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LOFT TECHNICAL REPORT LTR 128-4

EG&G REPORT NUMBER RE-A-77-005

JUNE, 1977

ALLOWABLE OUTAGE ANALYSIS
FOR THE LOFT CIS AND
REFLOOD ASSIST BYPASS VALVES

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DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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LOFT Technical Report LTR 128-4

Technical Report No. RE-A-77-005

Date June, 1977

Published by CDCS 1-19-78 *sh*

RELIABILITY AND STATISTICS
BRANCH

TECHNICAL REPORT

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LOFT TECHNICAL REPORT

TITLE Allowable Outage Analysis for the LOFT CIS and Reflood Assist Bypass Valves		REPORT NO. LTR-128-4
AUTHOR J. E. Trainer ⁹²¹ and S. D. Matthews ⁹⁰⁷	GWA NO. 52191-125-100	ACCOUNT NO.
SECTION Reliability Analysis & Statistical Analysis	Published by CDCS 1-19-78	
BRANCH Reliability and Statistics	DATE June, 1977	

ABSTRACT

To determine the outage time allowable for a typical 1 of 2 redundant valve configuration, a Markov model was created to analyze the various operating states for the valves. Since no performance criteria have been specified, an availability model was constructed with regard to the valve outage.

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The subject LTR was based on frequency information obtained from a preliminary draft of the LOFT Technical Specifications. Comparing this information with that contained in the approved Rev. 2 Technical Specifications indicates the following deviations.

1. The containment isolation system is now covered in Technical Specification section 3.6.3.1 rather than 3.3.3.3 as stated in 5.2.1 of this LTR.
2. The frequency of periodic testing the CIS valves is stated in section 5.3.4 as once per week. The current Technical Specifications (section 4.6.3.1) states the tests will be performed once every 92 days. Since the failure rate is dependent on the number of demands placed on the system, the less frequent demands placed on the system by testing would enhance the system reliability. So the conclusions reached in the LTR are still valid.
3. A reactor shutdown is stated to occur when both valves have failed in 8 hours. The current Technical Specifications requires that the reactor must be shutdown within one hour of determining both valves have failed. This shorter time enhances the reliability of the isolation system.

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1.0 Introduction

Plant technical specifications for both test and commercial nuclear reactors have, in the past, provided for a specific amount of time to restore a failed branch of a given redundant engineering safeguard during normal operations before the operators are required to bring the reactor to a shutdown condition. This outage time has been negotiated, apparently, without any technical justification for the amount of time allowed. The purpose of this report, then, is to provide a basis for the determination of the allowed outage time for components of the LOFT Containment Isolation System (CIS) and the Reflood Assist Bypass valves. Although a typical CIS valve combination was used in the determination of the final outage values, it will be shown in the following sections that the results obtained will conservatively apply to the Reflood Assist Bypass valves.

2.0 Summary of Results and Conclusions

2.1 Allowable Outage Results

An availability Markov model was constructed to represent all of the various operating states for a typical CIS redundant double-isolation valve configuration. From this model, the allowable outage for repair for 1 of 2 CIS valves is given as 684 hours. This value was calculated using a 95% lower simulation bound on the results by Monte Carlo methods. This statement says that if one valve of a pair of redundant isolation valves has been detected as failed, as many as 684 hours can be utilized to repair the one failed valve and that the required performance criteria (developed in Section 5.3 of this report) for the valve combination will be met or exceeded 95% of the time. If a higher than 95% confidence is desired in the valve outage time, Table 1 can be consulted for the appropriate bound.

VALVE ALLOWABLE OUTAGE IN HOURS

SIMULATION BOUNDS

<u>Simulation Bound (Percent)</u>	<u>Valve Allowable Outage (Hours)</u>
90.0	1956
95.0	684
97.5	264
99.0	70
99.5	31

TABLE 1

2.2 Conclusions

Due to the inherent error in the data and the assumptions made, it is recommended that at least the 95% simulation interval and preferably,

an even higher simulation bound be used as the technical specification requirement for the uncertainty spread for allowable outage. With the 95% simulation bound, as many as 684 hours can be utilized to affect a repair of a failed CIS or Reflood Assist Bypass Valve with the other valve operable and still not exceed the specified unavailability. These results support the conclusion that one valve can safely be repaired during normal operation of the reactor.

