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WANL-TME-1737

February 11, 1968

Westinghouse Astronuclear Laboratory

XE-1 PNEUMATIC ACTUATOR FAILURE MODE ANALYSIS

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February 11, 1968

WESTINGHOUSE ELECTRIC CORPORATION

Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

XE-1 PNEUMATIC ACTUATOR FAILURE MODE ANALYSIS

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Prepared By:

I. R. Spezialetti

I. R. Spezialetti
Reliability Engineering

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TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
INTRODUCTION	1
DESCRIPTION	2
CONCLUSION	5
FAILURE MODE ANALYSIS	6 - 27
TABLE I	28

WANL-TME-1737

CONTROL DRUM PNEUMATIC ACTUATOR

XE-1 PNEUMATIC ACTUATOR FAILURE MODE ANALYSIS

SUMMARY

A failure mode analysis of the XE-1 Pneumatic Actuator Mechanism has been conducted. This report presents a detailed analysis of the mechanism, and conclusions regarding the likely failure modes.

On the basis of the failure mode analysis the XE-1 Pneumatic Actuator Mechanism was found to have no failure mode producing a critical or hazardous condition.

INTRODUCTION

The purpose of this report is to present the detailed results of the analysis of the XE-1 Pneumatic Actuator Mechanism and the conclusions regarding the likely failure modes that exist.

The failure mode analysis of the XE-1 Pneumatic Actuator Mechanism was conducted by the subcontractor, General Electric*, in compliance with WANL contractual requirements. The significant failure modes as determined by that analysis have been listed on the WANL Failure Mode Analysis Worksheets included in this report. Each failure mode is considered as to the possible cause, its effect, the frequency of occurrence (including the failure rate per 10^6 hours as determined by GE) and the status of any corrective action that may be required. (The symbols used on the worksheets are identified in Table 1.)

*

"Failure Mode and Effects Analysis of XE-1 Pneumatic Control Drum Actuator",
DMS 66-3 of August 15, 1966.

The worksheets also include a listing of certain failure modes as encountered by WANL* with the actual XE-1 actuators.

DESCRIPTION

The XE-1 Pneumatic Actuator Mechanism is a hydrogen gas driven servo sub-system designed to rotate the control drums of the XE-1 reactor. Each of twelve pneumatic actuators is connected mechanically to a control drum assembly.

Each control drum assembly is equipped with a relatively strong "Scram" spring which functions to rotate the actuator toward the decrease reactivity direction, both under normal and scram conditions. The actuators power the control drums in the increase reactivity direction only, and function to limit the rate of control drum rotation in the decrease reactivity direction, caused by the force of the scram spring.

The actuator description can be simplified by grouping the elements into two categories. First, those that are basic to accomplish the function of providing rotary output motion and, second, those that provide secondary (sometimes interrelated) functions. All elements are mounted to, or integrated into, a forged aluminum housing which forms the actuator basic structure.

1. Description of Basic Elements

The following elements comprise the basic actuator.

1.1 A two sided single stage servo valve (with dynamic pressure feedback) regulates the control gas pressures that are ducted to opposing ends of pistons which are

*

Letter dated November 15, 1967, W. H. Arnold to J. L. Dooling; Subject: Problem Chronology - XE Control Drum Actuators.

attached to each end of a rack.

1.2 The rack engages an output shaft pinion gear, thus converting the piston linear motion to the desired rotary output motion.

1.3 The rack is held in engagement with the pinion gear by a spring loaded bearing carrier.

1.4 A three cup position potentiometer is mounted to the actuator housing and is connected to the shaft output coupling. The three cups (for redundancy) are for control feedback, and a buffered redundant output is used for remote indication of actuator position.

1.5 Forged aluminum covers cap the two piston cylinders and the servo valve; a machined cover encloses the potentiometer. These covers and the housing form a pressure vessel structure, designed for and proof pressure tested at 1000 psi.

2. Description of Secondary Elements

2.1 Soft Stop Spring

A soft stop spring is utilized to limit the maximum deceleration of the load inertia at both ends of the actuator stroke. Action takes place from 15° to 0° in the decrease direction and from 165° to 180° in the increase direction.

2.2 Rebound Spring

A rebound spring limits drum rebound resulting from a scram penetration into the soft stop zone.

2.3 Lock System

A double lock system prevents inadvertent operation of the actuator.

It is incorporated primarily for personnel safety during hot reactor ground testing.

The system incorporates a key operated primary 'manual lock' that over-rides a secondary, electrically operated actuator shaft lock pin.

A set of switches are actuated by the lock pin to provide external electrical position indication of the secondary lock.

