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RELIABILITY ANALYSIS
OF THE FFTF
CONCEPTUAL PLANT PROTECTION SYSTEM

October 1969

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RELIABILITY ANALYSIS OF THE FFTF
CONCEPTUAL PLANT PROTECTION SYSTEM

By

O. B. Monteith

Reactor and Plant Technology Department
FFTF Division

October 1969

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ABSTRACT

A study in comparative reliability evaluation of the FFTF (Fast Flux Test Facility) Conceptual Plant Protection System. The study is based on individual treatment of each parameter subsystem in the Plant Protection System and yields the long-term availability for each. Although system design is in the preliminary stages, the study indicates that the instrument sensors and signal conditioning electronics are the major contributors to subsystem unavailability.

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INTRODUCTION

This report is a comparative reliability evaluation of the FFTF (Fast Flux Test Facility) Conceptual Plant Protection System. The long term availability for each parameter subsystem in the Plant Protection System is determined with comparative values presented for three testing intervals and a range of component failure rates. This method of analysis is employed because absolute failure rate data for the components are lacking, and because of the preliminary state of the system design.

One purpose of this analysis is to provide a guide for estimating the testing interval for the Plant Protection System.

This report also contains a mathematical derivation of the long-term availability for redundant components where coincident operation of multiple units is required for success.

As used herein, "availability" is the long-term availability of a system to perform its intended function: i.e., it is the probability that the system will be ready to perform at a randomly selected time in the future. "Unavailability" is the probability that the system will not be ready to perform.

SUMMARY AND CONCLUSIONS

This reliability analysis of the FFTF Conceptual Plant Protection System includes unavailability studies for each parameter subsystem. The results are a range of values obtained for three testing intervals and an assumed range of component failure rates. It is concluded that the major contributors to subsystem unavailability are the instrument sensors and signal conditioning electronics.

Based on these unavailability results, the recommended initial test interval is approximately 170 hours (weekly) for the Plant Protection System.

The following stipulations are deemed necessary in view of anticipated design safety criteria for the system:

- The instrument channel failure rates in the fail-unsafe mode should not exceed the "nominal" values used in this report.
- Additional system design refinements, such as the bypass , function, should not contribute further to the unavailabilities as determined in this report.
- Administrative procedures are needed to insure that the low level neutron monitors will be backed-up by the intermediate level neutron monitors, and these in turn will be backed-up by the power level neutron monitors. This requisite compensates for the higher unavailability of the low and the intermediate level neutron monitors.

SYSTEM DESCRIPTION

The Plant Protection System is a combination of several instrumentation subsystems that monitor various parameters and functions in the FFTF. The system provides the necessary components, mechanisms, and electrical circuits to implement automatic shutdown of the reactor and actuation of containment. These actions are initiated in the event of conditions, sensed by the monitoring instrumentation, which are hazardous to the reactor building, occupants, or surroundings.

A conceptual design of the Plant Protection System is shown in Figures 1 through 11.

The Plant Protection System performs the following functions:

- Initiates reactor scram whenever protective instrumentation detects an unsafe condition.
- Initiates the containment of the facility when the containment protective instrumentation detects an unsafe condition. (Emergency core cooling protective system is not included in this analysis because the ECC system is not defined).
- Coordinates and integrates instrumentation, electrical, mechanical, and control systems to assure that the Plant Protection System is a complete system from primary sensor to final control element.

The system includes instrumentation sensors, signaling condition components, and logic elements, but it does not include the reactor safety rods and their actuating devices. Redundant components and channels are employed throughout the system. A two-out-of-four coincidence logic is the scheme used for most of the parameter subsystems. Two-out-of-three

coincidence logic is selected for the low level and intermediate level neutron subsystems. Elsewhere, one-out-of-two redundancy of component groups is used.

Parameters which are monitored by the system, and for which scram actions result if safe limits are exceeded, are:

- Low level neutron flux level (in-vessel)
- Low level neutron flux level (out-of-vessel)
- Low level neutron flux period
- Intermediate level neutron flux level
- Intermediate level neutron flux period
- Power level neutron flux level
- Power level neutron flux rate-of-change
- Bulk outlet coolant temperature
- Primary Loop IHX outlet temperature, each of 3 primary loops
- Closed loop primary coolant outlet temperature, each of 6 closed loops
- Closed loop flux-flow ratio, each of 6 closed loops
- Reactor flux-flow ratio
- Reactor vessel coolant level
- Electrical power supply
- Seismoscope
- Primary loop coolant flow, each of 3 primary loops
- Containment system actuation
- Open test loop outlet temperature, each of 3 open loops
- Closed loop surge tank level, each of 6 closed loops
- Closed loop IHX outlet temperature, each of 6 closed loops
- Experimental equipment, each of 6 closed loops (FUTURE)
- Process channel outlet temperature (FUTURE)

The reactor is designed with two emergency shutdown safety rod systems, designated the primary and secondary rod systems, each of which has the independent capability of scrambling the reactor. The Plant Protection System provides one complement

of instrumentation monitors with two different rod scram release logic circuits to actuate the two safety rod systems. Thus, the Plant Protection System is only partially duplicated for the primary and secondary rod systems.

METHOD OF ANALYSIS

The approach employed in this analysis is to derive the mathematical relationships which will yield the steady-state, or long-term, availability of the system to perform its intended function. In the case of the reactor protection system, the equipment is tested at regular intervals and then returned to the quiescent state. During the intervals between tests, failures in the equipment can occur. Some of these failures will be annunciated and their occurrence immediately known. These failures are termed "fail-safe" because they result in a protective action from the system though no response was required. Other failures can occur which are not detected until the equipment is tested. These failures are "unsafe" because they render the system unresponsive to a valid requirement for protective action. It is the "unsafe" failures that result in the unavailability of the system to perform its intended function during the interval between checks. The following mathematical treatment evaluates the unavailability of the system as a result of "unsafe" failures.

ASSUMPTIONS

Some simplifying assumptions have been employed in the analysis, and a list of the more important of these follows.

1. Components are operating in their useful life phase where the failure rate is constant and the distribution of times between failures can be expressed by exponential distributions.
2. Periodic checking procedures are implemented; that is, the system will be tested at regular intervals.