It is interesting to note from Table 1 that at the 95% simulation bound, the allowable outage time in hours exceeds the length of an expected mission. That is to say, that even if a valve were detected as failed as soon as reactor operations had begun and the corresponding redundant valve can be shown to be operable, then the entire mission (on the average, 200 hours) could be completed without degrading beyond an adequate level of plant safety. The reason this lengthy outage allowance occurs is the inherent high availability for each of the CIS valves. From Section 5.3 of this report, it can be seen that the availability for a single pneumatic automatic-closing valve is as high as that predicted for most redundant systems in WASH-1400.

The outage results presented in Section 2.1 are based on an availability model for a typical CIS double-isolation valve configuration, specifically a Type I containment penetration. The Type I classification refers to lines which connect to potential sources of radioactive contaminants. One isolation valve is located within the containment boundary, and the other valve is outside. These outage results should conservatively apply to the other CIS penetration classifications and the two Reflood Assist Bypass Valves; i.e., the calculated outage allowance for the Type I valve configuration is less than that which would have been obtained from a similar analysis of the other valve configurations for the following reasons:

- (1) Since the Type I valves are air-operated, automatic-closing valves they have higher failure rates and repair rates than any of the other types of valves (check, manual, and motor-operated) considered.
- (2) One of the Type I valves was located within the containment making it inaccessible for repair during normal operations. The other valve types are either configured this way or are both located outside the containment; an exception to the above is the reflood assist bypass valves which are both located within the containment. However, maintenance during normal operations for the two reflood assist bypass valves is limited to the proposed control instrumentation for indication of the position. The assumption is that this instrumentation will be located in a non-restricted area. Accessibility to components for repair actions enhances availability; i.e., repair considerations make it easier for a system to meet availability goals than for systems where repair is limited. In addition, the failure rate for instrumentation is less than that of the Type I air-operated valves.

3.0 System Description

Nuclear reactors have associated with them safeguards which have been provided in order to mitigate the consequences resulting from postulated accidents, e.g., the loss-of-coolant-accident (LOCA). One such safeguard is the Containment Isolation System (CIS) which is inactive during normal periods of reactor operation, but is required to minimize the leakage of fission products from the containment vessel in the event of a LOCA by activating isolation valves in ducts and piping that penetrate the containment boundary.

Figure 1

Figure 1 above is typical of the double-isolation valve combinations which are used to isolate piping penetrations through the containment vessel. This specific example is a Type I classification, indicating a line which connects directly to the primary coolant system. These valves are air-operated, automatic closing valves with indications of position in the main control room. Both are designed to remain normally open, but fail closed upon loss of instrument air, electric power, or by actuation by CIS initiation signals.

Technical specifications for LOFT require the reactor to be shutdown if at any time a test shows a safeguard to be failed. Due to the inherent redundancy designed into most engineering safeguards such as the CIS, a provision allows that any one of a pair of double-isolation valves may be

inoperative for a specified amount of time before the shutdown requirement is imposed. (As stated previously, the purpose of this report is to provide a basis for the determination of this specific allowed outage in order that plant availability can be enhanced without degrading beyond an adequate level of plant safety.) Since the CIS is mostly inactive, and it is not feasible to continuously monitor its components, some failures might occur unannounced. In order that the CIS remains in a state of readiness, its components are periodically tested or inspected. If the inspection reveals that one or more components have failed, they are subsequently repaired or replaced. Hazardous radiation levels during normal operations prevent maintenance actions on valves located within the containment; these radiation levels remain high enough to preclude repair actions on some CIS valves even though they are located outside the containment shell.

4.0 Methodology

4.1 Markov Model Review

The Markov chains can be used to model a physical process given the following properties (Ref. 7):

- i. The set of possible outcomes is finite.
- ii. The probability of the next outcome depends only on the outcome immediately preceding.
- iii. The probabilities are constant over all times.

For example, considering the 1 of 2 redundant system given in Figure 2, a truth table defining the possible operating conditions, or states, can be constructed per Table 2, where '0' denotes a failed state of the element and a '1' denotes a success state of the element.