2.4 Cooling Provisions

Cooling gas is routed, by specially determined paths, through the actuator to provide control of temperature due to the radiation heating.

Gas enters the unit through a filter and seal assembly at the actuator/pedestal interface. After passing through the actuator, the gas exists through an exhaust port, also located at the actuator/pedestal interface.

The total cooling gas flow is determined by the clearance area of two 'gap' seals and is, therefore, variable over a considerable range to suit changing needs.

2.5 Double External Sealing

Double static seals are provided on all cover flanges. The space between the seals is ducted to the actuator/pedestal interface flange, where it communicates with a low pressure exhaust port in the pedestal.

CONCLUSIONS

On the basis of the failure mode analysis, the XE-1 Pneumatic Actuator Mechanism was found to have no failure mode producing a critical or hazardous condition, except in the unlikely event of multiple actuator failures.

The analysis also revealed that failures which result in actuator position movement toward increased reactivity, or which prevent the actuator from returning to the minimum position upon command, have a low probability and are of a fatigue and greatest flaw type of failure.

It was also revealed that failures causing or requiring the actuator to return to the minimum position, or result in actuator movement toward decreased reactivity, also have a low probability and are of a fatigue and greatest flaw type of failure.

The effect of all these failures can not cause a reactor failure but could result in degradation of test performance and endurance.

Regarding the problems encountered by WANL with the actual XE-1 actuators, many were insignificant in that the functional requirements of the actuator were not affected. However, the problems were corrected.

Those problems having some affect on actuator functional requirements have also had corrective action taken. It should be noted that in some cases the problems were encountered at other than design conditions; however, corrective action was taken to prevent potential difficulties.

FAILURE MODE ANALYSIS XE-1 Pneumatic Actuator Mechanism

Title: _____ Ident. Code: _____ Description, Sketch or Reference: WANL 938J485GO1

System: XE-1 Engine Test System XE-1

Assembly: Pneumatic Actuator Mechanism

Part: _____

Material: _____

Function: To Position A Control Drum In Response To Command From Actuator Control Amplifier

Related FMA Sheet No.: _____

Operating Conditions & Environment: _____ By: L. R. Spezialetti Date: 2/11/68 Sheet: 1 of 22

* Failure Rates per 10^6 hours from GE Report DMS-66-3, of August 15, 1966.

Failure Mode	Possible Cause	Effect			Severity Code	* Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator jams in maximum operating position.	Seizure of piston and cylinder liner.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 1.60 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator jams in maximum operating position.	Piston ring fractures and seizes.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.60 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 2 of 22

Failure Mode	Possible Cause	Effect		Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test				
Actuator jams in maximum operating position.	Rack and pinion seizure.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.50 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator jams in maximum operating position.	Rack fractures and jams pinion.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.01 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator jams in maximum operating position.	Mechanical stop fractures and jams mechanism.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.005 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.

Form 59653
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WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____ Ident. Code: _____ Date: 2/11/68 Sheet: 3 of 22

Failure Mode	Possible Cause	Effect		Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test					
Actuator jams in maximum operating position.	Marmon clamp fractures or loosens causing mechanism to jam.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.50 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator jams in maximum operating position.	Output shaft ball bearing seizes or breaks.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.90 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator jams in some operating position between minimum and maximum.	Seizure of piston and cylinder liner.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.40 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 4 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator jams in some operating position between minimum and maximum.	Piston ring fractures and seizes.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.60 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator jams in some operating position between minimum and maximum.	Rack and pinion seizure.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.90 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator jams in some operating position between minimum and maximum.	Rack fractures and jams pinion.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.16 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
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WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____ Ident. Code: _____ Date: 2/11/68 Sheet: 5 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator jams in some operating position between minimum and maximum.	Mechanical stop fractures and jams mechanism.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.09 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator jams in some operating position between minimum and maximum.	Marmon clamp fractures or loosens causing mechanism to jam.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 2.00 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator jams in some operating position between minimum and maximum.	Output shaft ball bearing seizes or breaks.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.90 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
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FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 6 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator jams in some operating position between minimum and maximum.	Wave washer fractures.	A single actuator failure renders one control drum inoperable and could result in core temperature profile distortion. Multiple failures may affect reactor scram capability, depending on number actuators operable and shutdown margin available.	CR	-	NP	L 0.007 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to maximum out position; unable to scram pneumatically.	Torque motor seizes.	The failure of a single actuator would result in loss of control over one control drum and cause core temperature profile distortion.	CR	-	NP	L 0.15 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to maximum out position; unable to scram pneumatically.	P ₂ orifice faults.	The failure of a single actuator would result in loss of control over one control drum and cause core temperature profile distortion.	CR	-	NP	L 0.25 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	

