Motor-Operated Globe Valve Performance
In A Liquid Sodium Environment*

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Abstract

This study investigates motor-operated globe valve (MOV) performance in a liquid sodium environment as reported to the Centralized Reliability Data Organization (CREDO) from site representatives at several liquid metal reactors and liquid metal test facilities. The CREDO data base contains engineering histories for 179 motor-operated globe valves. Thirty nine failures have been documented for these components in over 8.7 million hours of operation. The most common MOV events were anomalies with the limit and torque switches, although human initiated problems were also frequent causes of failures. The failure data suggest that an improved preventive maintenance program with a higher frequency of inspection of the limit and torque switches should increase MOV availability and reliability. The event rate for all failure modes was computed as 4.47 events per 10^6 operating hours by assuming a Poisson distribution of failures over valve operating time. The 5% and 95% confidence limits based on a chi-squared (χ^2) probability distribution function were computed as 3.36 and 5.83 events per 10^6 operating hours, respectively. The operating performance of these liquid metal MOVs was compared to similar data for MOVs in commercial light water reactors and was found to exhibit similar failure rates.

Introduction

CREDO is a component-based data system and data analysis center, which since 1985 has been jointly sponsored by the United States Department of Energy (DOE) and the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. Efforts within CREDO are focused on reliability, availability, and maintainability (RAM) data and analyses for mechanical, electrical, and electronic components (e.g., valves, pumps, power supplies, etc.) designed to function in liquid metal environments and their support systems[1]. Data are received from a variety of sources, including the Experimental Breeder Reactor II (EBR-II), Fast Flux Test Facility (FFTF), the Energy Technology Engineering Center (DOE facilities), and the O-arai Engineering Center (PNC Facility). The CREDO database management system contains three types of data files: engineering, event, and operating data. Information in the engineering data file includes component type, system and subsystem affiliation, operating and duty factors, design and operating parameters, etc., on more than 20,000 advanced reactor components. The database also contains over 2,000 event histories on the temporary or permanent component malfunctions (including keywords for event type, mode, cause, date, maintenance or repair information, and event narratives, etc.) for more than 2 billion component operating hours.

CREDO has supported a number of activities in risk assessment work. Component failure information has been provided for probabilistic risk assessment (PRA) analyses for the EBR-II and FFTF. Information from the database has also been supplied for the SP-100 nuclear powered space satellite under development by General Electric Company, the Advanced Liquid Metal Reactor (ALMR), and PNC's MONJU demonstration fast breeder reactor. Analyses have been documented by CREDO in many papers on liquid metal component reliability, availability, and maintainability. This paper examines logged events and determines event rates for globe type MOVs operating in a liquid sodium environment. Calculated event rates are compared with event rates from MOVs operating in a light water environment.

Sources Of MOV Data

Information on approximately 5000 valves is contained within the CREDO database. Of these, 179 engineering reports document motor-operated globe valves (MOV) operating in a liquid sodium environment. These MOVs have logged over 8.7 million operating hours in which 39 primary events were recorded, according to data records submitted to CREDO. A variety of sodium valve types (globe, gate, butterfly, needle) with motor operators have been reported to CREDO, although there is insufficient data to warrant inclusion of the latter three valve types in this report. Globe valves are the largest population of MOVs in the CREDO data base. Table 1 provides the distribution of the globe valve population and the number of events as reported to CREDO for these components. Following Table 1, a brief description of each site will be provided and some of the documented events reported by that site will be discussed.

Table 1: Distribution of MOV Data in CREDO for Globe Valves

Site	Population	Operating Hours	Number of Events Reported
EBR-II	3	247,854	0
FFTF	48	3,265,653	13
SPTF	2	9,504	3
JOYO	10	1,149,701	11
CRDMTL	5	220,825	4
PLANDTL	2	17,966	0
SFTL	26	1,114,484	4
50MWSGTF	83	2,708,559	4
All	179	8,734,546	39

EBR-II is a pool type reactor with a design power level of 62.5 MWt. The three globe valves reported by EBR-II operate as flow control valves for 2.54 cm (1 in) and 5.08 cm (2 in) piping in the radioactive sodium chemistry loop. Two of these valves are vital for the operation of the plugging temperature indicator, while the other controls flow to a sodium sampling system.

