			Guides absorber assembly during movement							
			Guides coolant flow	Distorts, buckles, collapses or otherwise deforms	Thermal distortion, excessive compressive stress, scram impact effects and irradia-	2	5	May jam absorber assembly	Detailed analyses needed to assure satisfaction of design requirements	Absorber Assembly

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART, ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept	P/N: EDSK 379114J Revision: Preliminary 8-28-74	PREPARED BY: G. F. Wandell/T. Pitterle	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					tion effects on material properties. Of lesser importance might be differential pressure, residual stresses, scram hydraulic pressure transient effects.				which would reduce probability factor to unity. Duct bowing tests should be considered to verify insertion predictions for bowed ducts. Tests of insertion impact effects on irradiated ducts should also be considered.	
				Wall breaks	Insertion impact effects; irradiation effect on material properties.	1	1	None, unless accompanied by distortion	Normal design processes.	None
				Outer duct galls	Rod withdraws with hex to hex contact due to clearances in torque taker key way	3	4	Potential increase in insertion drag forces	Limit CA lifetime so that wear effects will not impact performance. Review material couples for materials with minimal wear features.	Materials development program
				Rotation of outer duct	Excessive inter-assembly gap clearances or core assembly motion	2	4	Retarding force during insertion from contact of hex wear pads on control rod and outer duct	Perform core restraint analyses to verify acceptable limits of duct rotation	Core restraint system

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept	P/N: HDSK 379114J Revision: Preliminary 8-28-74	PREPARED BY: G. F. Wandell/T. Pitterle	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
3		Control rod coupling (including shaft and additional couplings up to the absorber assembly).	Connects absorber assembly to control rod drive mechanism; Limits lower travel of the absorber assembly	Internal coupling, connection to CRDM seizes	Galling, self-welding or contamination	2	2	Unable to separate CRD coupling for refueling operations	Assure satisfaction of design requirements for a breakaway joint feature	Breakaway joint feature
					Burr at inside diameter of CRD coupling	1	2	CRD or coupling galling causing difficulties in disconnect operation.	Break or radius inside diameter corner	CRD affected
				Shaft buckles	Pin bundle, jammed by an unidentified mechanism	1	4	Buckled shaft could result in binding during further withdrawals or insertions.	Assure design margin against potential buckling loads. Shaft designed to withstand max. PCRDM drive-in force without buckling.	Pin bundle
		Pin bundle	Contains B_4C moved in and out of the reactor core for control and shutdown purposes	Top plate to adapter plate weld joints fail circumferentially.	Poor weld quality	1	3	Pin bundle disconnects from the shaft causing spurious insertion	Normal design and quality assurance processes Circumferential weld failure highly improbable due to low loads on weld.	Welding processes
				Inner duct distorts, buckles, collapses or otherwise deforms	Excessive compressive stress, residual stresses, pin bowing or swelling from thermal and irradiation effects, pin rupture, thermal distortion, differential pressure during insertion, and irradiation effects on materials.	2	5	May jam pin bundle insertion.	Provide sufficient clearance between inner and outer duct Provide margins against pin failure Consider test to verify effects of pin rupture on inner duct Maintain adequate pin to duct clearance. Verify effect of pressure buildup during scram insertion.	Outer duct; pins

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Conc[illegible]

P/N: CDSK 379114J Revision: Preliminary 8-28-74

PREPARED BY: G. F. Wandell/T. Pitterle

DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Upper pin support plate to pin end cap weld fails	Overload due to insertion impact or thermal effects; quality assurance	2	2	Pins not restrained axially within the absorber assembly	Normal design and quality assurance processes.	Pins; weld processes
				Upper pin support plate distorts	Thermal effects	2	1	Weakens pins	Normal design process	Pins
				Contamination or debris clogs upper or lower pin support flow passage	Coolant chemistry or cleanliness causes deposits of contamination or debris	2	1	None, unless several clogged	Control coolant chemistry and cleanliness	Coolant; absorber pins
				Lower pin support plate distorted	Thermal effects	1	1	Imposes load on absorber pins	Normal design process Lower plate is at essentially isothermal inlet coolant conditions	Absorber pins
				Upper or lower wear pad loose between inner duct and outer duct	Weld failure and loss of pin	1	4	Retards control rod insertion	Normal design process; Maintain press fit of pin	Outer duct and inner duct
				Contamination or debris collects at upper or lower wear pad	Coolant chemistry or cleanliness causes deposits of contamination or debris	2	4	Restricts control rod movement	Control coolant chemistry and cleanliness; Utilize special core assemblies with filters for initial CRBR coolant cleanup to remove foreign particles potentially left from reactor construction	Outer duct and inner duct

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept
P/N: FDSK 3791141 Revision: Preliminary 8-28-75
PREPARED BY: G. F. Wandell/T. Pitterle
DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Upper or lower wear pad galls	Materials incompatability; self-welding, contamination, debris	2	4	Potential increase in insertion drag forces	Verify materials compatability by test; control coolant chemistry and cleanliness Limit CA lifetime so wear effects will not impact performance	Outer duct
				Lower absorber pin end plug galls, seizes in lower pin support plate	Materials incompatability, self-welding	2	2	Pin buckles; may rupture. End plug to clad weld may fail.	Same	Lower pin support plate End plate to clad weld
				Lower or upper absorber end plug pin area broken off	Flow induced vibration	1	2	None, unless further damage to pin occurs	Normal design process	Other absorber pins
				Lower or upper end plug to clad weld fails	Quality control; overstress due to high internal pressure; ratcheting pin bowing; lower end plug jamming in lower capsule plate	2	3	B_4C could enter coolant. No significant effect unless additional pins fail	Normal quality assurance and design processes	Coolant; particle sensitive reactor components possibly affected.
				Clad ruptures	High internal pressure; irradiation effects on materials, B_4C pellet or outgassing	2	4	B_4C may enter coolant; potential loss of rod worth	Normal design process	Same
								Rapid Release of Gas distorts Adjacent Pins and/or Inner-Duct.	Tests will show potential distortions will not significantly impact scram insertion	

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept
P/N: EDSK 379114D Revision: Preliminary 8-28-75
PREPARED BY: G. F. Wandell/T. Pitterle
DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Clad bulges	High internal pressure; irradiation effects on material; B_4C pellet swelling or outgassing.	1	2	Could contribute to clad loads with increased likelihood of pin rupture	Normal design process	Same
				Clad melts	Cooling flow blocked	1	3	B_4C enters coolant No effect unless additional pins fail	Control coolant chemistry and clean-lines; essentially total flow blockage would be required to melt clad	Coolant sensitive reactor components possibly affected
				Absorber pin bows	Uneven heating or cooling	4	2	Increased potential for pin failure	Same	Coolant; pin bundle and outer duct; clad
				Wire wrap weld fails	Design/quality assurance	2	2	No effect, however may cause damage to clad; may allow pins to touch causing hotspots	Normal design and quality assurance processes	Welding process; clad
				Wire wrap breaks	Wear; irradiation effects on materials	2	2	Same	Normal design process;	Clad
					Excessive pin bowing or pin vibration				Increased cross-sectional area of side channel wire wrap is preferrable to reduced wire diameter	
				Wire wrap loose	Thermal effects; irradiation effects on materials	3	2	Same	Normal design process	Same
				Pellet holddown spring relaxes or breaks	Overheating; irradiation effects on materials	2	2	Pellets free to move a short distance within the pin; potential exists for small reactivity oscillations	Same	Same

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept	P/N EDSK 379114J Revision: Preliminary 8-28-75	PREPARED BY G. F. Wandell/T. Pitterle	DATE July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Upper or lower plenum seizes in clad	Material incompatability; pin overheating	1	2	Pellets unable to move; possible failure of clad or clad to lower end plug weld	Same; plus normal quality control. Also, select same material for plenum spacer and clad and provide adequate clearance for spacer.	Clad to end plug weld
				B_4C pellets melt	Insufficient coolant flow; Excess gap between pellets and clad.	1	3	Clad failure could result	Control coolant chemistry and cleanliness; Normal design requirements specify no melting even in transients to minimize uncertainties in pin behavior	Coolant; clad
				B_4C pellets break	Thermal stresses from non-uniform heat generation and cooling.	3	1	Potential for rod worth change if small chips of B_4C are formed	Limit B_4C pellet length to reduce cracking potential	
				B_4C pellet seizes to clad	Pellet cocks; contamination or debris; B_4C swells due to irradiation effects	2	2	Clad interaction rate increases with B_4C contact. Provides potential for axial motion of pellets.	Normal design processes. Design requirements specify no pellet to clad pressure contact so that seizing is highly improbable.	

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Primary Control Assembly-37 Pin Concept	EDSK 379114J Revision: Preliminary 8-28-75	G. F. Wandell/T. Pitterle	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Insulator pellet melts	Insufficient coolant flow; Excess gap between pellet and clad Excessive B_4C temperatures	1	2	Distortion of the lower plenum and/or clad could result.	Control coolant chemistry and cleanliness Appropriate selection of insulator pellet material	Coolant; clad
				Insulator pellet cracks	Thermal stresses	2	1	None	None required	
				Insulator pellet seizes in clad	Pellet cocks; contamination or debris material incompatability; overheating	1	2	Lower plenum expansion restricted; possible failure of tube to lower end plug weld	Provide adequate pellet to clad clearance	Clad to lower end plug weld
				One or more pin assemblies installed upside down	Inadequate quality control	1	3	Reduction in rod worth	Differences in diameter between top and bottom end caps preclude upside down insertion.	Coolant; PC assembly
				Internal pin assembly parts not installed in correct sequence; some wrong parts installed	Same	2	3	Loss of rod worth from misalignment of B_4C most probable effect	Normal quality control process.	Coolant; PC assembly
				No inert gas in pin assembly at beginning of life	Same	2	1	Increased potential for clad failure	Same	Coolant; clad