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WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____ Ident. Code: _____ Date: 2/11/68 Sheet: 7 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator fails to maximum out position; unable to scram pneumatically.	P ₂ bellows screw loosens.	The failure of a single actuator would result in loss of control over one control drum and cause core temperature profile distortion.	CR	-	NP	L 0.06 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to maximum out position; unable to scram pneumatically.	P ₂ bellows yields or fractures.	The failure of a single actuator would result in loss of control over one control drum and cause core temperature profile distortion.	CR	-	NP	L 0.25 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Loss of feedback signal.	Potentiometer coupling and shaft shears.	The failure of a single actuator would result in loss of control over one control drum and cause core temperature profile distortion.	CR	-	NP	L 0.905 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator position is in error.	Potentiometer mounting fractures causing change in pot position.	The failure of a single actuator would result in unknown control drum position and could cause core temperature profile distortion.	CR	-	NP	L 1.08 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 8 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator position is in error.	Potentiometer coupling deforms.	The failure of a single actuator would result in unknown control drum position and could cause core temperature profile distortion.	CR	-	NP	L 0.085 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator position is in error.	Potentiometer clamp loosens.	The failure of a single actuator would result in unknown control drum position and could cause core temperature profile distortion.	CR	-	NP	L 1.08 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator position is in error.	Potentiometer changes position.	The failure of a single actuator would result in unknown control drum position and could cause core temperature profile distortion.	CR	-	NP	L 0.43 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator position is in error.	Rebound spring fractures.	The failure of a single actuator would result in unknown control drum position and could cause core temperature profile distortion.	CR	-	NP	L 0.15 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 9 of 22

Failure Mode	Possible Cause	Effect		Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test					
Actuator fails to the minimum position.	P ₁ orifice fouls.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.25 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator fails to the minimum position.	Torque motor seizes.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.15 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator fails to the minimum position.	Loss of drive current to torque motor.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.01 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Actuator fails to the minimum position.	Torque motor current shorted thru the connector.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.015 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 10 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator fails to the minimum position.	Cylinder cover cracks or leaks.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.009 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to the minimum position.	Seizure of piston and cylinder liner.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 1.60 per 10^6 hr.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to the minimum position.	Piston ring fractures and seizes.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.60 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to the minimum position.	Rack and pinion seizure.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.30 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____ Ident. Code: _____ Date: 2/11/68 Sheet: 11 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator fails to the minimum position.	Rack fractures and jams pinion.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.03 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to the minimum position.	Pinion gear shaft shears.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.40 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to the minimum position.	Mechanical stop fractures and jams mechanism.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 0.005 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator fails to the minimum position.	Marmon clamp fractures or loosens causing mechanism to jam.	The failure of a single actuator would render one control drum inoperable. Could result in core temperature profile distortion.	CR	-	NP	L 2.50 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
Attachment Sheet

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 12 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Overtemperature of the actuator.	Servo valve cover cracks or loosens.	The effects of an over-temperature condition depend upon the cause and the degree. Overtemperature due to coolant leakage can result in local hot spots and may or may not degrade actuator performance. Loss of coolant flow is more critical and may result in an inoperable actuator.	CR	-	NP	L 0.026 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Overtemperature of the actuator.	Seals do not seal properly and permit coolant leakage.	The effects of an over-temperature condition depend upon the cause and the degree. Overtemperature due to coolant leakage can result in local hot spots and may or may not degrade actuator performance. Loss of coolant flow is more critical and may result in an inoperable actuator.	CR	-	NP	L 0.109 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	Interface seal surface now protected by a full surface rubber gasket during shipping. Also, shipping adapters reworked to remove rough edges.

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____ Ident. Code: _____ Date: 2/11/68 Sheet: 13 of 22