3. Component failures are independent. Dependent, or secondary, failures are not considered.
4. The system and components are performing exactly as designed at the beginning of each time period, and there are no design deficiencies.
5. Testing and/or repairs neither alter the original design nor add new faults.
6. Only permanent failures are considered; transient or intermittent failures are not analyzed.
7. The time required to complete the periodic check is small compared to the time between checks.

MATHEMATICAL MODEL

Single Instrument Channel

The probability density function of a single instrument channel is expressed as

$$\text{p.d.f. } f(t) = \lambda_c e^{-\lambda_c t} \quad \text{for } t \geq 0,$$

where λ_c is the "unsafe" failure rate of the serial chain of the instrument sensor, amplifier, trip comparator, and channel trip device; that is,

$$\lambda_c = \lambda_I + \lambda_A + \lambda_T + \lambda_R + \dots$$

If the channel is checked at equal intervals of T hours, then the probability of no failures, R , during the interval between checks is,

$$R(T) = \int_T^{\infty} f(t) dt = \int_T^{\infty} \lambda_c e^{-\lambda_c t} dt = e^{-\lambda_c T} \quad .$$

The probability of a failure, Z , occurring in the interval T , with the channel remaining in the failed state for a period of time v (where $v \leq T$) is

$$Z(T, v) = \int_{T-v}^{\infty} \lambda_c e^{-\lambda_c t} dt = e^{-\lambda_c (T-v)} \quad ,$$

and the p.d.f. is

$$z(T, v) = \lambda_c e^{-\lambda_c (T-v)} \quad .$$

The period of time, v , is the duration of failure in the interval T . The mean duration of failure averaged over the intervals in which the failures have occurred is

$$\begin{aligned} D = \text{mean of } v &= \frac{\int_0^T v z(T, v) dv}{\int_0^T z(T, v) dv} = \frac{\int_0^T v \lambda_c e^{-\lambda_c (T-v)} dv}{\int_0^T \lambda_c e^{-\lambda_c (T-v)} dv} \\ &= \frac{1}{\lambda_c} \left(\frac{\lambda_c T - 1 + e^{-\lambda_c T}}{1 - e^{-\lambda_c T}} \right) \quad . \end{aligned}$$

This expression for D is the mean time the channel will be in a failed state (given a failure) or the expected downtime in those intervals between checks when a failure occurs.

During an interval between checks, the expected amount of time that the channel is in a good state, G , is the sum of the expected portion of intervals with no failures plus that portion of the intervals with failure in which the system is in a good state:

$$\begin{aligned}
G &= T e^{-\lambda_c T} + (T-D) (1-e^{-\lambda_c T}) \\
&= T e^{-\lambda_c T} + \left[T - \frac{\lambda_c T - 1 + e^{-\lambda_c T}}{\lambda_c (1-e^{-\lambda_c T})} \right] (1-e^{-\lambda_c T}) \\
&= T - \left(\frac{\lambda_c T - 1 + e^{-\lambda_c T}}{\lambda_c} \right) = \frac{1 - e^{-\lambda_c T}}{\lambda_c}
\end{aligned}$$

The proportion of time that the channel is capable of performing its function, the interval availability A , is the ratio of the expected time in the good state to the total time in the interval

$$A = \frac{G}{T} = \frac{1 - e^{-\lambda_c T}}{\lambda_c T} \quad \text{(This result agrees with that obtained in Reference 1.)}$$

This is the availability in any check interval of length T because of the assumption that the equipment is as good as new after each check. The expression for A above is thus the long-term availability of a continuous series of check intervals of length T .

The approximations for the evaluation of D and A for the condition when the product $\lambda_c T$ is small compared to unity ($\lambda_c T \ll 1$) are given by

$$D \approx \frac{T}{2}$$

and

$$A \approx 1 - \frac{\lambda_c T}{2}.$$

Two Redundant Instrument Channels with One-Out-Of-Two Logic

The reliability function of two redundant channels in which either channel can provide the required action (shown graphically as $\textcircled{1/2}$) is,

$$\textcircled{1/2} \quad R(t) = 2e^{-\lambda_c t} - e^{-2\lambda_c t}$$

The probability density function $f(t)$ is

$$\textcircled{1/2} \quad \text{p.d.f. } f(t) = \frac{-dR(t)}{dt} = 2\lambda_c (e^{-\lambda_c t} - e^{-2\lambda_c t})$$

Proceeding through the same mathematical development as for the case of a single channel yields the following results.

$$R(T) = \int_T^\infty f(t) dt = 2e^{-\lambda_c T} - e^{-2\lambda_c T}$$

$$Z(T, v) = \int_{T-v}^\infty f(t) dt = 2e^{-\lambda_c (T-v)} - e^{-2\lambda_c (T-v)}$$

$$z(T, v) = 2\lambda_c e^{-\lambda_c (T-v)} - 2\lambda_c e^{-2\lambda_c (T-v)}$$

$$\textcircled{1/2} \quad D = \frac{T - \frac{2}{\lambda_c} (1 - e^{-\lambda_c T}) + \frac{1}{2\lambda_c} (1 - e^{-2\lambda_c T})}{1 - 2e^{-\lambda_c T} + e^{-2\lambda_c T}}$$

$$(1/2) \quad A = \frac{3 - 4e^{-\lambda_c T} + e^{-2\lambda_c T}}{2\lambda_c T}$$

The approximations for D and A for the condition when $\lambda_c T$ is small compared to unity ($\lambda_c T \ll 1$) are

$$(1/2) \quad D \approx \frac{T}{3}$$

and

$$(1/2) \quad A \approx 1 - \frac{(\lambda_c T)^2}{3}.$$

Three Redundant Instrument Channels with Two-Out-Of-Three Logic

The reliability function of three redundant channels, in which any two of the three provide the required action, is

$$(2/3) \quad R(t) = 3e^{-2\lambda_c t} - 2e^{-3\lambda_c t}$$

The results for D and A for this redundancy combination are

$$(2/3) \quad D = \frac{T - \frac{3}{2\lambda_c} (1 - e^{-2\lambda_c T}) + \frac{2}{3\lambda_c} (1 - e^{-3\lambda_c T})}{1 - 3e^{-2\lambda_c T} + 2e^{-3\lambda_c T}}$$

and

$$\frac{2}{3} A = \frac{5 - 9e^{-2\lambda_c T} + 4e^{-3\lambda_c T}}{6\lambda_c T}$$