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept	P/N: EDSK 379114J Revision: 8-28-75	PREPARED BY: G. F. Wandell/T. Pitterle	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
5		Shielding Assembly	Provides shielding to protect the core support structure	Flow passages clog	Debris or contaminant in coolant	2	1	None, unless several blocked	Perform gas flow test as last step in manufacturing. Large particle debris (>.25") blocked by core support structure	Coolant; Manufacturing and quality assurance processes
				Shielding parts not installed in correct orientation	Inadequate quality control	1	1	Some loss of shielding effectiveness Potential increase in flow rate	Insure adequate quality control. Design is not sensitive to orientation	Manufacturing and quality assurance processes
				Shielding assembly to inlet nozzle weld fails	Design/quality control	1	2	Coolant flow to pin bundle may become restricted	Normal design and quality assurance processes	Welding process
				Shielding parts break	Thermal effects	1	2	Same	Normal design process	Pin bundle
6		Orifice Plate Assembly	Control pin bundle coolant flow for certain core locations (Group 1 assemblies contain the orifice plate; Group 2 assemblies do not).	Orifice plate assemblies installed or not installed contrary to requirements	Inadequate quality control	1	3	Overheating of assembly leading to reduction of its life or, conversely overcooling	Perform gas flow test as last step in manufacturing	Manufacturing and quality assurance processes
				Orifice plates incorrectly oriented relative to each other during assembly	Same	1	1	Higher flow rate through the assembly	Same	Same

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept	P/N: EDSK 379114J Revison: Preliminary 8-28-75	PREPARED BY: G. F. Wandell/T. Pitterle	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Weld to inlet nozzle fails	Differential temperature effects; Inadequate quality control	1	1	Orifice plate assembly loose	Normal design and quality assurance processes	Outer duct
7		Inlet Nozzle	Supports lower end of control rod assy.	Inlet flow passage clogs	Large particle debris or contamination	1	3	Overheating of control rod assy.	Inlet modules filter coolant to particle size smaller than inlet passages.	Inlet modules
			Contains orifice plate assy. and shielding parts;						Blockage of one passage would not restrict flow.	
			Connects to outer duct	Weld to outer duct fails	Design/quality control	1	4	Control system misalignments increase; significant misalignment effect would require total shear failure of weld which is considered incredible	Normal design and quality assurance processes.	Control rod system; welding process.
				Weld near orifice plate assembly fails.	Differential temperature effects; quality control	1	2	Flow bypasses orifices; potential overheating of control rod assembly	Design analyses needed to determine the effect, if any of probable weld cracks on control rod assembly flow	Same

6487-2

TABLE C.S.1-22

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept				P/N: LDSK 379114J Revision 8-28-75				PREPARED BY: G. F. Wandell/T. Pitterle		DATE: July 31, 1975
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
8		Piston Ring	Provides a seal between nigh pressure sodium inlet and low pressure region between assemblies	Not installed	Inadequate quality control	1	2	Potential reduction in flow rate	Insure adequate quality control	Manufacturing and quality control process
				Ring broken	Manufacturing/quality	1	2	Same	Insure proper manufacturing and quality control processes.	Same
				Ring not adequately seated	Debris or contamination on the control rod assembly or on the mating inlet module	1	2	Same	Insure cleanliness of reactor components and coolant	Coolant; inlet modules

6487-2

TABLE C.S.1-23

STEPS
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Motor Tube Assembly | P/N: 128J004 Revision H | PREPARED BY: G.F.Wandell,ARD/J.Moody,Royal | DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128J004	Lower motor tube	Houses rotor assembly	1. Break at weld joint	Poor weld quality	1	3	Pressure boundary penetrated; scram capability not affected.	The component has been designed and installed to make this failure highly improbable. Cover gas leakage can occur only if bellows also fails.	Motor tube assembly
				2. Outer wall deflects radially inward	Safe shutdown earthquake	1	4	Insertion retarded.	Sufficient analysis illustraing insignificant radial deflection; testing	
	128J004	Center motor tube	Houses rotor assembly	1. Break at weld joint	Poor weld quality	1	3	Pressure boundary penetrated; scram capability not affected.	The component has been designed and installed to make this failure highly improbable. Cover gas leakage can occur only if bellows also fails.	Motor tube assembly
				2. Outer wall deflects radially inward	Safe shutdown earthquake	1	3	Wall would push on segment arms potentially leading to spurious scram.	Sufficient analysis illustrating insignificant radial deflection; testing	
	128J004	Leadscrew withdrawal housing	Houses withdrawn leadscrew	1. Break at weld joint	1. Poor weld quality	1	3	Pressure boundary penetrated; scram capability not affected.	The component has been designed and installed to make this failure highly improbable. Cover gas leakage can occur only if bellows also fails.	Motor tube assembly

PROBABILITY NUMBERS	DEFINITIONS
5 4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3 2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

6487-1

5. Failure of a PCRS to insert (A PCRS consists of a single PCRDM, PCRD, and PCA).
4. A slowed PCRS insertion. Partial loss of reactivity.
3. A spurious PCRS insertion or other unscheduled outage.
2. No effect on safety, repair of PCRS deferred until scheduled outage.
1. No effect on safety or operation.

TABLE C.S.1-23

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CRDM Motor Tube Assembly	P/N: 128J004 Revision H	PREPARED BY: G.F.Wandell,ARD/J.Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				2. Outer wall deflects radially inward	2. Safe shutdown earthquake	1	4	Insertion retarded.	Sufficient analysis illustrating insignificant radial deflection;testing	
	128J014-1	Motor tube holddown ring	Holds motor tube assembly in position	1. Break	1. Defective part	1	4	CRDM misalignment may lead to contact of leadscrew and housing with increased drag forces. Potential pressure boundary penetration.	Component designed to make failure highly improbable	Motor tube assembly lower assembly
					2. Excessive mechanical stresses during installation			Same	Same as above	
				2. Inward radial deflection toward rotor assembly	1. Safe shutdown earthquake	1	4	Insertion retarded.	Sufficient analysis illustrating that during an earthquake this failure mode is highly improbable testing	
	128F010 and 128F012	Position indicator housing including guide bushing	Protects position indicator mechanism	1. Loses pressure seal	1. Leak caused by defective gaskets and seals	2	3	Indicates a bellows failure. Pressure boundary penetrated.	Quality control in manufacturing and assembly; component is designed to make this failure mode unlikely	Position indicator and leadscrew
					2. Leak caused by safe shutdown earthquake			Same	Component is designed to make this failure mode unlikely; testing	
				2. Jams or galls to leadscrew inside diameter	1. Misalignment	1	4	Insertion retarded	Proper design makes this failure mode highly improbable Flexibility of housing minimizes drag forces.	
					2. Falling chips or debris			Same	Same	

6487 2

TABLE C.S.1-23

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Motor Tube Assembly	P/N: 128J004 Revision H -	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128F018	Position indicator	Indicates leadscrew position	1. Sensor failure	1. Excessive heating	2	1	Inaccurate position indication	Component is designed to make this failure mode unlikely	Leadscrew assembly upper mechanisms
					2. Safe shutdown earthquake			Same	Same and testing	
					3. Aging			Same	Component is designed and tested to make this failure mode unlikely	
				2. Loss of signal	1. Electrical wire break	2	1	One indicator out	Repair wire; monitor signal during operation	
					2. Failed meter			Same	Meter is designed to make this failure mode unlikely	
	128c203	Argon pressure transducer	Indicates pressure within motor tube	1. Inaccurate	1. Normal wear (aging)	2	2	1. Bellows failure undetected 2. Unnecessary bellows and seal examination	Operational data from FFTF indicates this failure mode is unlikely	Upper mechanisms position indicator housing
					2. Faulty switch			3. Inability to detect leak in upper CRDM seals to head access area	Switch designed to make this failure mode unlikely	
					3. Safe shutdown earthquake			Same		

6487-2

TABLE C.S.1-23

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Motor Tube Assembly	P/N: 128J004 Revision H	PREPARED BY: G.F.Wandell, ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128F093	Conoseal gasket	Seals Position indicator housing	Leaks	1. Wear aging	2	3	Argon pressure transducer indicates a leak. Pressure boundary penetrated.	Seal designed to make this failure mode unlikely	Position indicator housing - leadscrew assembly
					2. Incorrect installation			Same	Cover gas leakage if bellows also fails. Quality control during manufacturing and installation Operational data from FFTF indicates failure is unlikely	
					3. Faulty seal			Same	Same	

6487-2

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: [illegible] Lower Assembly	P/N: 128J003 Revision H	PREPARED BY: C.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	[illegible]	Scram assist spring	Provides initial scram assist force	1. Break	1. Defective spring material	2	4	Insertion retarded Potential bellows damage.	Spring designed and material selected to make this failure mode unlikely	Scram assist spring - tube guide
					2. Fatigue			Same	Spring designed and fatigue tested to make this failure mode unlikely	
				2. Spring relaxes	1. Thermal creep	2	4	Insertion retarded slightly	Spring designed and fatigue tested to make this failure mode unlikely	
					2. Excessive Temperature			Same	Same	
				3. Galling to guide tube	1. Debris	1	4	Same	Components are designed to make this failure mode highly improbable	
					2. Spring-tube guide interaction			Same	Same	
					3. Excessive sodium condensation on guide tube			Same	Same	
				4. Self welds to guide tube	1. Dwell time	1	4	Same	Operational data from FFTF confirms that this failure mode is highly improbable	
				5. Spring binds on guide tube	1. Spring buckle	1	4	Insertion retarded slightly	Spring design to make this failure unlikely	
	128J132	Guide tube	Guides scram spring	1. Galling to scram spring	1. Debris	1	4	Insertion retarded slightly	Components are designed to make this failure mode highly improbable	Guide tube - scram spring
				2. Self welding to scram spring	1. Dwell time	1	4	Same	Operational data from FFTF confirms that this failure mode is highly improbable	