Figure 2
1 of 2 Redundant System

SYSTEM OPERATING STATES

State	1	Block	2	Operating State 1 of 2 Required
1	0		0	Failure
2	0		1	Success
3	1		0	Success
4	1		1	Success

TABLE 2

Given the operating states defined in Table 2, the Markov state diagram can be drawn as shown in Figure 3.

Figure 3
Markov State Diagram

As shown in Figure 3, the probability of being in any state, or operating condition, at any time, t , is the probability of entering that state from another state plus the probability of remaining in that given state. Thus, mathematically the probabilities of being in any state at any time for the system shown in Figure 2 can be expressed by the following:

$$P_1(T + \Delta T) = (1 - (\mu_1 + \mu_2)\Delta T) P_1(T) + \lambda_2\Delta TP_2(T) + \lambda_1\Delta TP_3(T)$$

$$P_2(T + \Delta T) = \mu_2\Delta TP_1(T) + (1 - (\mu_1 + \lambda_2)\Delta T)P_2(T) + \lambda_1\Delta TP_4(T)$$

$$P_3(T + \Delta T) = \mu_1\Delta TP_1(T) + (1 - (\lambda_1 + \mu_2)\Delta T)P_3(T) + \lambda_2\Delta TP_4(T)$$

$$P_4(T + \Delta T) = \mu_1\Delta TP_2(T) + \mu_2\Delta TP_3(T) + (1 - (\lambda_1 + \lambda_2)\Delta T)P_4(T)$$

Then, these equations can be reduced to the following form:

$$\frac{P_1(T + \Delta T) - P_1(T)}{\Delta T} = -(\mu_1 + \mu_2)P_1(T) + \lambda_2P_2(T) + \lambda_1P_3(T)$$

$$\frac{P_2(T + \Delta T) - P_2(T)}{\Delta T} = \mu_2P_1(T) - (\mu_1 + \lambda_2)P_2(T) + \lambda_1P_4(T)$$

$$\frac{P_3(T + \Delta T) - P_3(T)}{\Delta T} = \mu_1P_1(T) - (\lambda_1 + \mu_2)P_3(T) + \lambda_2P_4(T)$$

$$\frac{P_4(T + \Delta T) - P_4(T)}{\Delta T} = \mu_1P_2(T) + \mu_2P_3(T) - (\lambda_1 + \lambda_2)P_4(T)$$

As is easily discernible if the $\lim_{\Delta T \rightarrow 0}$ of each equation is evaluated, the following differentials are derived:

$$\dot{P}_1(T) = -(\mu_1 + \mu_2)P_1(T) + \lambda_2P_2(T) + \lambda_1P_3(T)$$

$$\dot{P}_2(T) = \mu_2P_1(T) - (\mu_1 + \lambda_2)P_2(T) + \lambda_1P_4(T)$$

$$\dot{P}_3(T) = \mu_1P_1(T) - (\lambda_1 + \mu_2)P_3(T) + \lambda_2P_4(T)$$

$$\dot{P}_4(T) = \mu_1P_2(T) + \mu_2P_3(T) - (\lambda_1 + \lambda_2)P_4(T)$$

The above equations can also be expressed by the following vector notation.

$$\begin{bmatrix} \dot{P}_1(T) \\ \dot{P}_2(T) \\ \dot{P}_3(T) \\ \dot{P}_4(T) \end{bmatrix} = \begin{bmatrix} -(\mu_1 + \mu_2) & \lambda_2 & \lambda_1 & 0 \\ \mu_2 & -(\mu_1 + \lambda_2) & 0 & \lambda_1 \\ \mu_1 & 0 & -(\lambda_1 + \mu_2) & \lambda_2 \\ 0 & \mu_1 & \mu_2 & -(\lambda_1 + \lambda_2) \end{bmatrix} \begin{bmatrix} P_1(T) \\ P_2(T) \\ P_3(T) \\ P_4(T) \end{bmatrix}$$

At the steady state condition ($T \rightarrow \infty$), when the system reaches equilibrium and all the changes in the system are constant, the differentials are equal to:

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} -(\mu_1 + \mu_2) & \lambda_2 & \lambda_1 & 0 \\ \mu_2 & -(\mu_1 + \lambda_2) & 0 & \lambda_1 \\ \mu_1 & 0 & -(\lambda_1 + \mu_2) & \lambda_2 \\ 0 & \mu_1 & \mu_2 & -(\lambda_1 + \lambda_2) \end{bmatrix} \begin{bmatrix} P_1(T) \\ P_2(T) \\ P_3(T) \\ P_4(T) \end{bmatrix}$$