The approximations for D and A for the condition where $\lambda_c T$ is small compared to unity ($\lambda_c T \ll 1$) are

$$\frac{2}{3} D \approx \frac{T}{3}$$

and

$$\frac{2}{3} A \approx 1 - (A_c T)^2$$

Four Redundant Instrument Channels with Two-Out-Of-Four Logic

The reliability function of four redundant channels in which any two of the four provide the required action is

$$\frac{2}{4} R(t) = 6e^{-2\lambda_c t} - 8e^{-3\lambda_c t} + 3e^{-4\lambda_c t}$$

The results for D and A in this redundancy combination are

$$2/4) \quad D = \frac{T - \frac{6}{2\lambda_c} (1 - e^{-2\lambda_c T}) + \frac{8}{3\lambda_c} (1 - e^{-3\lambda_c T}) - \frac{3}{4\lambda_c} (1 - e^{-4\lambda_c T})}{1 - 6e^{-2\lambda_c T} + 8e^{-3\lambda_c T} - 3e^{-4\lambda_c T}}$$

and

$$2/4) \quad A = \frac{13 - 36e^{-2\lambda_c T} + 32e^{-3\lambda_c T} - 9e^{-4\lambda_c T}}{12\lambda_c T}$$

The approximations for D and A for the condition where $\lambda_c T$ is small compared to unity ($\lambda_c T \ll 1$) are

$$2/4) \quad D \approx \frac{T}{4}$$

and

$$2/4) \quad A \approx 1 - (\lambda_c T)^3$$

COMPONENT FAILURE RATES

Table 1 lists the major functional components in the Plant Protection System along with the three failure rates that are relevant to the analysis. These failure rates are composite values made up from failure rates listed in References 2 through 5 and as adjusted by engineering judgement.

The failure rates listed in Table 1 are not to be construed as documented and absolute values. The author wishes to emphasize that these listings are guideline values only. They are used here to provide a comparative analysis for various testing intervals of the Conceptual Plant Protection System.

The range of failure rates for each component is chosen to extend at least $\pm$ one order of magnitude from the nominal value, and is representative of values listed in the above-mentioned references for similar equipment. This method of ranging the failure rates is especially advantageous in this

TABLE 1. *Failure Rates* (Failures per million hours)*

	<u>Pessimistic</u>	<u>Nominal</u>	<u>Optimistic</u>
Scram Relays R9, etc. (electromechanical)	100	10	0.1
Scram Relay Contact Pair	100	10	0.1
Logic Relays R5, etc. (electromechanical)	10	1	0.01
Logic Relay Contact Pair	100	10	0.1
Trip Comparator	200	20	2
Seismoscope Sensor	10	1	0.01
Seismoscope Monitor	200	20	2
Thermocouple	200	20	0.2
Thermocouple Ref. and Amplifier	200	20	2
Coolant Level Sensor	200	20	0.2
Coolant Level Monitor	200	20	2
Coolant Flowmeter Output	20	2	0.02
Flowmeter Monitor	200	20	2
Electrical Power Failure Relay	100	10	1
Power Failure Relay Contact Pair	100	10	1
Ion Chamber	500	50	5
Ion Chamber Cable	100	10	0.1
Ion Chamber High Voltage P.S.	200	20	2
Linear Amplifier	200	20	2
Operational Amplifier (Log-level, Period, Rate)	200	20	2
Electronic Buffer (Active Element)	200	20	2
Flow Totalizer	200	20	2
Flux/Flow Ratio Monitor	200	20	2
Pressure Sensor	200	20	2
Radiation Detector	500	50	5
Potential Transformer (See text)			
Surge-Suppressor Diode (See text)			

* *The tabular value is the total failure rate for the component. The fail-unsafe portion used in this report is discussed in the text.*

present analysis of the Plant Protection System for the following reasons:

1. The system being analyzed is the Conceptual Plant Protection System, CSDD 99.
2. Components and parts are not yet specified as to make or model, and specification control will follow later design refinements.
3. Some electronic components exist only as "black-box" concepts in the system, and their definitive design will take place in the future.
4. Failure rate data on many of the components is non-existent, and the effect of the FFTF environment in other instances is unknown.

FAIL - UNSAFE PORTION OF FAILURE RATES

The literature is sparse on the subject of failure rates for various failure modes of components and equipment. Reference 5 briefly treats the portions of failure rates that are failed-short-circuited and failed-open for some basic electronic components such as resistors, capacitors, and solid state devices. It indicates that for these components (except fixed resistors) both the open and short circuit failure rate portions are each 50% of the total failure rate. Depending on the application in a circuit, the fail-unsafe portion is 50% of the total failure rate for these components.

In the absence of additional data and lacking the detailed circuit design of the PPS, it is estimated that most components shown in the Conceptual System Description will have a fail-unsafe failure rate of 50% of the component's total failure rate. Through failure detection circuits and administrative procedures for monitoring PPS instrumentation, some of these failures will be annunciated and corrected before the regular

periodic test. The extent to which these measures will reduce the PPS unavailability can be determined only by detailed analysis of individual circuits. Though arguments may be advanced for reducing the percentage, a 50% portion is allocated to the fail-unsafe mode for all components, except two, because this assumption will probably yield a conservative result. A better estimate cannot be made at this time.

The two exceptions from the blanket 50% allocation are the relay coil surge-suppressor diodes and the potential transformers for the power failure monitors (the last two items of Table 1). Neither of these two components is considered to have a fail-unsafe mode in the system application. In the case of the potential transformer, if all primary power is lost, there is not a failed condition of the transformer that will maintain energy to the power failure monitor; and in the case of the surge-suppressor diode, if the circuit to a relay coil is de-energized, there is not a failed condition of the diode that will provide current to the relay coil. It is concluded, therefore, that failures of these two components in the system application are fail-safe only.

DISCUSSION

GENERAL

An activity currently underway by a national committee will establish design criteria for reactor plant protection systems. One proposed standard for the committee's consideration is that for each protective function, the unavailability of the protection system to perform the intended function shall be less than 10^{-5} . It is emphasized that this is a proposed criterion, and it is stated here to reflect that design criteria with possible requirements for assessing protection system unavailability are anticipated.