Failure Mode	Possible Cause	Effect		Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test					
Overtemperature of the actuator.	Potentiometer cover cracks or loosens.	The effects of an over-temperature condition depend upon the cause and the degree. Overtemperature due to coolant leakage can result in local hot spots and may or may not degrade actuator performance. Loss of coolant flow is more critical and may result in an inoperable actuator.	CR	-	NP	L 0.012 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.
Overtemperature of the actuator.	Coolant inlet filter clogs.	The effects of an over-temperature condition depend upon the cause and the degree. Overtemperature due to coolant leakage can result in local hot spots and may or may not degrade actuator performance. Loss of coolant flow is more critical and may result in an inoperable actuator.	CR	-	NP	L 0.10 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 14 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Coolant leakage externally from the actuator.	Mounting flange cracks.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.045 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Coolant leakage externally from the actuator.	Servo valve cover cracks.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.015 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Coolant leakage externally from the actuator.	Potentiometer cover cracks.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.15 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Coolant leakage externally from the actuator.	Actuator housing cracks.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.029 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 15 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Coolant leakage externally from the actuator.	Cylinder cover cracks.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.176 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Coolant leakage externally from the actuator.	Lock bellows loosens or leaks.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.525 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Coolant leakage externally from the actuator.	Seals do not seal properly permit coolant leakage.	The effects of coolant leakage, excluding overtemperature conditions, is negligible. Any leakage will dump into an inerted chamber.	R	-	NP	L 0.38 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	Interface seal surface now protected by a full surface rubber gasket during shipping. Also, shipping adapters reworked to remove rough edges.
Reduction of actuator operating range.	Servo valve manifold cracks.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.006 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

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Attachment Sheet

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 16 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Reduction of actuator operating range.	Servo valve seal leaks.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.008 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Reduction of actuator operating range.	Porous orifice faults.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 1.00 per 10^6	NACT	No action required. Adequate environmental testing has been performed.	
Reduction of actuator operating range.	P ₁ cylinder cover cracks and leaks.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.171 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Reduction of actuator operating range.	Actuator housing cracks and bleeds P ₁ pressure.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion. Gross leakage may starve supply to other actuators.	CR	-	NP	L 0.004 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 17 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Reduction of actuator operating range.	Supply gas filter clogs.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.52 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Reduction of actuator operating range.	Potentiometer changes position.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.258 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Reduction of actuator operating range.	Potentiometer has open track.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.08 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Reduction of actuator operating range.	Potentiometer coupling deforms.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.009 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

Form 59653
Attachment Sheet

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 18 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Reduction of actuator operating range.	Potentiometer mounting fractures.	The failure of a single actuator would result in loss of complete control over one control drum and could cause core temperature profile distortion.	CR	-	NP	L 0.03 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator becomes unstable.	Servo valve increases gain.	The failure of a single actuator would result in loss of complete control over one control drum. Actuator would probably "hunt" and affect core temperature profile.	CR	-	NP	L 0.032 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator becomes unstable.	Rack and pinion break a tooth.	The failure of a single actuator would result in loss of complete control over one control drum. Actuator would probably "hunt" and affect core temperature profile.	CR	-	NP	L 0.30 per 10 ⁶ hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator will not unlock.	Lock seizes or breaks.	Reactor test will not be started, until repairs made.	R	-	NP	L 0.057 per 10 ⁶ hrs.	CMPLT	No action required. Adequate environmental testing has been performed.	Lock cylinders honed to improve surface finish and increase clearance.

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____ Ident. Code: _____ Date: 2/11/68 Sheet: 19 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator will not unlock.	Lock pin bends.	Reactor test will not be started, until repairs made.	R	-	NP	L 0.003 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	Less brittle and more radiation resistant insulation used for coil wire. Also, a varnish applied as a filler and binder within the coil.
Actuator will not unlock.	Solenoid valve fouls or cocks.	Reactor test will not be started, until repairs made.	R	-	NP	L 2.40 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator will not unlock.	Solenoid coil opens or shorts.	Reactor test will not be started, until repairs made.	R	-	NP	L 3.20 per 10^6 hrs.	CMPLT	No action required. Adequate environmental testing has been performed.	
Actuator will not unlock.	Solenoid leads short.	Reactor test will not be started, until repairs made.	R	-	NP	L 0.06 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator will not unlock.	Piston seizes in cylinder liner.	Reactor test will not be started, until repairs made.	R	-	NP	L 0.84 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	
Actuator will not unlock.	Seals leak and do not permit sufficient pressure buildup.	Reactor test will not be started, until repairs made.	R	-	NP	L 0.013 per 10^6 hrs.	NACT	No action required. Adequate environmental testing has been performed.	