The resultant equations have a singular solution, but the following equation can also be substituted for any differential

$$1 = P_1(T) + P_2(T) + P_3(T) + P_4(T)$$

Thus,

$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ \mu_2 & -(\mu_1 + \lambda_2) & 0 & \lambda_1 \\ \mu_1 & 0 & -(\lambda_1 + \mu_2) & \lambda_2 \\ 0 & \mu_1 & \mu_2 & -(\lambda_1 + \lambda_2) \end{bmatrix} \begin{bmatrix} P_1(T) \\ P_2(T) \\ P_3(T) \\ P_4(T) \end{bmatrix}$$

These equations have the form $A = BX$ and by matrix inversion: $B^{-1}A = X$. The resultant values will then provide the probabilities of being in each state i for the system shown in Figure 2 at the equilibrium time T .

The availability of this system is merely the sum of the probabilities of the success states. Thus, the system availability is: $A_{sys} = P_2(T) + P_3(T) + P_4(T)$.

5.0 Analysis Procedures

5.1 Markov Model Analysis

Referring to Figure 1 and the accompanying discussion in Section 3 of this report, the redundant double-isolation valves provided for each containment penetration can be represented by the reliability block diagram as shown in Figure 4:

Figure 4

Success for the above model requires that one of the two valves must be operable, i.e., be able to change state from the open to the closed position, for successful containment isolation. No repair is considered for valve 2 due to its location within the containment, while valve 1 is assumed to be located in a non-restricted area allowing repair when its failure has been detected.

In order to evaluate how long a given valve can be out, essentially operating with a non-redundant CIS, it was necessary to construct an availability Markov model which represents all of the various operating states for the double valve combination of Figure 4. This methodology was discussed previously in Section 4.1 of this report entitled "Markov Model Review".

Since the CIS valves are only shown to be operational on a demand or test basis, the operating state of each valve cannot be definitely determined without inspection. Thus, there are two operating states (good and failed) and there are two inspection states (condition known and condition not tested yet), for a total of 2^4 or 16 states for the two CIS valves as shown in Table 3. However, not all 16 states are valid. For example, an invalid state, or contradictory state, is state "1001", since it is illogical that the status of valve 2 would be known without knowing the status of valve 1. A basic assumption during this analysis is that the corresponding valve will be tested for operability when one of a pair of isolation valves has been detected as failed.

From the states listed in Table 3, an availability Markov model state diagram can be drawn as shown in Figure 5. It should be noted that the states in Figure 5 correspond to the respective success and failure states given in Table 3. The transition rates for the various states are described in Section 5.3, System Parameters.

A discussion of the Markov Model is as follows:

It is assumed that prior to the start of operations or a "mission", it has been demonstrated that both valves are operable as required by the technical specifications, representing state 1. As soon as the mission is underway there is an instantaneous transition to state 2 where both valves are operable but the status is not known. From state 2, valve 1 can fail at the rate of λ to state 6. Similarly valve 2 can fail to state 3. Before either of these failures are detected, the corresponding valve could fail, leading to state 7 from either state 6 or state 3. When inspection reveals that valve 1 is failed and valve 2 is operable, two transitions from state 4 are possible. Either valve 1 is repaired in the maximum amount of time allowed (which is the value that is solved for in this report) or valve 2 also fails

TABLE 3
MARKOV MODEL STATES FOR 1 OF 2
CIS ALLOWABLE OUTAGE ANALYSIS

<u>State</u>	<u>Valve 1 Operating State</u>	<u>Valve 1 Status</u>	<u>Valve 2 Operating State</u>	<u>Valve 2 Status</u>	<u>Comment</u>
7	0	0	0	0	Failed
	0	0	0	1	Not Valid
6	0	0	1	0	Success
	0	0	1	1	Not Valid
	0	1	0	0	Not Valid
5	0	1	0	1	Failed
	0	1	1	0	Not Valid
4	0	1	1	1	Success
3	1	0	0	0	Success
	1	0	0	1	Not Valid
2	1	0	1	0	Success
	1	0	1	1	Not Valid
	1	1	0	0	Not Valid
8	1	1	0	1	Success
	1	1	1	0	Not Valid
1	1	1	1	1	Success

Note: "1" denotes success and condition known.