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Lower Assembly | P/N: 128J003 Revision H | PREPARED BY: G.F. Wandell ARD/J. Moody, Royal | DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128J016	Nozzle	Holds CRDM in position	1. Fracture	1. Excessive thermal and mechanical stresses	1	4	Primary boundary penetrated. CRDM misalignments increased.	Nozzle has been designed and analyzed to make this failure mode highly improbable. Nozzle loads and motion are limited by shield-seismic support structure.	Nozzle, torque tube, scram spring housing
					2. Safe shutdown earthquake			Same	Same	
				2. Inward radial deflection	1. Safe shutdown earthquake	1	4	Insertion retarded due to increased misalignment.	Same and testing	
	128J122	Leadscrew	Provides for axial translation of driveline	1. Threads damaged or eliminated locally	1. Roller nut engagement	3	3	CRDM will not drive leadscrew, but no effect on insertion	Operational data from FFTF & proper design makes this failure mode unlikely	Leadscrew-roller nut
					2. Ratcheting due to control failure			Same	Same	
					3. Wear-aging			Same	Same	
					4. Manufacturing defects			Same	Quality control during manufacturing	
				2. Galling	1. Accumulation of metal chips	1	4	Retards insertion due to increased contact with leadscrew bushings	Components have been designed to make this failure mode highly improbable	Leadscrew - upper bellows support, upper and lower guide bushings
				3. Self welding	1. Dwell time	1	4	Same	Component couples have been tested to make this failure mode highly improbable	
				4. Bowing	1. Safe shutdown earthquake	2	4	Same	Component has been designed and analyzed to make this failure mode unlikely; testing	

6487-2

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CRDM Lower Assembly	P/N: 128J003 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					2. Faulty installation			Same	Quality control during installation acceptance testing would detect error.	
					3. Faulty manufacturing			Same	Quality control during manufacturing acceptance testing would indicate error.	
				5. Teeth develop high friction coefficient	1. Severe damage due to unusual abuse in service	1	5	Sufficient force to overcome high friction and disengage segment arms may not be present	Life testing and component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable. Evaluate margin of segment arm springs against high friction coefficients.	Roller Assembly
					2. Sodium Buildup due to failed Bellows	1	5	Same as above	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable. Testing to confirm capability to operate with a failed bellows	Same as above
	128J125	Upper bellows support	Supports upper bellows, houses leadscrew	1. Bellows loosens	1. Weld breaks	2	2	Bellows free at upper end Potential entry of sodium vapor to upper mechanism.	Quality control on welding and operational data from FFTF makes this failure mode unlikely	Upper bellow support-leadscrew Upper bellow support-main bellows
				2. Deflects radially inward	1. Safe shutdown earthquake	1	4	Insertion retarded	Component is designed to make this failure mode highly improbable; testing	
				3. Excessive Sodium buildup on I.D.	1. Failed Bellows allows sodium condensation on cool CRDM parts	1	4	Same	Testing to confirm capability to operate with a failed bellows.	

6487 2

C.S.1-59

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CRDM Lower Assembly	P/N: 128J003 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128J013	Main bellows	Permits motion of leadscrew while maintaining a pressure boundary	1. Leak leading to failure and separation of bellows pieces	1. Defective weld	3	4	Sodium vapor could reach upper assembly and retard insertion	Reliability test program to determine probability and failure modes and their effort upon insertion. System designed for operation with failed bellows	Main bellows- upper bellow support
					2. Hairline crack from fatigue			Same	Same	
					3. Pin hole from hot spots			Same	Same	
					4. Wear			Same	Same	
					5. Caustic attack			Same	Same	
				2. Interacts with leadscrew	1. Leadscrew misalignment	1	4	Retards insertion	Components are designed, manufactured, and installed to make this failure mode unlikely; testing to verify no interaction with leadscrew.	Main bellows-leadscrew
					2. Bowing of leadscrew			Same	Same	
	128G140-1	Holddown bearing ring	Holds lower assembly in place	1. Loosens	1. Installation errors	1	3	Cover gas in head compartments. No effect on insertion.	Proper design, quality control in manufacturing and installation makes this failure mode.	Holddown bearing ring upper bellows support
					2. Holddown bolts loosen			Same	Same	
	128C126	Upper guide bushing	Supports leadscrew	1. Locks leadscrew	1. Falling	1	5	Leadscrew may become bound to bushing and unable to scram	Operational data from FFTF indicates this failure mode unlikely; Reliability Tests CRDM designed to minimize potential for chips to enter bushings	Upper guide bushing-leadscrew extension

6487-2

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
PCRDM Lower Assembly	128J003 Revision II	G.G. Wandell ARD/ J. Moody, Royal	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				2. Bushing breaks up in service.	Defective material or manufacture or fatigue endurance.	1	5	Debris is generated which may be of sufficient size to inhibit unlatching.	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Leadsrew. Upper Guide Bushing
				3. Fails in Service	Defective material or manufacture or fatigue endurance.	1	5	Allows Leadscrew to move sideways and fail to disengage one Segment Arm.	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Leadscrew
	128C143	Holddown bolt	Supports holddown bearing ring	1. Becomes loose (one bolt)	1. Locking cup fails	1	2	Holddown bearing ring becomes loose. Potential cover gas leakage if more than one bolt fails	Proper design of locking cup makes this failure mode highly improbable	Holddown bolt-holddown bearing ring
				2. Strips and fails out (one bolt)	1. Poor installation	1	2	Same	Quality control during installation	
					2. Safe shutdown			Same	Proper design and analysis of component makes this failure mode highly improbable	
	128F138-1	Conseals	Seals lower mechanisms	Leaks	1. Incorrect installation	1	2	Lack of cover gas into CRDM no effect on insertion capability	Quality control in manufacture and installation Seals to be tested before operation to assume negligible leak rate	
					2. Defective part			Same	Same	
	128J175-1	Torque tube	Guides torque taker	1. Keyway looses shape	1. Wear during operation	1	3	Retards torque reaction of leadscrew	Operational data from FFTF indicates this failure mode is highly improbable.	Torque tube - torque taker
				2. Galling	1. Torque taker - torque tube interaction	1	4	Insertion retarded	Same	

6487-2

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCPDM Lower Assembly	P/N: 128J003 Revision H	PREPARED BY: G.F. Vandell ARD/J. Moody, Royal	DATE: August 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				3. Self-welding	2. Debris Dwell time	1	5	Insertion prevented	Negligible potential for self-welding	
	128F350 F349 F354 F151	Torque taker	Reacts torque in leadscrew	1. Galling	1. Operational forces	1	4	Insertion retarded or prevented; CRDM will not drive leadscrew	Operational data from FFTF makes this failure mode highly improbable	Torque taker - torque tube
					2. Debris in keyway			Same	Same	
				2. Key wears	3. Excessive NA buildup on torque taker Operational motions	1	3	Retards torque reaction of leadscrew	Same	
				3. Key fails	1. Fatique	1	4	Causes bellows failure; potential increase in contact force bewteen control rod, wear pad, and outer duct. Causes bellows failure; CRDM cannot drive out may jam control rod assembly.	Same as above and sufficient analysis to show this failure mode is highly improbable	
	128C128	Lower bushing guide	Guides lead screw	1. Locks leadscrew extension	Falling chips	2	5	Insertion retarded or prevented	Component is designed to make this failure mode unlikely; tests to verify absence of failure mode	Lower bushing - leadscrew extension
				2. Excessive Sodium buildups on I.D.	Failed Bellows allow sodium condensation on cool mechanism parts	1	4	Insertion prevented or retarded due to rubbing on translating assembly.	Same	Same
	128J133	Scram spring actuator	Cocks-scram spring	1. Breaks	1. Defective material	1	4	Insertion retarded	Proper design of component and quality control of material selection makes this failure mode highly improbable	Scram spring actuator-scram spring
					2. Excessive load			Same	Same	

6487-2

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: [illegible] Lower Assembly	P/N: 128J003 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: August 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					3. Excessive vibrations during scram			Same	Same	
				2. Galls	Excessive sodium buildup on guide tube			Insertion retarded	Same	
	125J120	Lower bellows support	Supports lower bellows and houses leadscrew extension	1. Bellows loosens	1. Weld breaks	2	2	Bellows free at lower end. Potential entry of sodium vapor to upper mechanism.	Quality control on welding and operational data from FFTF makes this failure mode unlikely	Lower bellows support-main bellows Lower bellows support-leadscrew extension
				2. Deflects radially inward	1. Safe shutdown earthquake	1	4	Insertion retarded.	Proper design and analysis makes this failure mode highly improbable; Testing	
	128C356	Spring seat ring	Translates motion between Scram spring and scram spring actuator	1. Wear	Motion during scram	2	4	Retards insertion & damages bellows	Friction and wear test data	Spring seat ring scram spring
				2. Galling	1. Chips	2	4	Retards insertion	Operational data from FFTF indicates this failure mode is unlikely; life test	Spring seat ring scram spring actuator
					2. Frictional heating			Same	Same	
					3. Excessive sodium buildup.			Same	Same	
				3. Breaks up in service.	Defective material or workmanship	1	4	Retards insertion	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	
	128J119	Leadscrew Extension	Translates axial motion from leadscrew to driveline	Locks	Falling chips between upper or lower guide bushings and leadscrew extension	2	5	Leadscrew may become bound in bushing and unable to scram	Component is designed to make this failure mode unlikely; life test.	Leadscrew extension upper and/or lower guide bushing

6487-2

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRD Lower Assembly | P/N: 128J003 Revision H | PREPARED BY: G.F. Wandell ARD/J. Moody, Royal | DATE: August 31, 1975

ITEM NO.	PART ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
									A slight increase in retarding forces is more probable than scram failure	
	128C131	Lock pin	Couples lower bellows support with leadscrew extension	Break	1. Defective material	1	3	Allows inadverent scram only if leadscrew extension unscrews from lower bellows support.	Quality control on material selection	Lock pin - bellows support
					2. Excessive shock			Same	Component is designed to make this failure mode highly improbable	
	128F072-1	Anti-ejection pawl	Restricts outward motion when roller nuts are disengaged	1. Anti-ejection pawl becomes inoperative	1. Spring breaks	2	2	Outward motion of leadscrew is not restricted	Proper spring design for application; life test	Anti-ejection pawl; segment arm No mechanism exists for outward motion of CRD and CA even if anti-ejection pawl fails
					2. Tooth wears or breaks			Outward motion of leadscrew is not restricted	Proper pawl design to make this failure unlikely	
					3. Pivot pin galls and locks			Outward motion of leadscrew is not restricted	Operational data from FFTF	
					4. Lock pin fails			Outward motion of leadscrew is not restricted	Proper lock pin design to make this failure unlikely	
				2. Excessive contact force with leadscrew during scram	1. Debris (chips) in threads or anti-ejection pawl	1	4	Increased drug force of pawl on leadscrew	1. Operationl data from FFTF 2. Pawl has been designed to make this failure unlikely	
					2. Defective part			Same	Pawl has been designed to make this failure unlikely	
					3. Galling of pivot pin			Same	Quality control in material selection. FFTF test data show this effect unlikely	