This report presents an investigative analysis of the long-term availability of each parameter subsystem of the FFTF Plant Protection System. Unavailability is calculated and exhibited in accordance with the mathematical relationship $U = 1 - A$ for unavailability U and availability A . The absolute value of subsystem unavailability is not determined. Instead, a range of values is obtained with the objective of estimating the testing interval required to meet anticipated design safety criteria of the Plant Protection System.

The range of values for unavailability is determined by considering three testing intervals. These intervals are 1500 hr, 168 hr, and 8 hr and correspond to performance of tests after each reactor refueling cycle, each week and each shift, respectively. An additional variable is obtained by using three different failure rates for each test interval. The three failure rates are postulated as a nominal value (which is a best estimate for the equipment at this time), a pessimistic value and an optimistic value--where the latter two are at least one order of magnitude removed from the nominal value.

Thus, nine separate calculations of unavailability for each parameter subsystem configuration are established. The results are given in Tables 2, 3, and 4. Each subsystem is listed with the unavailability results in a three-by-three matrix. There are some instances of essentially identical subsystems in the Plant Protection System, and the result for one subsystem of each such group is listed in each table. These are:

- Primary Loop IHX Outlet Temperatures for Loops 1, 2, and 3. (Subsystem No. 8 in Tables.)
- Reactor Flux-Flow Ratio and Closed Loop Flux-Flow Ratio (Subsystem No. 9 in Tables).

TABLE 2. *Plant Protection System Unavailability Primary or Secondary Rod Scram*

Subsystem	Time Between Tests		
	8 Hr	168 Hr	1500 Hr
1. Low Level Neutron Flux (Note 1)			
Pessimistic	5×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	5×10^{-7}	2×10^{-4}	2×10^{-2}
Optimistic	3×10^{-9}	1×10^{-6}	1×10^{-4}
2. Low Level Neutron Flux Period			
Pessimistic	6×10^{-5}	3×10^{-2}	5×10^{-1}
Nominal	6×10^{-7}	3×10^{-4}	2×10^{-2}
Optimistic	4×10^{-9}	2×10^{-6}	1×10^{-4}
3. Intermediate Level Neutron Flux			
Pessimistic	4×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	4×10^{-7}	2×10^{-4}	1×10^{-2}
Optimistic	2×10^{-9}	1×10^{-6}	8×10^{-5}
4. Intermediate Level Neutron Flux Period			
Pessimistic	5×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	5×10^{-7}	2×10^{-4}	2×10^{-2}
Optimistic	3×10^{-9}	1×10^{-6}	1×10^{-4}
5. Power Level Neutron Flux			
Pessimistic	4×10^{-7}	2×10^{-3}	3×10^{-1}
Nominal	2×10^{-9}	3×10^{-6}	2×10^{-3}
Optimistic	3×10^{-13}	1×10^{-9}	7×10^{-7}
6. Power Level Neutron Flux Rate-of-Change			
Pessimistic	5×10^{-7}	3×10^{-3}	3×10^{-1}
Nominal	2×10^{-9}	4×10^{-6}	2×10^{-3}
Optimistic	4×10^{-13}	2×10^{-9}	1×10^{-6}
7. Bulk Outlet Temperature			
Pessimistic	2×10^{-7}	9×10^{-5}	2×10^{-2}
Nominal	2×10^{-9}	9×10^{-7}	7×10^{-5}
Optimistic	2×10^{-13}	9×10^{-11}	7×10^{-9}

TABLE 2. (contd)

Subsystem	Time Between Tests		
	8 Hr	168 Hr	1500 Hr
8. Primary Loop IHX Outlet Temperature (Note 2)			
Pessimistic	2×10^{-7}	4×10^{-4}	1×10^{-1}
Nominal	2×10^{-9}	1×10^{-6}	3×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
9. Reactor Flux-Flow (Note 3)			
Pessimistic	3×10^{-6}	2×10^{-2}	6×10^{-1}
Nominal	5×10^{-9}	2×10^{-5}	5×10^{-3}
Optimistic	2×10^{-12}	2×10^{-8}	1×10^{-5}
10. Reactor Vessel Coolant Level (Note 4)			
Pessimistic	2×10^{-7}	4×10^{-4}	1×10^{-1}
Nominal	2×10^{-9}	1×10^{-6}	3×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
11. Electrical Power Supply			
Pessimistic	8×10^{-7}	4×10^{-4}	3×10^{-2}
Nominal	8×10^{-9}	4×10^{-6}	3×10^{-4}
Optimistic	6×10^{-11}	3×10^{-8}	2×10^{-6}
12. Seismoscope			
Pessimistic	2×10^{-7}	2×10^{-4}	6×10^{-2}
Nominal	2×10^{-9}	1×10^{-6}	2×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
13. Primary Loop Coolant Flow (Note 5)			
Pessimistic	2×10^{-7}	2×10^{-4}	6×10^{-2}
Nominal	2×10^{-9}	1×10^{-6}	2×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
14. Containment System Actuation			
Pessimistic	2×10^{-6}	3×10^{-3}	4×10^{-1}
Nominal	1×10^{-8}	8×10^{-6}	2×10^{-3}
Optimistic	1×10^{-12}	7×10^{-10}	8×10^{-7}

TABLE 2. (contd)NOTES

1. *Low level neutron flux: Results are the same for either in-vessel or out-of-vessel subsystem in Tables 2, 3, and 4.*
2. *Primary Zoop IHX outlet temperature: Results are for one IHX outlet temperature subsystem. Results are the same for closed Zoop IHX outlet temperature as well as closed and open Zoop outlet temperature subsystems in Tables 2, 3, and 4.*
3. *Reactor flux/flow: Results are the same for closed Zoop flux/flow subsystem in Tables 2, 3, and 4.*
4. *Reactor vessel coolant level: Results are the same for closed Zoop surge tank level subsystem in Tables 2, 3, and 4.*
5. *Primary loop coolant flow: Results are for one Zoop coolant flow subsystem in Tables 2, 3, and 4.*