"0" denotes failure and condition unknown prior to inspection.

Legend:

λ = CIS Valve Failure Rate
 μ = CIS Valve Repair Rate
 ν = Inspection Rate
 ρ = Reactor Shutdown Rate
 X = CIS (1 of 2) Allowable Outage Rate

Figure 5
CIS Valves Markov Model
State Diagram

State Annotation: X X X X

Valve 2 Status
 (1 - Condition Known,
 0 - Condition Unknown)
 Valve 2 Operating State
 (1 - Success, 0 - Fail)
 Valve 1 Status
 (1 - Condition Known,
 0 - Condition Unknown)
 Valve 1 Operating State
 (1 - Success, 0 - Fail)

before the repair is completed resulting in the failed condition of state 5. When inspection reveals that valve 2 is failed and valve 1 is operable (state 8) and considering that valve 2 is located within the containment preventing repair, a shutdown would be required by the technical specifications if the allowed outage time is less than the time required to complete the mission. This situation is shown on the model as the transition at the shutdown rate ρ to state 8*. After shutdown, the valve could be repaired back to the all good state 2 at the average repair rate μ . However, from state 8, valve 1 could also fail before shutdown is completed, resulting in failed state 5. Failed state 5 can also be reached from state 7 when inspection reveals that both valves are in a failed condition. Since technical specifications don't permit both valves to be out simultaneously, an immediate shutdown from state 5 to state 5* is required. Once down, then both valves can be repaired back to the all good state 2. The probability of remaining in each state is shown on the self-loops in the model. For example, the probability of remaining in state 4 is one minus the probability of leaving state 4 $[1 - (\lambda + X)\Delta T]$.

Using the various input parameters and the methodology described in Section 4.0, the Markov model can be solved for the outage time allowable for 1 of 2 CIS valves. Section 5.4 describes the solution of the Markov model.

5.2 Assumptions

The following are assumptions which were made in performing the analysis:

1. The provisions of Section 3.3.3.3 of the LOFT Technical Specifications regarding the Containment Isolation System valves are applicable to this analysis. The basic assumption applied from the specifications is that only one of a pair of double-isolation valves can be inoperative for a "To Be Determined" period of time during reactor operations,

2. Some CIS valves and the Reflood Assist Bypass (RAB) valves are inaccessible due to location.
3. Corrective maintenance tasks on CIS and RAB valves or associated components are performed in non-restricted areas and with due concern for safety.
4. The corresponding valve will be tested for operability when one of a pair of double-isolated valves have been detected as failed.
5. It is assumed that the control instrumentation contemplated to be added for indicating the position of the two Reflood Assist Bypass valves will be located in a non-restricted area.
6. Transition from the "all good" state 1111 to the state where both valves are working but their status is unknown (state 1010) is assumed to occur instantaneously.
7. The availability model derived in Section 5.1 assumed constancy for the input parameters for the entire time period.
8. The condition of the CIS and RAB valves is immediately known upon inspection.

5.3 System Parameters

5.3.1 Availability

Performance criteria, such as preassigned reliability or availability numerical "goals", have not been established for reactor engineering safeguards. However, solving the availability model, which was constructed to express the CIS double-isolation valves performance, requires some determination of availability that the combination must satisfy. Therefore, a median availability was calculated for the redundant valves using the geometric mean method as documented in the WASH-1400 study. This value was determined as follows:

From WASH-1400, the unavailability ($\bar{A}$) for an air-operated valve failing to operate is 3×10^{-4} /demand. Using this pure probability value for each of the redundant valves and if complete independence between the valves is assumed, their combined unavailability is:

$$\bar{A} = (3.0 \times 10^{-4})(3.0 \times 10^{-4}) = 9.0 \times 10^{-8}$$

If complete dependence between the valves is assumed, the unavailability for both is the same as for one, 3.0×10^{-4} . Thus, the median value lies somewhere between these two values and is calculated by:

$$\begin{aligned}\bar{A}_{\text{median}} &= \sqrt{(3.0 \times 10^{-4})(9.0 \times 10^{-8})} \\ \bar{A}_{\text{median}} &= 5.2 \times 10^{-6}\end{aligned}$$