Amend. 25
Aug. 1976

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Lower Assembly | P/N: 128J059 Revision H | PREPARED BY: G.F. Vandell ARD/J. Moody, Royal | DATE: August 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				3. Breaks up in service	Debris generated	1	4	Debris falls into upper guide bushing	Proper pawl design to make this failure unlikely	Upper Guide bushing
	128F065-503	Roller Assembly	Drives the leadscrew	1. Threads chip or break	1. Defective part	2	4	1. CRDM cannot drive leadscrew 2. Insertion prevented when debris falls between bushings and leadscrew	Roller threads has been designed to make this failure unlikely; testing	Roller assembly-leadscrew Roller assembly-segment arm
					2. Ratcheting due to control failure			Same	Control system designed to make this failure unlikely; testing	
				2. Roller nut will not revolve	1. Failure in electrical system	1	3	CRDM cannot drive leadscrew	Sufficient operational data from FFTF	
					2. Debris from ball bearing failure			CRDM cannot drive leadscrew	Roller bearings have been designed to make this failure unlikely; testing	
				3. Roller bearing failure	1. Ball bearing failure	1	5	1. CRDM cannot drive leadscrew. Bearing failure could jam leadscrew which could retard or prevent insertion.	Roller bearings have been designed to make this failure unlikely; testing	
					2. Pin drops out of bearing			Same	Same	
					3. Race failures			Same	Same	
				4. Retainer breaks up in service.	Defective material or workmanship.	1	5	Provides a source of debris which may jam translating assembly.	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	

TABLE C.S.1-24

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Lower Assembly	P/N: 128J059 Revision H	PREPARED BY: G.F. Wandell ARD/J.Moody, Royal	DATE: August 31, 1975

ITEM NO	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				5. Teeth develop high friction coefficient	1. Severe damage due to unusual abuse in service	1	5	Sufficient force to overcome high friction and disengage Segment Arms may not be present.	Life testing and component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Leadscrew
					2. Sodium buildup due to failed bellows.	1	5	Same as above	Component design, and material, selection, are such that this mode of failure is highly improbable	Leadscrew
	128C067	Spindle Roller	Support and locate axis of Roller Assembly	Pin fails allowing Roller Assembly to remain engaged with Leadscrew while Segment Arms retract.	Defective material or manufacture or fatigue endurance.	1	5	Leadscrew may not be released.	Component design, material, selection, manufacture, and inspection are such that this mode of failure is highly improbable	Leadscrew
	128F078 128F079	Segment Arm Spring(s)	Provide disengaging force for Rotor Assembly	1. Break in Service	1. Defective material or manufacture of fatigue endurance.	1	5	Sufficient force to disengage Segment Arms may not be present.	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable. Review design anslysis to ensure acceptable spring margin.	Segment Arms
				2. Relaxes in Service	1. Creep 2. Higher than design basis temperatures	1	4	Sufficient force to overcome high friction and disengage Segment Arms may not be present.	Same as above	
				3. Galls with Segment Arm	1. Excessive wear and/or sodium buildup due to failed bellows	1	4	Segment Arm disengagement is retarded	Failed bellows test planned to confirm absence of failure mode	Same as above

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRD Rotor Assembly				P/N: 128J059 RevisionH				PREPARED BY: G.F. Wandell ARD/J. Moody, Royal		DATE: August 31, 1975
ITEM NO	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128J090-1	Pivot pin	Fulcrum for Segment arm	1. Break	1. Defective material or manufacture or fatigue endurance	1	5	Segment arm not functional; insertion may be prohibited.	Pivot pin designed to make this failure mode highly improbable	Pivot pin-segment arm
					2. Excessive load			Same	Same and Life Test	
				2. Locks	1. Galling	1	5	Segment arm not functional; unlatching may be prevented	Operational data from FFTF and Life Test	
					2. Chips or debris			Same	Component design material selection, manufacture, and inspection are such that this mode of failure is highly improbable	
					3. Excessive Sodium buildup on O.D. due to failed Bellows	1	5	Unlatching may be prohibited.	Same as above	Same as above
				3. Bending	1. Excessive load	2	4	May retard segment arm motion	Pivot pin designed to make this failure mode unlikely; Life Test	
					2. Wear			Same	Same	
	128J006-1	Segment arm	Positions roller nuts	1. Locked in CRDM drive position	1. Pivot pin breaks or locks	1	5	CRDM will not release leadscrew	Pivot pin designed to make this failure mode highly improbable	Segment arm-roller nuts
					2. Debris in pivot pin hole			Same	Same	
					3. Wear and galling of pivot pin			Same	Same	
				2. Breaks	1. Fatigue	1	3	Spurious scram.	Segment arm designed and tested to make this failure mode highly improbable	

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CRDM Rotor Assembly	P/N: 128J059 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: August 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				3. Residual magnetism keeps arm locked in CRDM drive position	1. Rotor tube becomes magnetic	1	5	CRDM will not release leadscrew	Operational data from FFTF assures this failure mode is highly impobable	
				4. Galls with Rotor Tube	Sodium buildup due to failed Bellows	1	5	Segment Arm disengagement motion may be prohibited	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Segment Arms Rotor Tube
	128J060	Rotor Tube	Supports segment arm and anti-ejection pawl and rotates segment arm to drive leadscrew	1. Wall fails at pivot pin hole	1. Wear	1	5	Insertion retarded or prevented	Rotor tube designed, as well as sufficient FFTF operational data to make this failure mode highly improbable	Rotor tube-segment arm Rotor tube-anti-ejection pawl
				2. Tube will not revolve	1. Failure in control system	3	3	CRDM will not drive leadscrew	Control system designed to make this mode of failure unlikely	
				3. Excessive sodium buildup on I.D.	Failed Bellows allow sodium condensation on cool CRDM parts.	1	4	Insertion may be retarded by rubbing on leadscrew	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	
	128J085-1	Radial bearing assembly	Aligns rotor tube assembly	1. Outer or inner race locks with ball bearings	1. Defective part	1	3	CRDM will not drive leadscrew	Radial bearing is designed and assembled to make this failure mode highly improbable	Radial bearings-rotor tube
					2. Debris initiates galling			Same	Same	
					3. Bearing surface wears			Same	Same	

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CRDM Rotor Assembly | P/N: 128J059 Revision H | PREPARED BY: G.F. Randall ARD/J. Moody, Royal | DATE: August 31, 1975

ITEM NO.	PART ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				2. Outer or inner race deforms or breaks	1. Excessive radial or hoop stress loads	1	3	CRDM will not drive leadscrew	Radial bearing is designed to make this failure mode highly improbable	
				3. Ball bearing in retainer locks	1. Retainer surface wears	1	3	Same	Same	
					2. Failure in retainer			Same	Same	
				4. Race or bell retainer fails or disintegrates in service.	1. Defective material or manufacture, or fatigue endurance	1	5	Debris generated which may be of sufficient size to inhibit unlatching or Debris may jam synchronizer Bearing	Component design, Material Selection, Manufacture, and inspection are such that this mode of failure is highly improbable	Synchronizer Bearing Segment Arms
	128J083	Synchronizer bearing assembly	Causes segment arms to move together	1. Ball bearing locks	1. Defective part	1	5	Segment arms may not disengage leadscrew	Synchronizer bearing assembly is designed and installed to make this failure mode unlikely	Synchronizer bearing segment arms
					2. Debris initiate galling			Same	Same and Life Test	
					3. Bearing surface wears			Same	Same and Life Test	
					4. Erosion in ball bearings			Same	Same and Life Test	

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Rotor Assembly				P/N: 128J059 Revesion H				PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975	
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				2. Outer or inner race deforms	1. Excessive radial or hoop stress loads	1	5	Segment arms may not disengage leadscrew	Synchronizer bearing assembly is designed and installed to make this failure mode unlikely; Life Test	
				3. Synchronizer pin mounting boss fails	1. Fatigue	1	5	Same	Component is designed and fatigue tested to make this failure mode unlikely; Life Test	
					2. Heavy press fit causes axial split			Same	Component is designed and inspected by manufacturing before and after assembly to make this mode of failure unlikely; Life Test	
				4. Bearing breaks up in service.	1. Defective material or manufacture, or fatigue endurance	1	5	Debris generated which may be of sufficient size to inhibit unlatching or Debris may jam synchronizer	Component design, Material selection, Manufacture, and inspection are such that this mode of failure is highly improbable	Syncronizer Bearing Segment Arms
						1	4	Synchronizing action is lost	Same as above	Same as above
				5. Becomes coated with sodium deposits and jams or friction is increased	1. Failed Bellows	1	5	Same as above	Same as above	Same as above
	128C062-1	Synchronizer pin	Fulcrum for rotational motion of segment arm	1. Locked pin	1. Galling	1	5	Motion of segment arms may be inhibited	Component is designed to make this mode of failure unlikely; Life Test Sufficient FFTF testing to show this failure mode is very unlikely	Synchronizer pin-segment arms

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
PCRDM Rotor Assembly	128J059 Revision H	G.F. Wandell ARD/J. Moody, Royal	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					2. Debris			Same	Same	
					3. Defective pin			Same	Same	
				2. Breaks up in service.	1. Defective Material or manufacture or fatigue endurance	1	4	Synchronizing action is lost	Component design, Material Selection, Manufacture, and Inspection are such that this mode of of failure is highly improbable	Synchronizer Bearing Segment Arms
						1	5	Debris generated which may be of sufficient size to inhibit unlatching.	Same as above	Same as above
				3. Becomes coated with sodium deposits and jams or friction is increased	1. Failed Bellows	1	4	Same as above	Same as above	Same as above
	128C063	Rivet	Retains synchronizer pin	1. Break, allowing pin to be lost	1. Defective part	2	4	1. Sychronizer pin falls out which could retard unlatching due to loss of synchronizing action	The rivet has been designed and material selected to make this failure mode unlikely; Life Test	Rivet - synchronizer pin
					2. High stress and loads			Same	Same	
						1	5	2. Debris is penetrated which may be of sufficient size to inhibit unlatching.	Same as above	Same as above
	128F086	Rotor	Provides segment arms rotational indication to position indicator	1. Does not rotate with rotor tube	1. Broken pin	1	3	Position indicator failure	Pin has been designed to make this mode of failure unlikely	Rotor - rotor tube