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 20 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator performance erratic, using helium as test medium, and when testing without coolant being supplied.	Sensitivity to friction at low gain settings of the servo valve.	Erratic performance of actuators would result in erratic operation of the reactor under certain conditions. The likelihood of the conditions causing erratic performance is remote since the conditions are different than those for power testing. However, to increase design safety margins action was taken as noted.	R	-	NP	L	CMPLT	Reduce friction between rack and pinion.	Apply MoSe ₂ lubricant to rack.
Actuator performance erratic at temperatures (140°R) below design operating temperature limits (250°R min.) using helium as test medium.	Different thermal coefficients of expansion for servo valve flapper screws material produce pressure changes which cause erratic operation.	Erratic performance of actuators would result in erratic operation of the reactor under certain conditions. The likelihood of the conditions causing erratic performance is remote since the conditions are below the design operating temperature limits of the actuators. However, to increase design safety margins action was taken as noted.	R	-	NP	L	CMPLT	Change material of servo valve flapper screws. Add damping element in each path between servo valve and piston. Adjust servo valve at lower quiescent pressure.	Material substitution was made for servo valve flapper screws. Pneumatic resistive damping elements added. Servo valve adjustments made at lower quiescent pressure.

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68 Sheet: 21 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Actuator freeze-up at low temperature.	Impurities and trace containments in drive gas.	Actuators would be inoperable while subjected to cryogenic temperatures. This could result in inability to scram the reactor when desired or required.	R	-	NP	L	CMPLT	Prevent impurities and trace containments from entering actuators.	LN ₂ cold trap added to test facility thru which supply gas is passed to remove impurities and trace containments.
Actuator cannot lock at temperatures (120-130°R) below design operating temperature limits (250°R min.).	Unknown	No effect since the rebound from a scram is limited to 10 degrees as opposed to 7 degrees for a scram at warm conditions. The additional rebound is within the limits of the lock (15 degrees). The likelihood of this problem is remote since it occurred at conditions below design operating temperature limits.	I	-	NP	L	CNSDR		Investigation is continuing. Testing was conducted to determine amount of rebound and scram velocities.

Ⓢ Form 59653
Attachment Sheet

FAILURE MODE ANALYSIS (Continued)

Part: _____

Ident. Code: _____

Date: 2/11/68

Sheet: 22 of 22

Failure Mode	Possible Cause	Effect			Severity Code	Freq. Of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
		System	Ground Test	Flight Test					
Rust on actuator output shaft and spline.	Part of testing program results in heavy frost buildup on actuator. Exposure to this moisture results in rusting.	No effect since the amount of rusting is insignificant after the action noted is taken. However, any particles that may result from rusting are isolated from the actuator mechanism and the reactor. The coolant flow filter protects the actuator and the dome end screen protects the reactor core.	I	-	NP	L	CMPLT	Remove rust after testing and keep actuator at low humidity conditions until installation.	Rust is removed after testing and inspected. Assembly and storage is done in controlled low humidity room. Desiccant included in shipping container.
Rust on key for manual lock.	Part of testing program results in heavy frost buildup on actuator. Inadequate plating and exposure to this moisture results in rust.	No effect since key is not a functional part during actuator operation.	I	-	NP	L	CMPLT	Prevent rusting.	Key now coated with a more corrosion resistant plating.
Manual lock stiff and difficult to operate.	Unknown	No effect on actuator operation. If lock can be unlocked, it is not a functional part during actuator operation. If unable to unlock, it can be replaced to allow testing.	I	-	NP	L	CMPLT		Safety requirements now permit three XE-1 actuators to be manually unlocked. A proposal is in process to permit all manual locks to remain unlocked. Consideration being given to remove manual locks from future actuators.

Form 59653
Attachment Sheet

WANL-TME-1737

FAILURE MODE ANALYSIS XE-1 PNEUMATIC ACTUATOR MECHANISM

TABLE I

Effect						
Ground Test	Flight Test	Severity Code	Freq. of Occur.	Status	Features Or Action To Minimize Occurrence/Effect	Specific Actions Taken Or In Process
NRS	NRS	-	Causes Discontinuation of a Ground Test or a Flight Test Abort without meeting Major Test Objectives and with Possible Safety Effects of Concern			
NR	NR	-	Same as NRS, but without Possible Safety Effects of Concern			
CR	CR	-	Restartable; May Compromise Major Test Objectives; Causes Re-evaluation of Flight Mission			
R	R	-	Restartable; Affects Minor Test Objectives only; would not Abort a Flight Test			
I	I	-	Insignificant			
U	U	-	Unknown			
		PAM	-	Problem; Corrective Action Mandatory		
		PRM	-	Problem; Corrective Action Required; Design Review Mandatory		
		PRR	-	Problem; Corrective Action Desirable; Design Review Recommended		
		NP	-	No Problem		
		H	-	High		
		M	-	Medium		
		L	-	Low		
		I	-	Incredible or Insignificant		
		U	-	Unknown		
				CMPLT	-	Complete
				CNSDR	-	Under Consideration
				ACT ()	-	Required Action Defined with Reference to Action Serial No. ()
				NACT	-	No Action Required
				U	-	Unknown