The availability is equal to one minus the unavailability or

$$A = 1 - \bar{A} = 1 - (5.2 \times 10^{-6})$$

$$A = 0.9999948.$$

The above figure was used as the basis for determining the allowed outage as reported in Section 2. That is to say, if the allowed outage time for repair does not exceed the calculated figure, then the availability of the CIS double-isolation valves will not be less than the availability constraint as reported above. With few exceptions, the availability reported for various PWR and BWR redundant systems in WASH-1400 ranged from 0.999 to 0.99999 with the majority grouped around the lower figure; thus, the calculated median availability for the redundant valves as shown above provides a conservative constraint that the system must perform to. In other words, as the availability becomes larger, less and less downtime can be allowed and still meet the availability goal or constraint.

5.3.2 Failure Rate

On the average, the CIS valves are actuated or demanded weekly, thus the failure rate (λ) for an air-operated valve failing to operate can be calculated as:

$$\lambda = \frac{\text{Unavailability}}{\text{Demand Frequency}} = \frac{3 \times 10^{-4} \text{ fail/demand}}{168 \text{ hours}} = 1.78 \times 10^{-6} \text{ failures/hour}$$

5.3.3 Repair Rate

The repair rate for the CIS valves used in the solution of the Markov model was taken from RE-S-77-10, "Estimated Component Repair Times for ECC and Containment Isolation Systems During LOFT Operation". The repair rate (μ) is equal to:

$$\mu = \frac{1}{\text{mean-time-to-repair}}$$

MTR from the above referenced report for CIS pneumatic valves is 12 hours.

$$\mu = \frac{1}{12 \text{ hours}} = 0.083 \text{ repairs/hour.}$$

5.3.4 Inspection Rate

As the CIS valves are actuated only on a demand basis, the valves must be tested periodically to determine the condition of each valve. Until the inspection occurs, the operating condition of the valves cannot be definitely ascertained. However, on the average, the time to detect a failure after a failure occurs between inspections is one-half the inspection interval. So, mathematically, the inspection time used is one-half the inspection interval. Although it is felt that most failures would be detected within one or two operating shifts, the inspection interval was conservatively taken as the weekly demand period of 168 hours. The inspection rate (ν) is equal to:

$$\nu = \frac{1}{1/2 \text{ inspection interval}} = \frac{1}{84 \text{ hours}} = .012 \text{ inspections/hour}$$

5.3.5 Reactor Shutdown Rate

The final system parameter used in the Markov model was the reactor shutdown rate. The technical specifications presently dictate that when both CIS valves are found to be failed, or if one failure exceeds a specified amount of time, then the reactor must be shutdown until a repair can be affected. A normal reactor shutdown was assumed to be 8 hours. The shutdown rate (ρ) is equal to:

$$\rho = \frac{1}{\text{shutdown time}} = \frac{1}{8 \text{ hours}} = 0.125 \text{ shutdowns/hour.}$$

These system parameters used in the solution of the CIS valve Markov model analysis are summarized in Table 4 below:

TABLE 4
CIS AVAILABILITY MODEL PARAMETERS

<u>Item</u>	<u>Value</u>
1. Unavailability for the Redundant Valves	5.2×10^{-6}
2. CIS Valve Failure Rate (failures/hr.)	1.78×10^{-6}
3. CIS Valve Repair Rate (repairs/hr.)	8.3×10^{-2}
4. Reactor Shutdown Rate (shutdowns/hr.)	1.25×10^{-1}
5. CIS Valve Inspection Rate (inspections/hr.)	1.2×10^{-2}

5.4 Markov Model Solution

From the Markov state diagram provided in Figure 5, the diagram can be reduced to a mathematical model as indicated in Section 4.0. The Markov model probability equations are given in matrix form by Figure 6. These equations have the matrix form:

$$Y = AP,$$

Then, by matrix inversion, the equations assume the form:

$$\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ \lambda & -(\lambda+\nu) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -(\lambda+\chi) & 0 & 0 & \nu & 0 & 0 & 0 \\ 0 & 0 & \lambda & -\rho & 0 & 0 & 0 & \lambda & 0 \\ 0 & 0 & 0 & \rho & -\frac{\mu}{2} & 0 & 0 & 0 & 0 \\ \lambda & 0 & 0 & 0 & 0 & -(\lambda+\nu) & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & 0 & \lambda & -\nu & 0 & 0 \\ 0 & 0 & \nu & 0 & 0 & 0 & 0 & -(\lambda+\rho) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho & -\mu \end{bmatrix} \begin{bmatrix} P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_{5^*} \\ P_6 \\ P_7 \\ P_8 \\ P_{8^*} \end{bmatrix}$$