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: [illegible] Assembly	P/N: 128J059 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					2. Loose collar			Same	Collar has been designed and will be inspected after installation to make this failure unlikely	
				2. Fails to respond to electro-magnetic field	1. Rotor becomes too hot during operation and looses electro-magnetic properties	1	3	Same	Sufficient operational data from FFTF to insure this mode of failure is higly improbable	
				3. Cracks or breaks	1. Fatigue	1	3	Same	Component has been designed and fatigue tested to insure this mode of failure is highly improbable	
	128C088	Rotor collar	Supports rotor to rotor tube	1. Becomes loose	1. Broken pin	1	3	Position indicator failure	Pin has been designed to make this mode of failure unlikely	Rotor collar - rotor Rotor collar - rotor tube
					2. Pin falls out due to broken lip			Same	Rotor collar has been designed to make this mode of failure unlikely	
	128C084	Spacer radial bearing	Separates radial and synchronizer bearings	1. Compresses	1. Defective part	1	2	Small motion of syncronizer bearing. No effect on scram performance	Component has been designed to make this failure mode highly improbable	Spacer - radial bearings Spacer - rotor tube Spacer - synchronizer bearings
					2. High mechanical and/or thermal stresses			Same	Same	
	128F082	Nut for thrust bearing	Holds thrust bearing in place on rotor assembly	1. Becomes loose	1. Vibrations	1	2	Retards CRDM from driving leadscrew	Operational data from FFTF makes this failure mode unlikely Rotation of threaded nut is prevented by deforming nut into motor assembly	Nut - thrust bearing
					2. Temperature gradients and cycling			Same	Same	

6487-2

TABLE C.S.1-25

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: FCRD Rotor Assembly	P/N: 128J059 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					3. Defective threads			Retards CRDM from driving leadscrew	Component has been designed and inspected to make failure mode unlikely	
					4. Deformed groove fails at both 180° places			Same	Same	
					5. Wrong torque setting during assembly			Same	Inspection of component after installation insures failure is unlikely	
	128F082			1. Nut strips or fails in service	1. Defective material or manufacture or fatigue endurance.	1	5	If Rotor Assembly falls into contact with Lower Mechanism, the Segment Arms may be prevented from opening.	Component design material selection, manufacture, and inspection are such that this mode of failure is highly improbable	**Rotor Assembly Segment Arms**
	128F100	Rotor Assembly Nut	Supports Thrust Bearing and Rotor Assembly	2. Fails in service	1. Defective material or manufacture or fatigue endurance	1	5	If Rotor Assembly falls into contact with Lower Mechanism the Segment Arms may be prevented from opening.	Component design material selection, manufacture, and inspection are such that this mode of failure is highly improbable	**Rotor Assembly Motor Tube**
	128F064	Latch rotational stop	Limits upward motion of leadscrew	1. Spring breaks	1. Fatigue	2	2	Increased length in CRDM for withdrawal motion. Withdrawal would be stopped by other stops such as torque taker travel	Spring designed and fatigue tested to minimize failure probability	**Latch rotational stop-leadscrew** Latch-rotational stop-spring
					2. Defective part			Same	Spring properly designed and manufacturing to insure failure is likely	
				2. Lock pin breaks	1. Defective part	1	3	Same	Lock pin designed to make failure unlikely	
				3. Pivot pin breaks	1. Defective part	1	3	Same	Pivot pin designed to make failure unlikely	

TABLE C.S.1-26

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Rotor Assembly/PCRDM Strator-Jacket Assembly
P/N: 128J059 Revision H
PREPARED BY: G.F. Wandell ARD/J. Moody, Royal
DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				4. Latch breaks up in up in service	Defective material or manufacture or fatigue endurance	1	5	Debris is generated which may be of sufficient size to inhibit unlatching	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Leadscrew Upper Guide Bushing
				5. Jams Segment Arm with leadscrew	Sodium buildup due to failed Bellows	1	5	Unlatching may be prohibited	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	
	128J017	Stator-Jacket Assembly	Converts electrical power to magnetic field to engage and drive segment arms	1. Residual magnetism	1. Improper material in stator laminations 2. Extraneous external field	1	4	Segment arm disengagement is retarded	Adequate quality control and material certification Acceptance testing will ensure that this failure mode is highly improbable	PCRDM Rotor Assembly Segment arms
				2. Stator windings fail open or short	1. Overheating	1	3	Loss of magnetic field will cause spurious insertion	The stator-jacket assembly incorporated provisions for cooling	
					2. Insulation Breakdown				Adequate quality control and material certification	
					3. Wire breakage				Connecting wire protection is provided	
				3. Coolant flow or jacket fails	1. Safe shutdown earthquake	1	3	Loss of coolant will cause stator failure and spurious rod insertion	The stator-jacket assembly will be designed and tested to ensure that this failure mode is highly improbable	

TABLE C.S.1-26

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
CRDM Stator-Jacket Assembly	128F080 Revision H	G.F. Wandell ARD/J. Moody, Royal	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128J112-1	Thrust bearing; outer and inner race's	Reacts the CRDM radial and thrust loads	1. Locked	1. Bearing surface wears	2	3	CRDM will not drive leadscrew	1. Sufficient lubrication 2. Proper design of component 3. Sufficient wear data of material coup'·s	Thrust bearing-upper mechanisms
					2. Defective part			CRDM will not drive leadscrew	Proper design of component	
					3. Debris initiates galling			CRDM will not drive leadscrew	Sufficient operational data of thrust bearings	
				2. Outer or inner race deforms	Excessive radial or hoop stress loads	2	3	Will retard CRDM from driving leadscrew	This component has been designed and installed to make this failure unlikely	
				3. Outer race cage fails	1. Poor assembly technique	1	5	Gross misalignment of leadscrew causing failure to insert control rods	1. Assembly quality control 2. Proper mounting design, making this failure highly improbable	
				4. Race breaks up in service	Defective material or workmanship	1	5	Debris is generated which may be of sufficient size to inhibit unlatching	Component design, material selection, manufacture, and inspection, are such that this mode of failure is unlikely	Leadscrew, Upper Guide Bushing
	128F080	Thrust Bearing	Supports and locates Rotor Assembly	1. Race or ball retainer fails or breaks up in service		1	5	Debris is generated which may be of sufficient size to inhibit unlatching	Component design material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Segment Arms
				Same as above	Same as above	1	5	If Rotor Assembly falls into contact with Lower Mechanism the Segment Arms may be prevented from opening	Same as above	Segment Arm, Rotor Assembly

TABLE C.S.1-27

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: PCRDM Thrust Bearing Assembly	P/N: 128F080 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128F108	Thrust bearing retainer assembly	Spaces and seats balls	Locked	1. Retainer bearing surface wears	1	3	Will retard CRDM from driving lead-screw	1. Sufficient lubrication 2. Sufficient wear data or operational data for thrust bearings	Thrust bearing - upper mechanisms
					2. Failure in retainer			Will retard CRDM from driving lead-screw	The component has been designed to make this failure highly improbable	
				2. Retainer breaks up in service	Defective material or manufacture or fatigue endurance.	1	5	Debris is generated which may be of sufficient size to inhibit unlatching	Component design, material selection, manufacture and inspection are such that this mode of failure is highly improbable	Leadscrew, Upper Guide Bushing

TABLE C.S.1-28

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
CRDM Shield Plug Assembly	H4-22458 Revision H	G.F. Wandell ARD/J. Moody, Royal	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	H4-22458	CRDM shield plug	Shielding	1. Breaks	1. Defective material	1	3	Debris falls into coolant	Component is designed to make this mode highly improbable	Shield plug - driveline
					2. Safe shutdown earthquake			Same	Same and testing	
				2. Inward radial deflection	1. Safe shutdown earthquake	1	4	Retards Insertion	Component is designed and analyzed to make this failure mode highly improbable	
				3. Distorts	1. Thermal gradients	1	4	Retards Insertion	Same	
	H4-22458	CRDM shield plug extension	Prevents dashpot cup from moving upward	1. Breaks	1. Defective material	1	3	Debris falls into coolant; dashpot cup could be lifted by drag forces in rod withdrawl	Componet is designed to make this failure mode high-improbable	Shield plug extension - driveline
					2. Safe shutdown			Same as above	Component is designed and analyzed to make this failure mode highly improbable	
				2. Inward radial deflection.	1. Safe shutdown earthquake	1	4	CRDM will not insert control rods	Same and testing	Shield plug extension - dashpot cup
				3. Distorts	1. Thermal gradients	1	4	Retards or prevents insertion	Same	

TABLE C.S.1-29

STEPS
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CPD Driveline Extension Assembly | P/N: 128J300 Revision H | PREPARED BY: G.F. Wandell ARD/J. Moody, Royal | DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128F303	Upper disconnect actuating shaft	Actuates disconnect	1. Locked	Galling and self welding	2	2	Disconnects are inoperative	Component is designed to make this failure mode unlikely	Upper disconnect actuating shaft - upper driveline
	128F316	Driveline extension shaft flange	Couples driveline extension with CRDM lower assembly	1. Breaks	1. Defective material	2	3	Control rod cannot be withdrawn	Quality control on material selection proper design of component	Driveline extension shaft flange - upper driveline
					2. Safe shutdown earthquake			Same	Proper design of component to make this failure more unlikely; testing	
					3. Bolts fail			Same	Same	
				2. Bent	1. Safe shutdown earthquake	1	5	Retards or prevents insertion	Component has been designed and analyzed to make this failure mode extremely unlikely; testing	
	128F317	Bellows assembly	Permits motion of driveline while maintaining pressure boundary	1. Leak	1. Defective weld	3	4	Sodium vapor could reach CRDM upper mechanism and retard insertion	Reliability Test Program to determine probability and failure modes and their effect upon insertion	Bellows assembly - upper driveline
					2. Hairline crack from fatigue			Same	Same	