TABLE 3. *Plant Protection System Primary Rod
Scram Unavai Zabi Zity*

Subsystem	Times Between Tests		
	8 Hr	168 Hr	1500 Hr
1. Low Level Neutron Flux (Refer to Table 2, Note 1)			
Pessimistic	5×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	5×10^{-7}	2×10^{-4}	2×10^{-2}
Optimistic	3×10^{-9}	1×10^{-6}	1×10^{-4}
2. Low Level Neutron Flux Period			
Pessimistic	6×10^{-5}	3×10^{-2}	5×10^{-1}
Nominal	6×10^{-7}	3×10^{-4}	2×10^{-2}
Optimistic	4×10^{-9}	2×10^{-6}	1×10^{-4}
3. Intermediate Level Neutron Flux			
Pessimistic	4×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	4×10^{-7}	2×10^{-4}	1×10^{-2}
Optimistic	2×10^{-9}	1×10^{-6}	8×10^{-5}
4. Intermediate Level Neutron Flux Period			
Pessimistic	5×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	5×10^{-7}	2×10^{-4}	2×10^{-2}
Optimistic	3×10^{-9}	1×10^{-6}	1×10^{-4}
5. Power Level Neutron Flux			
Pessimistic	4×10^{-7}	2×10^{-3}	3×10^{-1}
Nominal	2×10^{-9}	3×10^{-6}	2×10^{-3}
Optimistic	3×10^{-13}	1×10^{-9}	7×10^{-7}
6. Power Level Neutron Flux Rate-of-Change			
Pessimistic	5×10^{-7}	3×10^{-3}	3×10^{-1}
Nominal	2×10^{-9}	4×10^{-6}	2×10^{-3}
Optimistic	4×10^{-13}	2×10^{-9}	1×10^{-6}
7. Bulk Outlet Temperature			
Pessimistic	2×10^{-7}	1×10^{-4}	2×10^{-2}
Nominal	2×10^{-9}	9×10^{-7}	8×10^{-5}
Optimistic	2×10^{-13}	9×10^{-11}	7×10^{-9}

TABLE 3. (contd)

Subsystem	Times Between Tests		
	8 Hr	168 Hr	1500 Hr
8. Primary Loop IHX Outlet Temperature (Refer to Table 2, Note 2)			
Pessimistic	2×10^{-7}	4×10^{-4}	1×10^{-1}
Nominal	2×10^{-9}	1×10^{-6}	3×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
9. Reactor Flux-Flow (Refer to Table 2, Note 3)			
Pessimistic	3×10^{-6}	2×10^{-2}	6×10^{-1}
Nominal	5×10^{-9}	2×10^{-5}	5×10^{-3}
Optimistic	2×10^{-12}	2×10^{-8}	1×10^{-5}
10. Reactor Vessel Coolant Level (Refer to Table 2, Note 4)			
Pessimistic	2×10^{-7}	4×10^{-4}	1×10^{-1}
Nominal	2×10^{-9}	1×10^{-6}	3×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
11. Electrical Power Supply			
Pessimistic	8×10^{-7}	4×10^{-4}	4×10^{-2}
Nominal	8×10^{-9}	4×10^{-6}	3×10^{-4}
Optimistic	6×10^{-11}	3×10^{-8}	2×10^{-6}
12. Seismoscope			
Pessimistic	2×10^{-7}	3×10^{-4}	7×10^{-2}
Nominal	2×10^{-9}	1×10^{-6}	2×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
13. Primary Loop Coolant Flow (Refer to Table 2, Note 5)			
Pessimistic	2×10^{-7}	3×10^{-4}	7×10^{-2}
Nominal	2×10^{-9}	1×10^{-6}	2×10^{-4}
Optimistic	2×10^{-13}	1×10^{-10}	4×10^{-8}
14. Containment System Actuation			
Pessimistic	2×10^{-6}	3×10^{-3}	4×10^{-1}
Nominal	1×10^{-8}	8×10^{-6}	2×10^{-3}
Optimistic	1×10^{-12}	7×10^{-10}	8×10^{-7}

TABLE 4. *Plant Protection System Secondary Rod Scram
Unavai Zabi Zity*

Subsystem	Time Between Tests		
	8 Hr	168 Hr	1500 Hr
1. Low Level Neutron Flux (Refer to Table 2, Note 1)			
Pessimistic	5×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	5×10^{-7}	2×10^{-4}	2×10^{-2}
Optimistic	3×10^{-9}	1×10^{-6}	1×10^{-4}
2. Low Level Neutron Flux Period			
Pessimistic	6×10^{-5}	3×10^{-2}	5×10^{-1}
Nominal	6×10^{-7}	3×10^{-4}	2×10^{-2}
Optimistic	4×10^{-9}	2×10^{-6}	1×10^{-4}
3. Intermediate Level Neutron Flux			
Pessimistic	4×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	4×10^{-7}	2×10^{-4}	1×10^{-2}
Optimistic	2×10^{-9}	1×10^{-6}	8×10^{-5}
4. Intermediate Level Neutron Flux Period			
Pessimistic	5×10^{-5}	2×10^{-2}	4×10^{-1}
Nominal	5×10^{-7}	2×10^{-4}	2×10^{-2}
Optimistic	3×10^{-9}	1×10^{-6}	1×10^{-4}
5. Power Level Neutron Flux			
Pessimistic	9×10^{-7}	2×10^{-3}	3×10^{-1}
Nominal	7×10^{-9}	5×10^{-6}	2×10^{-3}
Optimistic	8×10^{-13}	1×10^{-9}	8×10^{-7}
6. Power Level Neutron Flux Rate-of-Change			
Pessimistic	1×10^{-6}	3×10^{-3}	3×10^{-1}
Nominal	7×10^{-9}	6×10^{-6}	2×10^{-3}
Optimistic	9×10^{-13}	2×10^{-9}	1×10^{-6}
7. Bulk Outlet Temperature			
Pessimistic	7×10^{-7}	3×10^{-4}	3×10^{-2}
Nominal	7×10^{-9}	3×10^{-6}	3×10^{-4}
Optimistic	7×10^{-13}	3×10^{-10}	3×10^{-8}

TABLE 4. (contd)