Figure 6
Markov Model State Transition
Probability Matrix

$$A^{-1}Y = P,$$

These state probabilities, P , have the form indicated by Figure 7.

Since the availability for the CIS valves, or the sum of the probabilities of the success states, is given by:

$$A_{\text{valves}} = P_2 + P_3 + P_4 + P_6 + P_8 + P_{8*}$$

the outage allowable can be solved in terms of the given valve availability. Algebraically, then, the outage allowable can be expressed as a function of the availability and state probabilities. The various state probabilities are shown by Figure 8. The outage allowable for 1 or 2 valves is given by the equation in Figure 9.

5.5 Monte Carlo Analysis

In order to provide some degree of confidence in the CIS valves allowable outage results given in Section 5.4, an error bound calculation was necessary. Monte Carlo Simulation (MOCARS) code was chosen to provide error bounds on the allowable outage results. The only inputs required for MOCARS were the Monte Carlo sample size, the type of distribution to sample the data from, the median input values and the error factors.

The sampling distributions were chosen for each of the respective parameters in the model on the basis of how well the distribution simulates the empirical failure or repair times. As shown in Reference 9, the exponential distribution can be chosen as a failure distribution if the failures of the valves are random rather than due to wearout. This concept seems reasonable for the valves in question considering the low incidence of usage. Also shown in Reference 9, the lognormal distribution has applicability as a model for maintainability problems. Thus, the lognormal distribution was used to model the valve repair rate. Finally, the normal distribution was used to model the shutdown and inspection rates. Since any deviation from the mean shutdown

$$\begin{array}{l}
 P_2 \\
 P_3 \\
 P_4 \\
 P_5 \\
 P_{5*} \\
 P_6 \\
 P_7 \\
 P_8 \\
 P_{8*}
 \end{array}
 =
 \begin{array}{l}
 1/\alpha \\
 \frac{\lambda}{(\lambda+v) \cdot \alpha} \\
 \lambda v / (\lambda+v)(\lambda+X)\alpha \\
 \frac{1}{\alpha} \left[\frac{\lambda^2 v}{\rho(\lambda+v)(\lambda+X)} + \frac{\lambda^2 v}{\rho(\lambda+v)(\lambda+\rho)} + \frac{2\lambda^2}{\rho(\lambda+v)} \right] \\
 \frac{1}{\alpha} \left[\frac{2\lambda^2 v}{\mu(\lambda+v)(\lambda+X)} + \frac{2\lambda^2 v}{\mu(\lambda+v)(\lambda+\rho)} + \frac{4\lambda^2}{\mu(\lambda+v)} \right] \\
 \lambda / (\lambda+v)\alpha \\
 2\lambda^2 / v(\lambda+v)\alpha \\
 \lambda v / (\lambda+v)(\lambda+\rho)\alpha \\
 \lambda v \rho / \mu(\lambda+v)(\lambda+\rho)\alpha
 \end{array}$$

where $\alpha = 1 + \lambda v \rho / \mu(\lambda+v)(\lambda+\rho) + \lambda v / (\lambda+v)(\lambda+\rho) + 2\lambda^2 / v(\lambda+v) + \lambda / \lambda+v + 2\lambda^2 v / \mu(\lambda+v)(\lambda+X) + 2\lambda^2 v / \mu(\lambda+v)(\lambda+\rho) + 4\lambda^2 / \mu(\lambda+v) + \lambda^2 v / \rho(\lambda+v)(\lambda+X) + \lambda^2 v / \rho(\lambda+v)(\lambda+\rho) + 2\lambda^2 / \rho(\lambda+v) + \lambda v / (\lambda+v)(\lambda+X) + \lambda / (\lambda+v)$