PROBABILITY NUMBERS — DEFINITIONS

5-4 AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME

3-2 AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES

1 AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

6487-1

5 Failure of a PCRS to insert (A PCRS consists of a single PCRDM, PCRD, and PCA).

4 A slowed PCRS insertion. Partial loss of reactivity.

3 A spurious PCRS insertion or other unscheduled outage.

2 No effect on safety; repair of PCRS deferred until scheduled outage.

1 No effect on safety or operation.

TABLE C.S.1-29

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: CRD Driveline Extension Assembly	P/N: 128J300 Revision H	PREPARED BY: G.F. Wandell ARD/J. Moody, Royal	DATE: July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
					3. Pin hole due to hot spots			Sodium reaches CRDM lower assembly	Design of CRD and temperature profile is such that failure of bellows does not significantly effect operation	
					4. Wear			Same	Same	
	128F309	Disconnect shaft support spring	Lifts upper disconnect actuating shaft	1. Spring relaxes or breaks	1. Fatigue	1	1	No effect as functions only to keep coupling in unlatched mode during refueling	Spring designed and material selected to make this failure mode extremely unlikely	Disconnect shaft support spring - disconnect actuating shaft
					2. Defective material			Same	Same	
	128C331	Spring support ring	Supports disconnect shaft support spring	1. Galls to shaft center disconnect	1. Metal chips	1	2	Same	Component designed to make this failure mode extremely unlikely	Spring support ring - disconnect shaft support spring
					2. Corrosion			Same	Same	
					3. Self welding			Same	Same	
	128F322	Position indicator rod (PIR)	Verifies completion of disconnect operation	1. PIR retracted	1. PIR holddown spring fails	2	2	Insertion of CRD coupling into control assembly for coupling connection is more difficult under misaligned conditions	Spring is designed and tested to make this failure mode unlikely	Position indicator rod - disconnect actuating shaft
				2. False couple	1. PIR holddown spring fails	2	2	Operator thinks couple is complete.	Components are designed to make this failure mode unlikely	

6487-2

TABLE C.S.1-30

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
CPD Driveline	766J602 Revision H	G.F. Wandell/J. Moody, Royal	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	766J602	Dashpot cup	Provides dampening during scram, guides dashpot piston	1. Dampening effect inactive	1. Leak in dashpot cup	2	2	Insertion impact on absorber duct exceeds design limits	Sufficient qaulity control and proper material selection	Dashpot cup - dashpot piston
					2. Clearance too large			Same	Proper design of components make this failure mode unlikely	
					3. Wear or errosion between dashpot cup and dashpot piston, or shaft and dashpot			Same	Same	
				2. Downward motion of driveline is prevented	1. Debris caught in dashpot	2	4	Full insertion is prevented	Proper design of component to make this failure mode unlikely; testing	
					2. Dashpot cup deflected radially or cocked in shroud tube.			Same	Same	
	766J602	Dashpot piston	Provides dampening during scram	1. Galled	1. Metal chips between piston and cup	2	4	Insertion retarded or full insertion prevented	Sufficient wear test data and proper design	Dashpot piston - dashpot cup
				2. Distorted dashpot cup prevents motion of piston	1. Dashpot cup deflected radially or cocked in shroud tube.	2	4	Same	Proper design of components to make this failure mode unlikely; testing	
				3. Dashpot doesn't fill with sodium	1. Assembly errors	1	3	Dashpot piston is damaged from drop; will not prevent control rod insertion	Quality control during assembly and proper design to make this failure mode unlikely	

6487-2

TABLE C.S.1-30

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
CRD Driveline	765J602 Revision H	G.F. Wandell ARD/J. Moody, Royal	July 31, 1975

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
	128C123-1	Lockring	Retains Lockpin for Magnet assembly	Lockring breaks up in service.	Defective material or manufacture of fatigue endurance	1	5	Debris is generated which may be of sufficient size to inhibit unlatching	Component design, material selection, manufacture, and inspection are such that this mode of failure is highly improbable	Leadscrew, Upper Guide Bushing
	200J295 IT.2	Lockring	Retains pins for torque taker	Lockring breaks up in service	Same	1	5	Debris is generated which may inhibit insertion	Same	Driveline
	200J295 IT. 5	Jackscrew	Seals Conoseal at lower mechanism drive	Jackscrew breaks up in service	Same	1	5	Same	Same	Driveline

TABLE C.S.1-31

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Secondary Control Rod Drive Mechanism			

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1		Carriage Position Indication Mechanism		Fails to operate	·Loss of power ·Electro-mechanical	3	2	Operator unable to detect carriage position accurately. Possible error in coupling or uncoupling unless repaired		·Repair at next outage ·Rely on limit switch at SCRDM housing for back-up ·Fails to operate. It would be noted and repaired after shutdown.
				Operates False	·Electro-mechanical	3	2	Incorrect sensing of position of collet and drive with respect to SCA housing. This could lead directly to Operator error: · unable to detect movement of carriage such as drift or pull up (both require additional failure) · More difficult positioning of carriage during recoupling and refueling		·Repair at next outage ·Might notice false indication during routine exercising ·Limit switch would indicate movement from normal positions. ·Sensing rod used for coupling sequence.

PROBABILITY NUMBERS	DEFINITIONS
6-4	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF-NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION

6487-1

TABLE C.S.1-32

STEPS:
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: SCRDM Assembly | P/N: | PREPARED BY: | DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
2		Positioning Motor		Operates false	·Electro-mechanical ·False signal to motor ·Power supply failure	2	3	(1) Normal operation: ·Motor pull up which would pull the absorber pins and damper assy. up until they hit the extension on the handling socket (see SCA - Item 10)		This should be prevented by the brake mechanism which is treated separately as Part 3.
						2	3	·Motor rundown = - little, (1/2")- no problem - > 1/2" requires action (possible shutdown)		Movement of the carriage would require shutdown to repair. If motor off gravity and hydraulic forces would cause drift if brake also fails
						2	3	(2) Shutdown or refueling: ·Motor pull up may disallow proper recoupling and/or disengaging of control rod		
				Fails to operate	·Electro-mechanical ·Bearing failure ·Loss of power	2	3	Unable to recouple rod after shutdown. Also unable to disengage SCRD Assy. from SCA and withdraw driveline as required during refueling.		This would not cause a shutdown, but it could extend the outage.

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME, HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	[illegible] OUTAGE
2	NO EFFECT ON SAFETY - REPAIR DEFERRED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION

6487-1

TABLE C.S.1-32

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
SCRDM Assembly			

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
3		Brake Mechanism (On Positioning Motor)		Fails to prevent movement of positioning motor and carriage	Excessive wear of steel to friction material contacts	1/2	3/2	•Allows carriage to drift. Most likely drift will be downward in safe direction due to hydraulic and gravitational forces		Position indicators would alert operator of drift. Shutdown of plant would be necessary. If slow drift, carriage could be driven up periodically.
						1	2	•Upward drift is possible, but very unlikely. Effect is probably negligible		Position indicators would alert operator of drift. Shutdown of plant might be necessary.
				Prevents Movement of Carriage	•Binding of brake •Electrical lead failure •Coil burn-out	3	2	Unable to move carriage •during refueling •during shutdown		Failure to move carriage would not affect plant during normal operation
4		Ball Screw Mechanism		Fails to operate	•Ball bearing seizure •metal chips •improper lub	2	2	Carriage unable to move		Inability of carriage movement would not affect normal operation. It would extend downtime for drive replacement.
					•Screw breaks	1	3	Carriage unable to move		Unlikely to fail - Screw able to take up to 10,000 lbs. (each).

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-32

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS [illegible] Assembly	P/N	PREPARED BY	DATE

ITEM NO	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
5		Drive Shaft Positioning Carriage		Fails to Move	·Position motor fails (see 2)	3	2	Unable to recouple after shutdown		Inability of carriage to move would not affect normal operation
					·Brake mechanism jams (see 3)			Unable to move for refueling		Shutdown could be extended if failure severe
					·Ball screw mechanism jams (see 4)					
				Spuriously moves	·Position motor operates false (see 2)	2	4	Motor runup		See Item 2 for consequences
						2	3	Motor rundown could cause spurious scram		
					·Brake mechanism fails to hold (see 3)	2	2	Failure of break allows drift		See Item 3 for consequences
6		Latch Position Indication Mechanism		Fails to Operate	Loss of power or electro-mechanical failure (e.g. LVDT fails, wire breaks)	3	2	Operator unable to detect if collet open or closed. No effect unless attempting to recouple.		During normal operation there is no effect, but during recoupling there would not be the confirmation of coupling to collet. Policy would prevent plant from operating.
				Operates false	Electro-mechanical failure (e.g., short in wiring or) calibration drift	3	2	Incorrect information regarding collet. ·coupling unconfirmed; repair during shutdown		

6487-2

TABLE C.S.1-32

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
... Assembly			

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
6 (cont.)						3	2	Uncoupled state indicated as coupled. Coupling head position indicator detects unlatched head		Rely on coupling head position indicator, item 7 to indicate lack of coupling
7		Coupling Head Position Indicator Mechanism		Fails to Operate	Loss of power or electro-mechanical failure	3	2	Lengthen outage due to replacement of drive.		No effect during normal operation. Need to know position of coupling head during recoupling.
				Operates false	Electro-mechanical failure	3	2	Lengthen Outage time		
						3	2	Require shutdown due to suspicion of stuck rod		
8		Coil Cord		Electrical and/or pneumatic lines break	Overstress	2	3	Spurious Scram		
9		Coil Cord Guide Pins		Jam	Friction	2	2	Causes Overtension of coil cord on run-down or runup		If loss of items 6 or 7
				Break	Tolerances Assembly	1	3			Only if internals break.