Subsystem	Time Between Tests		
	8 Hr	168 Hr	1500 Hr
8. Primary Loop IHX Outlet Temperature (Refer to Table 2, Note 2)			
Pessimistic	7×10^{-7}	6×10^{-4}	1×10^{-1}
Nominal	7×10^{-9}	3×10^{-6}	5×10^{-4}
Optimistic	7×10^{-13}	4×10^{-10}	6×10^{-8}
9. Reactor Flux-Flow (Refer to Table 2, Note 3)			
Pessimistic	3×10^{-6}	2×10^{-2}	6×10^{-1}
Nominal	1×10^{-8}	3×10^{-5}	5×10^{-3}
Optimistic	2×10^{-12}	2×10^{-8}	1×10^{-5}
10. Reactor Vessel Coolant Level (Refer to Table 2, Note 4)			
Pessimistic	7×10^{-7}	6×10^{-4}	1×10^{-1}
Nominal	7×10^{-9}	3×10^{-6}	5×10^{-4}
Optimistic	7×10^{-13}	4×10^{-10}	6×10^{-8}
11. Electrical Power Supply			
Pessimistic	1×10^{-6}	6×10^{-4}	5×10^{-2}
Nominal	1×10^{-8}	6×10^{-6}	5×10^{-4}
Optimistic	7×10^{-11}	3×10^{-8}	2×10^{-6}
12. Seismoscope			
Pessimistic	7×10^{-7}	5×10^{-4}	8×10^{-2}
Nominal	7×10^{-9}	3×10^{-6}	4×10^{-4}
Optimistic	7×10^{-13}	4×10^{-10}	6×10^{-8}
13. Primary Loop Coolant Flow (Refer to Table 2, Note 5)			
Pessimistic	7×10^{-7}	5×10^{-4}	8×10^{-2}
Nominal	7×10^{-9}	3×10^{-6}	4×10^{-4}
Optimistic	7×10^{-13}	4×10^{-10}	6×10^{-8}
14. Containment System Actuation			
Pessimistic	2×10^{-6}	3×10^{-3}	4×10^{-1}
Nominal	2×10^{-8}	1×10^{-5}	2×10^{-3}
Optimistic	2×10^{-12}	9×10^{-10}	8×10^{-7}

- Reactor Vessel Coolant Level and Closed' Loop Surge Tank Level (Subsystem No. 10 in Tables).
- Primary Loop Coolant Flow for Loops 1, 2, and 3. (Subsystem No. 13 in Tables.)

In addition, there are two cases of similar subsystems in which the unavailability results are identical, though differences exist in the sensor application. Such differences have not been considered in this present analysis. These are:

- In-Vessel and Out-of-Vessel Low Level Neutron Flux have identical results (Subsystem No. 1 in Tables).
- Open Test Loop Outlet Temperature, Closed Loop IHX Outlet Temperature, and Closed Loop Primary Coolant Outlet Temperature all have identical results to Primary Loop IHX Outlet Temperature (Subsystem No. 8 in Tables).

OTHER CONSIDERATIONS

The analytic results presented here do not include environmental effects on components, either favorable or unfavorable. Most of the electronic components will be maintained in a laboratory-type environment which will have favorable effect on these components. On the other hand, sensors and some interconnections are exposed to the unfavorable conditions of elevated temperature and radiation exposure. Because of the unknown effect of these conditions on component failure rates, they have not been considered in the analysis. In addition, no accounting has been included for equipment that will be required for conditioning of the in-reactor radiation monitors.

Other elements of the Plant Protection System which have not been considered in the analysis are the components that perform automatic bypass of instrumentation channels. The equipment and concept required to achieve the bypass function are not defined at this time. The dc power supplies for safety

rod circuits and relay logic circuits, and the ac power supplies for instrumentation channels are not included in the analysis because the system is fail-safe in design. Loss of any power supply results in a fail-safe condition of the component, subsystem, or system connected to the supply.

The equipment failures which are evaluated in this analysis are the random failures of components and parts. These failures are the result of remanent metallurgical flaws, manufacturing imperfections, and/or impurities of material which are undetected and not eliminated because of the prohibitive cost involved. There are other failures of components, sometimes called systematic failures, which are caused by phenomenon unknown or unexpected at the time of design. Systematic failures may result from environmental effects, human error, or unrecognized dependence on a common element. These kinds of failures are not amenable to a methodology since their occurrence is usually one-of-a-kind. No attempt has been made to analyze systematic failures in this report.

COMBINED PRIMARY AND SECONDARY ROD SCRAM

Table 2 is the list of results for the unavailability of each complete subsystem configuration to initiate scram action by either primary or secondary rod scram release circuits. The reliability block diagrams for the subsystems are shown in Figures 12 through 25. The underlying assumption in the results of Table 2 is that scrambling the reactor can be accomplished by either the primary safety rods or the secondary safety rods, or both. Results shown in Table 2 are for the Plant Protection System equipment only, and they do not include the safety rods.

PRIMARY SAFETY ROD SCRAM

Table 3 is the list of results for unavailability of each subsystem to provide the primary safety rods with scram release

action. In the reliability block diagrams (Figures 12 through 25), only those components which provide success paths to the primary safety rod solenoids are included in the determinations. Results shown in Table 3 are for the Plant Protection System equipment only, and they do not include the primary safety rods.

SECONDARY SAFETY ROD SCRAM

Table 4 is the list of results for unavailability of each subsystem to provide the secondary safety rods with scram release action. In the reliability block diagrams (Figures 12 through 25), only those components which provide success paths to the secondary safety rod solenoids are included in the determinations. Results shown in Table 4 are for the Plant Protection System equipment only, and they do not include the secondary safety rods.

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APPENDIX A

ADDITIONAL AVAILABILITY EXPRESSIONS

APPENDIX A

ADDITIONAL AVAILABILITY EXPRESSIONS

Long-term availability expressions have been determined for channel redundancy and coincidence combinations in addition to those developed in the Method of Analysis Section. Results, which include channel combinations from a single channel to a 5-out-of-5 coincidence logic, are listed below.

The approximations for these availability expressions, when the product $\lambda_c T$ is small compared to unity ($\lambda_c T \ll 1$) are also shown.

A = long-term availability

D = downtime when failure occurs

T = test interval

λ_c = channel failure rate.