X = rate to repair 1 of 2 valves (allowable outage rate)

μ = repair rate for valve within containment

v = inspection

ρ = shutdown rate

λ = failure rate

Figure 7

State Probabilities

$$\begin{bmatrix} P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_{5*} \\ P_6 \\ P_7 \\ P_8 \\ P_{8*} \end{bmatrix} = \begin{bmatrix} .9978 \\ 1.676 \times 10^{-4} \\ 1.794 \times 10^{-3} \\ 2.880 \times 10^{-8} \\ 8.640 \times 10^{-8} \\ 1.676 \times 10^{-4} \\ 5.632 \times 10^{-8} \\ 1.34 \times 10^{-5} \\ 2.0152 \times 10^{-5} \end{bmatrix}$$

Figure 8
Markov Model State Probabilities

$$\text{Outage Allowable} = \frac{1}{\left[\text{Availability} \cdot \left(\frac{1+\lambda\nu\rho}{\mu(\lambda+\nu)(\lambda+\rho)} + \frac{\lambda\nu}{(\lambda+\nu)(\lambda+\rho)} + \frac{2\lambda^2}{\nu(\lambda+\nu)} + \frac{2\lambda}{(\lambda+\nu)} + \frac{2\lambda^2\nu}{\mu(\lambda+\nu)(\lambda+\rho)} + \frac{4\lambda^2}{\mu(\lambda+\nu)} + \frac{\lambda^2\nu}{\rho(\lambda+\nu)(\lambda+\rho)} + \frac{2\lambda^2}{\rho(\lambda+\nu)} - \left(1 + \frac{2\lambda}{\lambda+\nu} + \frac{\lambda\nu}{(\lambda+\nu)(\lambda+\rho)} \right) + \frac{\lambda\nu\rho}{\mu(\lambda+\nu)(\lambda+\rho)} \right)]}$$

Figure 9
Allowable Outage Calculation

or mean inspection times are expected to be random and symmetric about the mean values, the normal distribution was chosen as a model for both the shutdown and inspection times (Reference 10).

The input parameter values and sampling distribution for each of the parameters in the model are shown in Table 5. It should be noted that because of inherent errors in the basic failure probability used in calculating the availability via the geometric mean approach, the input for the availability used the basic failure probability and the exponential distribution as a sampling distribution. Also, it should further be noted that the values for the shutdown time and the inspection time were entered into the Monte Carlo Simulation (MOCARS) code. After deriving an appropriate sampling value for the shutdown and inspection times, the MOCARS code converted the shutdown and inspection times to the appropriate rates for use in the outage allowable model.

Using the input values and sampling distributions for the parameters shown in Table 5, MOCARS used a sample size of 5000 to evaluate the outage allowable rate.

TABLE 5
MONTE CARLO SIMULATION PARAMETERS

<u>Input Parameters</u>	<u>Parameter Values</u>	<u>Sampling Distribution</u>
1. Availability	Mean: 3×10^{-4}	Exponential
2. Valve Failure Rate	Mean: 1.78×10^{-6}	Exponential
3. Valve Repair Rate	Median: 8.33×10^{-2} Error Factor: 3	Lognormal
4. Shutdown Time	Mean: 8 Standard Deviation: 2	Normal
5. Inspection Time	Mean: 84 Standard Deviation: 42	Normal

With the values given, the Monte Carlo MOCARS routine provided the error bound calculations for the CIS valve allowable outage results. At least the 95% simulation interval was desired to ensure adequate confidence and integrity in the CIS valves allowable outage. Table 6 provides the results of the Monte Carlo error bound analysis.

The results in Table 6 provide that as many as the stated number of hours for a desired simulation interval can be utilized in repairing a failed CIS valve and the unavailability goal as calculated by the WASH-1400 geometric mean method in Section 5.3 will not be exceeded with the stated degree of confidence.

TABLE 6
MONTE CARLO ERROR BOUND ANALYSIS

<u>Distribution Simulation Bound</u>	<u>Function Value</u>	<u>Allowable Outage (Hours)</u>
90.0	5.11×10^{-4}	1956
95.0	1.46×10^{-3}	684
97.5	3.78×10^{-3}	264
99.0	1.41×10^{-2}	70
99.5	3.21×10^{-2}	31

6.0 References and Drawings

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