6487-2

Amend. 25
Aug. 1976

TABLE C.S.1-33

STEPS:
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6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Rod Driveline (SCRD) | P/N | PREPARED BY | DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1		Tandem Pneumatic Cylinder								Extremely unlikely. Pressure relief provided.
		1.1 Cylinder Housing		Rupture	Overstress	1 1	3 3	Spurious Scram Inability to Recouple		
				Radial Deformation	• Overstress • Missile Damage	1 1	2 3	Leakage around Piston Spurious Scram		Extremely unlikely. Pressure relief provided.
				Radial Deformation at Piston	Missile Damage	1	5	Prevent Scram		
		1.2 Piston (2)		Seal Leakage	Degradation over Time and Temperature	2	3	Spurious Scram		
				Jam	Galling	2	5	Prevent Scram		Not likely. Prototype testing.
		1.3 Piston Rod		Fracture	Overstress	1	3	Spurious Scram		Large design margins.
				Relaxation	Creep	1	3	Spurious Scram		Not likely at temperatures present above reactor head.
				Piston Separation	Overstress	1	3	Spurious Scram		

PROBABILITY NUMBERS	DEFINITIONS
3-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3 2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
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1	NO EFFECT ON SAFETY OR OPERATION

6487-1

TABLE C.S.1-33

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Rod Driveline (SCRD)	P/N	PREPARED BY	DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
				Jam	• Missile Damage • Thermal Distortion	1	5	Prevent Scram		
		1.4 Piston Rod Bushings (2)		Jam	Galling	2	5	Prevent Scram		Not likely. Prototype testing.
		1.5 Piston Rod Seals		Leak	• Wear • Degradation • Change of Properties	2	2	Loss of Pressure		Early detection could allow planned shutdown.
						2	3	Spurious Scram		
		1.6 Spring, in pneumatic cycle		Relaxation	Creep	2	1	No Effect		
				Fracture	Overstress	3	1	No Effect		
		1.7 Tubing (8) Lines - Valves to Cylinder		• Rupture • Fracture	• Overstress • Fatigure • Missile Damage	2	3	Spurious Scram		
2		Tension Rod		Fracture	Overstress	1	3	Spurious Scram		
				Relaxation	Thermal Creep	2	1	Collet Pos. Ind. Error		Pneum. Cyl. takes up slack
				Jam	Crushing of Driveline and Sensing Tube	1	5	Prevent Scram		Requires large misalignments.
3		Coupling to Piston Rod		• Fracture • Thread Disengagement	Overstress	1	3	Spurious Scram		
4		Tension Rod Couplings		• Fracture • Thread Disengagement	Overstress	1	3	Spurious Scram		
5		Scram Valve (2)		Jam Exit Vent Closed	Manufacturing Defect	3	5	Prevent Scram		Only if both fail.
				Jam Exit Vent Open	Manufacturing Defect	3	2	Inability to Recouple		
				Exit Vent Fail Open	• Electrical Power Dip • Coil Failure	3	3	Spurious Scram		

8487-2

TABLE C.S.1-33

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Rod Driveline (SCRD)	P/N	PREPARED BY	DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBA-BILITY	CRITI-CALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
6		Valve Bracket		Fracture	Overstress	2	3	Lead to Fatigue Fracture of Tubing		See No. 1.7 above.
7		Sensing Sleeve		Jam	Lateral Motion of Control Assembly	2	3	Inability to Monitor Coupling Head		
				Rupture	Overstress	1	1	No Effect		
8		Bellows, Sensing Sleeve to Drive Shaft		Leak	• Wear • Overstress	2	4	Sodium will rise up into the mechanism and solidify.		Only if lower bellows or gas pressure also failed.
						3	2	Driveline pressure leakage to housing		
9		Sleeve Housing		Deform	Overstress	2	1	No Effect		
10		Spring, Sleeve Housing		Relaxation	Creep	3	1	No Effect		
				Fracture	Overstress					
11		Bellows, Sensing Sleeve (Lower)		• Leak	• Wear • Fatigue	2	4	Loss of Positive Na barrier gas flow into Na.		Positive pressure prevents Na entry into sleeve. Recommend monitoring gas flow.
				• Rupture	• Overstress	2	4	Na enters upper drive line and solidifies		Only if gas pressure fails (See 8).
12		End Plate (Guide Bushing for Tension Rod).		Jam	• Tolerances • Galling	2	5	Prevent Scram		Prototype Testing.
13		Cylinder Standoff Frame		Deformation	Missile Damage	1 1	3 1	Spurious Scram or No Effect		
					Buckling	1	3	Spurious Scram		
					Overstress	1	2	Sensor readings thrown off.		
14		Sensor Brackets		Deformation	• Overstress • Missile Damage	1	2	Sensor readings thrown off.		

0487-2

TABLE C.S.1-33

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Rod Driveline (SCRD) | P/N | PREPARED BY | DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
15		250 Psi Gas Line to Scram Valves		Rupture	• Overstress • Fatigue	2	3	Spurious Scram		
16		Drive Shaft Pressure Balance Line		Rupture	• Overstress • Fatigue	2	2	Sodium Vapors can enter mechanism housing.		Only in conjunction with bellows failure. In this case Na could freeze and bind the shaft.
17		Drive Shaft		Excessive Deformation	Overload Buckling	1	2	Inability to Recouple		
					Compression of Bulb End	1	5	Prevent Scram		Unlikely.
				Differential Axial Elongation	Swelling Differential	1	5	Prevent Scram by locking up tension rod.		Negligible.
				Radial Jamming	Lateral Motion of Control Assembly	1	2	Inability to Recouple		
				Fracture	• Shear • Overstress	1	5	Prevent Scram		Earthquake, unlikely
				Stick	Sodium Migration/ Deposition	1	2	Difficult Drive removal		Latch still operable with stuck shaft
18		Shaft Couplings		• Fracture • Thread Disengagement	Overstress	1	2	Inability to Recouple		Earthquake
						1	3	Spurious Scram		
19		Drive Shaft Bellows		Fracture Leak	• Fatigue • Overstress • Wear	3	2	Release housing gas into cover gas area.		No immediate problem.
20		Bulb End of Shaft		Blockage	Foul	1	5	Prevent Scram		Negligible.
21		Collet		Fracture of Finger(s)	• Overstress • Fatigue	1	5	Jam prevents scram		
						2	3	Spurious Scram		Requires more than one (1) finger to fail.
				Stick at Shaft Contact Surface	• Deposition (Foul) • Self-Weld	2	5	Prevent Scram		No Flowing sodium not likely

Amend. 25
Aug. 1976

TABLE C.S.1-33

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Rod Driveline (SCRD)				P/N				PREPARED BY		DATE
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
		Collet (cont'd.)		Stick around Sensing Rod	Deposition	1	5	Prevent Scram		Requires jam of sensing tube which is spring loaded down
				Finger(s) Held Out	• Rod Fracture • Foul	1	2	Unable to Recouple		
				Relaxation	Thermal Creep	1	3	Spurious Scram		Very Low Creep Rate
				Axial Deformation	Overload from Control Rod	2	3	Spurious Scram		
				Separation from Tension Rod	Thread Shear	2 2	3 3	Spurious Scram and/or Inability to Recouple		
22		Sensing Probe		Fracture or Permanent Deformation	Overload from Coupling Head (Overstress) or spring forces	2	2	Inability to Monitor Recoupling		
				Jam	Galling with Collet	2	2	Inability to Recouple		
						2	2	Inability to Monitor Scram		
23		Tension Rod/ Collet Coupling		Fracture	Overstress	2	3	Spurious Scram		
				Thread Disengagement	Overstress	2	3	Spurious Scram		
24		Tension Rod Bellows		Rupture	• Overstress • Fatigue	2	4	Loss of Positive Sodium Barrier, Gas Flow into Na		Positive pressure prevents Na entry into sleeve.
				Leak	• Wear	2	4	Na enters upper drive line and solidifies		Only if gas pressure fails.
25		Tension Rod/ Sleeve Bellows		Leak	Material Degradation	2	4	Sodium will rise up into mechanism and solidify.		Only if upper bellows also failed.
						2	4	60 psig gas leakage to housing		

6487-2

TABLE C.S.1-34

STEPS
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
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3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
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FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Assy (SCA) | P/N | PREPARED BY | DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1		Coupling head and shaft		Fails to release from grippers	·Self-Weld (due to sodium purity, over temperature, excess loads)	2	5	Unable to scram this rod		Possible common mode failure. Weldment most likely to grippers, but drawing shows possible weld to sensing rod.
					·Friction forces too high (incorrect long term calculations, e.g., improper material)	2	5	Unable to scram this rod		Test results expected to show friction no problem.
				Spurious release	·Holding forces too low; incorrect long term calculations, (normal operation)	2	3	Spurious scram		Replace entire driveline and/or control assy (SCA).
					·Incorrect recoupling (after scram)	3 3	1 3	·Spurious rod drop during shutdown mode ·(or possibly during normal operation)		May have to replace drive line and/or control assy (SCA).
				Coupling head Shaft failure	·Breaks due to excess load (e.g., spurious motor pull up)	1	3	Spurious scram		Replaces this SCA
					·Breaks at weld to damper	1	3	Spurious scram		Replace this SCA

PROBABILITY NUMBERS	DEFINITIONS
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CRITICALITY NUMBERS	DEFINITIONS
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4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
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6487 1

Amend. 25
Aug. 1976

TABLE C.S.1-34

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Secondary Control Assembly (SCA)	P/N	PREPARED BY	DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
2		Damper Assembly		Interference of housing	·Binding to SCA duct (outer duct) during scram.	1	5	Unable to insert rod		Possible common mode failure.
					·Binding to guide tube (dashram jams)	1	2	Extends shutdown		Extends shutdown to replace this SCA.
				Failure of Spring Assembly	·Arresting arm fails	1	1/2	No effect or extend shutdown		Rely on dashram timing
					·Spring jams	1	1/2	No effect or extend shutdown		Rely on dashram
3		Absorber Bundle		Absorber pins fail	·Cladding failure ·End cap failure	1	5	Leakage of absorber matl. into Na with possible binding of control rod or collet		Replace this SCA during shutdown. Low absorber loss due to sodium erosion.
					·Pellet failure (incorrect manufacturing) ·Spring/spacer failure	2	1	Small reactivity effect		No effect
4		Control Rod Duct		Interference of Duct	·Binds to guide tube	2	5	Unable to insert rod		Possible common mode failure.
5		Piston		Excess Leakage (around piston)	Chipping or breaking of piston due to excess loading, corrosion	1	2	Reduces hydraulic assist by reducing pressure drop.		Gravity should be sufficient for insertion
				Binding of piston to guide tube	·Foreign material jamming around piston	1	5	Unable to insert assembly		
					·Interference from guide tube distortion	2	5	Unable to insert assembly		
					·Piston twists and binds to guide tube	1	5	Unable to insert assembly		
6		Guide Tube		Interference to motion	·High thermal load ·Improper welds ·Overpressure ·Irradiation creep oval deformation	2	5	Unable to insert assembly		