SINGLE CHANNEL

$$D = \frac{T - \frac{1}{\lambda_c} (1 - e^{-\lambda_c T})}{(1 - e^{-\lambda_c T})}, \quad A = \frac{1 - e^{-\lambda_c T}}{\lambda_c T},$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{2} \text{ and } A \approx 1 - \frac{\lambda_c T}{2}$$

TWO REDUNDANT CHANNELS WITH 1-OUT-OF-2 LOGIC

$$D = \frac{T - \frac{2}{\lambda_c} (1 - e^{-\lambda_c T}) + \frac{1}{2\lambda_c} (1 - e^{-2\lambda_c T})}{1 - 2e^{-\lambda_c T} + e^{-2\lambda_c T}},$$

$$A = \frac{3 - 4e^{-\lambda_c T} + e^{-2\lambda_c T}}{2\lambda_c T},$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{3} \text{ and } A \approx 1 - \frac{(\lambda_c T)^2}{3}$$

TWO REDUNDANT CHANNELS WITH 2-OUT-OF-2 COINCIDENCE LOGIC

$$D = \frac{T - \frac{1}{2\lambda_c} (1 - e^{-2\lambda_c T})}{1 - e^{-2\lambda_c T}}, \quad A = \frac{1 - e^{-2\lambda_c T}}{2\lambda_c T},$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{2} \text{ and } A \approx 1 - \lambda_c T$$

THREE REDUNDANT CHANNELS WITH 1-OUT-OF-3 LOGIC

$$D = \frac{T - \frac{3}{\lambda_c} (1 - e^{-\lambda_c T}) + \frac{3}{2\lambda_c} (1 - e^{-2\lambda_c T}) - \frac{1}{3\lambda_c} (1 - e^{-3\lambda_c T})}{1 - 3e^{-\lambda_c T} + 3e^{-2\lambda_c T} - e^{-3\lambda_c T}}$$

$$A = \frac{11 - 18e^{-\lambda_c T} + 9e^{-2\lambda_c T} - 2e^{-3\lambda_c T}}{6\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{4} \text{ and } A \approx 1 - \frac{(\lambda_c T)^5}{4}$$

THREE REDUNDANT CHANNELS WITH 2-OUT-OF-3 COINCIDENCE LOGIC

$$D = \frac{T - \frac{3}{2\lambda_c} (1 - e^{-2\lambda_c T}) + \frac{2}{3\lambda_c} (1 - e^{-3\lambda_c T})}{1 - 3e^{-2\lambda_c T} + 2e^{-3\lambda_c T}}$$

$$A = \frac{5 - 9e^{-2\lambda_c T} + 4e^{-3\lambda_c T}}{6\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{3} \text{ and } A \approx 1 - (\lambda_c T)^2$$

THREE REDUNDANT CHANNELS WITH 3-OUT-OF-3 COINCIDENCE LOGIC

$$D = \frac{T - \frac{1}{3\lambda_c} (1 - e^{-3\lambda_c T})}{1 - e^{-3\lambda_c T}} \quad A = \frac{1 - e^{-3\lambda_c T}}{3\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{2} \text{ and } A \approx 1 - \frac{3\lambda_c T}{2}$$

FOUR REDUNDANT CHANNELS WITH 1-OUT-OF-4 LOGIC

$$D = \frac{T - \frac{4}{\lambda_c} (1 - e^{-\lambda_c T}) + \frac{3}{\lambda_c} (1 - e^{-2\lambda_c T}) - \frac{4}{3\lambda_c} (1 - e^{-3\lambda_c T}) + \frac{1}{4\lambda_c} (1 - e^{-4\lambda_c T})}{1 - 4e^{-\lambda_c T} + 6e^{-2\lambda_c T} - 4e^{-3\lambda_c T} + e^{-4\lambda_c T}}$$

$$A = \frac{25 - 48e^{-\lambda_c T} + 36e^{-2\lambda_c T} - 16e^{-3\lambda_c T} + 3e^{-4\lambda_c T}}{12\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{5} \text{ and } A \approx 1 - \frac{(\lambda_c T)^4}{5}$$

FOUR REDUNDANT CHANNELS WITH 2-OUT-OF-4 COINCIDENCE LOGIC

$$D = \frac{T - \frac{3}{0!}(1 - e^{-2\lambda_c T}) + \frac{8}{3\lambda_c} (1 - e^{-3\lambda_c T}) - \frac{4}{3\lambda_c} (1 - e^{-4\lambda_c T})}{1 - 6e^{-2\lambda_c T} + 8e^{-3\lambda_c T} - 3e^{-4\lambda_c T}}$$

$$A = \frac{13 - 36e^{-2\lambda_c T} + 32e^{-3\lambda_c T} - 9e^{-4\lambda_c T}}{12\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{4} \text{ and } A \approx 1 - (\lambda_c T)^3$$

FOUR REDUNDANT CHANNELS WITH 3-OUT-OF-4 COINCIDENCE LOGIC

$$D = \frac{T - \frac{4}{3\lambda_c} (1 - e^{-3\lambda_c T}) + \frac{3}{4\lambda_c} (1 - e^{-4\lambda_c T})}{1 - 4e^{-3\lambda_c T} + 3e^{-4\lambda_c T}}$$

$$A = \frac{7 - 16e^{-3\lambda_c T} + 9e^{-4\lambda_c T}}{12\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{3} \text{ and } A \approx 1 - 2(\lambda_c T)^2$$

FOUR REDUNDANT CHANNELS WITH 4-OUT-OF-4 COINCIDENCE LOGIC

$$D = \frac{T - \frac{1}{4\lambda_c T} (1 - e^{-4\lambda_c T})}{1 - e^{-4\lambda_c T}}$$

$$A = \frac{1 - e^{-4\lambda_c T}}{4\lambda_c T} \quad \text{and if } \lambda_c T \ll 1, D \approx \frac{T}{2} \text{ and } A \approx 1 - 2\lambda_c T$$