6487-2

TABLE C.S.1-34

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS Secondary Control Assembly (SCA)	P/N	PREPARED BY	DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
6		(continued)		Leakage	Guide Tube cracks	2	4	Reduce hydraulic assist by reducing pressure drop		Gravity should be sufficient for insertion
7		Shielding		Flow Interference	Corrosion, foreign particle build up	1	5	Unable to insert assembly		
8		Low Pressure Flow Ducting		Leakage or rupture	Thermal loads, corrosion	1	2	Reduce hydraulic forces for insertion		Gravity should suffice for insertion
				Flow Interference	Foreign particle, corrowion	1	5	Unable to insert assembly		
9		Nose Piece		Leakage or rupture	Corrosion	2	2	Reduce hydraulic forces for insertion		Gravity should suffice for insertion
				Break weld to Secondary Control Assembly Duct	Excess thermal load or corrosion	2	2	Reduce hydraulic forces for insertion		Gravity should suffice for insertion
				Flow interference	Foreign particle	2	2	Loss of cooling. Slow insertion if gravity releases latch.		Gravity should suffice for insertion
				Jams to core support plate	Corrosion	3	2	Unable to remove drive after shutdown		Could extend shutdown time excessively
10		Secondary Control Assembly Duct		Leakage or rupture	Excess thermal load or corrosion	1	2	Reduce hydraulic assist due to venting to reactor pressure		Gravity should suffice for insertion
				Distortion (bowing)	Excess thermal loading and irradiation gradients			See Item Numbers 2, 3, and 4		
11		Handling Socket		Excess leakage past seal between handling socket and drive line.	·Excess loading ·Corrosion ·Errosion	2	2	Reduce hydraulic assist by venting high pressure Na to channel.		Gravity should suffor insertion
				Gross leakage	Deformation (Earthquake only)	1	5	Prevent scram due to possible net upward force		
				End of driveline jams to socket	Excess load (Earthquake only)	1	2	Jam prevents withdrawal of drive after shutdown		Extends plant outage
				Interference with flow	·Deposition of impurities of foreign matter ·Differential expansion	1	5	Loss of cooling flow around absorber pins		

6487-2

TABLE C.S.1-35

TEPS 1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OR ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE
Drive Control & Position Indications			

TEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1		Carriage motor power supply and control		No power delivered	·Internal electrical fault ·Incoming power failure	3	2	Lengthen down times		Access port available to manually turn motor.
				False signal	·Internal fault ·Operator error	3	2	False operation. Could cause withdrawal at max. rate during start up. Could cause plant shutdown if inserted at power.		Rate limited by design. Interlocks to limit one rod withdrawal at a time.
2		Scram solenoid power input		Fail spuriously	·Lead failure ·Operator error ·Loss of power ·Protection system fault	3	3	Spurious scram		Analyzed with Protection system
				Fail to de-energize for scram	Short to electrical supply	2	5	Prevent scram		Separate scram leads from control leads and position ind. leads
					Protection system fault	2	5	Prevent scram		Analyzed with protection system
3		Position indication readout		No indication on any readout device	·Power supply fault	3	2	·No effect		Problem identified and fixed on line
				No indication on particular readout devices	·Sensor failure ·Wiring	3 3	2 2	·No effect ·Shutdown		Possibly required if signal and backup signal fail on more than one drive
				False indication	Internal electrical	3	2	·No effect if identifiable as readout fault		Fix on line

PROBABILITY NUMBERS	DEFINITIONS
5-4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3-2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME; HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENT IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF-NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH, NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION

6487-1

TABLE C.S.1-35

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Drive Control & Position Indications				P/N				PREPARED BY		DATE
ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
3	(cont)	Position indication readout (Cont)		Failure indication				·Treat as sensor failure if not identifiable as readout fault		
					Sensor failure			See SCRDM and SCRD FMEA's for specific sensor failure effects		

6487-2

TABLE C.S.1-35

STEPS
1. LIST EACH PART OR ASSEMBLY IN THE DESIGN
2. IDENTIFY ALL THE POSSIBLE FAILURE MODES WHICH THE PART OF ASSEMBLY MIGHT INCUR
3. IDENTIFY ALL THE POSSIBLE FAILURE CAUSES WHICH THE PART OR ASSEMBLY MIGHT INCUR FROM EACH FAILURE MODE
4. DETERMINE THE EFFECT OF EACH FAILURE ON THE PRODUCT PERFORMANCE
5. MAKE REFERENCE TO ANY OTHER PART OR ASSEMBLY WHICH THROUGH AN INTERFACE COULD LEAD TO ANOTHER FAILURE. MAKE ANY ADDITIONAL CONTRIBUTING REMARKS
6. ESTIMATE OR CALCULATE THE PROBABILITY OF OCCURANCE AND THE DEGREE OF CRITICALLY OF EACH FAILURE
7. IDENTIFY AND CARRY OUT CORRECTIVE OR PREVENTIVE ACTIONS TO PREVENT OR MINIMIZE THE POTENTIAL FAILURE

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS: Primary Control Assembly-37 Pin Concept | P/N: EDSK 379114J Revision: Preliminary 8-28-74 | PREPARED BY: | DATE:

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
1		Regulator		Fails Open	· Manufacturing Defect · Missile Damage	2	2	High Pressure Gas to Inlet Valve		All Pressures - When gas is req'd a false leak alarm results from too many vent valve functions.
				Leaks	· Manufacturing Defect · Missile Damage	3	4	Low Pressure Gas at Inlet Valve		5 & 65 psi-When leak signal is given gas vents out from inlet valve.·. loss of argon buffer.
						3	3			200 psi-Leak signal to inlet vlave will be repeated resulting in loss of presusre to cylinder and spurious scram.
2		Pressure Transducer		Fails to Indicate	· Manufacturing Defect · Missile Damage · Electrical Malfunction	3	4	·Does not Detect Leak ·Does not Detect Overpressure		All pressures-Loss of system function
				Indicates False	· Electrical Drift	3	1	·Drift to high side would allow overpressure		All pressures-Regulators would prevent significant overpressure
						3	3	·Drift to low side would permit undetected leaks		200 psi-Spurious Scram

PROBABILITY NUMBERS	DEFINITIONS
5 4	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY MAY BE EXPECTED TO OCCUR ONCE OR MORE DURING THE PLANT LIFETIME
3 2	AN OFF NORMAL CONDITION WHICH INDIVIDUALLY IS NOT EXPECTED TO OCCUR DURING THE PLANT LIFETIME. HOWEVER, WHEN INTEGRATED OVER ALL PLANT COMPONENTS AND SYSTEMS, EVENTS IN THIS CATEGORY MAY BE EXPECTED TO OCCUR A NUMBER OF TIMES
1	AN OFF NORMAL CONDITION OF SUCH EXTREMELY LOW PROBABILITY THAT NO EVENT IN THIS CATEGORY IS EXPECTED TO OCCUR DURING THE PLANT LIFETIME BUT WHICH NEVERTHELESS, REPRESENT EXTREME OR LIMITING CASES OF FAILURES WHICH ARE IDENTIFIED AS CONCEIVABLE

CRITICALITY NUMBERS	DEFINITIONS
5	FAILURE TO PERFORM SAFETY FUNCTION
4	DEGRADATION OF SAFETY FUNCTION
3	NO EFFECT ON SAFETY BUT CAUSES UNSCHEDULED OUTAGE
2	NO EFFECT ON SAFETY, REPAIR DEFERED UNTIL SCHEDULED OUTAGE
1	NO EFFECT ON SAFETY OR OPERATION

6487 1

TABLE C.S.1-35

FAILURE MODE AND EFFECTS ANALYSIS
CRITICALITY ANALYSIS

PART ASSEMBLY OR PROCESS	P/N	PREPARED BY	DATE

ITEM NO.	PART, ASSEMBLY OR PROCESS NUMBER	PART, ASSEMBLY OR PROCESS NAME	PART, ASSEMBLY OR PROCESS FUNCTION	FAILURE MODE(S)	FAILURE CAUSE(S)	PROBABILITY	CRITICALITY	FAILURE EFFECT(S)	CORRECTIVE ACTION OR PREVENTIVE ACTION	PART, ASSEMBLY OR PROCESS INTERFACINGS AND REMARKS
						3	4			65 psi-Loss of protective buffer.
						3	2			5 psi-Loss of protective buffer.
3		Solenoid Valve (Inlet)		Fails to Operate (Closed)	·Jammed plunger ·Open circuit	2	4	Cannot Pressurize		All pressures-Argon System function lost.
				Fails to Operate (Open)	·Jammed plunger	2	2	Continuous Venting of Outlet Valve		All pressures-Leak alarm given
				Leaks	·Sticking Plunger	3	2	Continued Venting of Outlet Valve		All pressures-Alarm for overpressure may be given.
4		Solenoid Valve (Outlet)		Fails to Operate (Closed)	·Jammed plunger ·Open circuit	2	2	Permits overpressure		All pressures-Over pressure alarm given.
				Fails to Operate (Open)	.Jammed plunger	2	2	Vent Argon		All pressures-Downstream pressure relief prevents significant under pressure
				Leaks	·Sticking Plunger	3	2	Pressure constantly added by inlet valve		All pressures-Downstream pressure relief prevents significant under pressure
5		System Logic Control		Fails to Operate	Electrical Malfunction	2	4	Loss of pressure control		All pressures-Argon System function lost.
				Operates Intermittently	Electrical Malfunction	3	4	Over or under pressures occur		65 psi-Bellows lose protective buffer.
						3	1			5 psi-Bellows lose protective buffer
						3	3			200 psi-Spurious Scram may occur

6487-2

CLINCH RIVER

BREEDER REACTOR PROJECT

PRELIMINARY SAFETY ANALYSIS REPORT

APPENDIX D

EVALUATION OF HYPOTHETICAL CORE DISRUPTIVE ACCIDENTS FOR THE CLINCH RIVER BREEDER REACTOR PLANT

PROJECT MANAGEMENT CORPORATION

Appendix D was deleted

in Amendment 24

CLINCH RIVER

BREEDER REACTOR PROJECT

PRELIMINARY SAFETY ANALYSIS REPORT

APPENDIX E

PRIMARY PIPE RUPTURE ACCOMMODATION

PROJECT MANAGEMENT CORPORATION

Appendix E was deleted

in Amendment 26

Appendix F was deleted in

Amendment 60