FIVE REDUNDANT CHANNELS WITH 1-OUT-OF-5 LOGIC

$$D = \frac{T - \frac{5}{\lambda_c} (1 - e^{-\lambda_c T}) + \frac{5}{\lambda_c} (1 - e^{-2\lambda_c T}) - \frac{10}{3\lambda_c} (1 - e^{-3\lambda_c T}) + \frac{5}{4\lambda_c} (1 - e^{-4\lambda_c T}) - \frac{1}{5\lambda_c} (1 - e^{-5\lambda_c T})}{1 - 5e^{-\lambda_c T} + 10e^{-2\lambda_c T} - 10e^{-3\lambda_c T} + 5e^{-4\lambda_c T} - e^{-5\lambda_c T}}$$

$$A = \frac{137 - 300e^{-\lambda_c T} + 300e^{-2\lambda_c T} - 200e^{-3\lambda_c T} + 75e^{-4\lambda_c T} - 12e^{-5\lambda_c T}}{60\lambda_c T}$$

$$\text{and if } \lambda_c T \ll 1, D \approx \frac{T}{6} \text{ and } A \approx 1 - \frac{(\lambda_c T)^5}{6}$$

FIVE REDUNDANT CHANNELS WITH 2-OUT-OF-5 COINCIDENCE LOGIC

$$D = \frac{T - \frac{5}{\lambda_c} (1 - e^{-2\lambda_c T}) + \frac{20}{3\lambda_c} (1 - e^{-3\lambda_c T}) - \frac{15}{4\lambda_c} (1 - e^{-4\lambda_c T}) + \frac{4}{5\lambda_c} (1 - e^{-5\lambda_c T})}{1 - 10e^{-2\lambda_c T} + 20e^{-3\lambda_c T} - 15e^{-4\lambda_c T} + 4e^{-5\lambda_c T}}$$

$$A = \frac{77 - 300e^{-2\lambda_c T} + 400e^{-3\lambda_c T} - 225e^{-4\lambda_c T} + 48e^{-5\lambda_c T}}{60\lambda_c T}$$

and if $\lambda_c T \ll 1$, $D \approx \frac{T}{5}$ and $A \approx 1 - (\lambda_c T)^4$

FIVE REDUNDANT CHANNELS WITH 3-OUT-OF-5 COINCIDENCE LOGIC

$$D = \frac{T - \frac{10}{3\lambda_c} (1 - e^{-3\lambda_c T}) + \frac{15}{4\lambda_c} (1 - e^{-4\lambda_c T}) - \frac{6}{5\lambda_c} (1 - e^{-5\lambda_c T})}{1 - 10e^{-3\lambda_c T} + 15e^{-4\lambda_c T} - 6e^{-5\lambda_c T}}$$

$$A = \frac{47 - 200e^{-3\lambda_c T} + 225e^{-4\lambda_c T} - 72e^{-5\lambda_c T}}{60\lambda_c T}$$

and if $\lambda_c T \ll 1$, $D \approx \frac{T}{4}$ and $A \approx 1 - \frac{5}{2} (\lambda_c T)^3$

FIVE REDUNDANT CHANNELS WITH 4-OUT-OF-5 COINCIDENCE LOGIC

$$D = \frac{T - \frac{5}{4\lambda_c} (1 - e^{-4\lambda_c T}) + \frac{4}{5\lambda_c} (1 - e^{-5\lambda_c T})}{1 - 5e^{-4\lambda_c T} + 4e^{-5\lambda_c T}}$$

$$A = \frac{9 - 25e^{-4\lambda_c T} + 16e^{-5\lambda_c T}}{20\lambda_c T}$$

and if $\lambda_c T \ll 1$, $D \approx \frac{T}{3}$ and $A \approx 1 - \frac{10}{3} (\lambda_c T)^2$

FIVE REDUNDANT CHANNELS WITH 5-OUT-OF-5 COINCIDENCE LOGIC

$$D = \frac{T - \frac{1}{5\lambda_c} (1 - e^{-5\lambda_c T})}{1 - e^{-5\lambda_c T}}$$

$$A = \frac{1 - e^{-5\lambda_c T}}{5\lambda_c T} \quad \text{and if } \lambda_c T \ll 1, D \approx \frac{T}{2} \text{ and } A \approx 1 - \frac{5\lambda_c T}{2}$$

FIGURE 1. Reactor Scram Logic Elementary Diagram

FIGURE 2. *Electrical Power Failure and Reactor Vessel Coolant Level Scrams*

NOTES
1. ALL AMMUNITIONS PROVIDED BY COMMUNICATIONS SYSTEM/3

SK-3-14016

FIGURE 3. Seismoscope and Various Temperature Outlet Scrams

NOTES
ALL ANNUNCIATORS PROVIDED BY
COMMUNICATIONS SYSTEMS.

SK-3-14017

FIGURE 4. Bulk Outlet Temperature Scram Lock Diagram

FIGURE 5. Nuclear Scram Instrumentation

SK-3-14020
FIGURE 6. Surge Tank el, Containment and Additional Outlet Temperature Scrams

SK-3-14022

FIGURE 7 Flow Scram Trips

SK-3-14082

FIGURE 8. Flux/Flow Ratio Scram Trip

SK-3-14083

NOTES

NEED FOR THIS MONITOR TO BE VERIFIED BY DESIGN STUDY DURING PRELIMINARY DESIGN.

FIGURE 10. *Containment Actuation Logic*

FIGURE 11. Instrumentation Logic Circuits

FIGURE 12. Low Level Neutron Flux Subsystem Reliability Diagram

FIGURE 13. Low Level Neutron Flux Period Subsystem Reliability Diagram

FIGURE 14. Intermediate Level Neutron Flux Subsystem Reliability Diagram

FIGURE 15. *Intermediate Level Neutron Flux Period Subsystem Reliability Diagram*

FIGURE 16. Power Level Neutron Flux Subsystem Reliability Diagram

FIGURE 17. Power Level Neutron Flux Rate-of-Change Subsystem Reliability Diagram

NOTES: 1. This diagram also represents the closed loop IHX outlet temperature, and closed and open loop outlet temperature subsystems.
 2. Blocks are omitted or unlabeled to avoid repetition.

FIGURE 19. Primary Loop IHX Outlet Temperature Subsystem Reliability Diagram

FIGURE 21. Reactor Vessel Coolant Level Subsystem Reliability Diagram

FIGURE 22. Electrical Power Subsystem Reliability Diagram

FIGURE 23. Seismoscope Subsystem Reliability Diagram

FIGURE 24. Primary Loop Coolant Flow Subsystem Reliability Diagram

NOTE: Blocks are omitted or unlabeled to avoid repetition

FIGURE 1

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