FFTF is a 400 MWt fast reactor designed specifically for the irradiation of nuclear fuels and materials. Of the 48 globe valves reported by FFTF, only one is used for flow control (to the primary sodium cold trap). The remaining 47 are used for primary and secondary loop isolation. There are three separate heat transport loops in FFTF, each with a primary and a secondary system. The primary loops circulate sodium at 49210 l/min (13000 GPM) at 504 °C (940 °F) in 71.12 cm (28 in) diameter hot leg piping and 360 °C (680 °F) sodium in 40.64 cm (16 in) diameter cold leg piping. The secondary loops also circulate sodium at 49210 l/min (13000 GPM) at 466 °C (870 °F) in the hot leg and 321 °C (610 °F) in the cold leg. Thirteen events were reported to CREDO from FFTF. One interesting case is due to an improper valve installation; the actuator's clutch was installed with a short lug nut making it difficult for the clutch to disengage. Although this problem was reported for only one component, an inspection of all the isolation valves at FFTF found 19 others with the same problem. Two other events at this site were due to improper installation of the valves. In these events, two valves were installed so that unanticipated loading occurred, creating a bending moment across the valve, resulting in significant seat leakage. Electrical problems led to six of the other events; two of these were failures of the anti-feedback band.

The Sodium Pump Test Facility (SPTF) at the Energy Technology Engineering Center (ETEC) has reported data for two globe valves. These are large 30.48 cm (12 in) valves used for flow control during normal operations and isolation when the system is shut down. Both valves have experienced contamination on the valve seats, resulting in sodium leakage. The other logged event was due to a limit switch failure, resulting in the valve seating with excessive tightness.

The JOYO Experimental Fast Reactor is operated by the Power Reactor and Nuclear Fuel Development Corporation (PNC) and has a design maximum power of 100 MWt. The ten globe valves at the JOYO reactor function as isolation valves. These valves have experienced 11 events. Seven of these events were attributed to problems with limit switches. Two others were reported as stuck, noting that the anomaly may have been attributed to problems with the limit switches, since the reported event cause was "drift" (the definition of drift in the CREDO manual[2] is "mechanical or electrical shift of setpoint, range, etc."). This indicates that there was a shift in the valve's limit switch set point. The remaining event reported by JOYO was attributed to a valve lubrication problem.

All of the five globe valves at the Control Rod Drive Mechanism Test Loop (CRDMTL) at the O-arai Engineering Center (OEC) in Japan function as isolation valves in 2.54 cm (1 in), 5.08 cm (2 in), or 7.62 cm (3 in) sodium lines. One event reported for these components stated that the valve stuck closed during an operation check when it was manually operated. There may have been some sodium oxide buildup on the valve stem. An electrical problem caused a failure of a valve to close, and an improper installation of packing resulted in a leakage of lubricating oil. The fourth event reviewed from CRDMTL documented a bellows failure which caused a small amount of sodium leakage.

The Plant Dynamics Test Loop (PLANDTL), also at the OEC, reported two globe valves which act as isolation valves. No events have been reported for this relatively new test facility.

Of the twenty-six globe valves reported by the Sodium Flow Test Loop (SFTL) at OEC, one functions as a flow control valve while the remaining twenty-five are used as isolation valves. There were only four events reported by SFTL. In one event, the packing leaked lubricant which coagulated causing the valve to stick at a 40% open position. In another the valve was accidently operated during a cold sodium condition leading to a bellows failure. Defective contacts were listed in another event report as a cause for internal leakage (indicating a malfunction of the limit/torque switch). The remaining event was a bellows failure resulting in a small amount of sodium leakage.

The OEC 50 MW Steam Generating Test Facility (50MWSGTF) reported data for nine flow control valves, three bypass valves, and 56 isolation valves. Four events have been reported for these components. A bellows failure caused a small sodium leak. Contamination on one of the valve seats resulted in a failure of the valve to close. Operational control was lost in one event due to problems with the valve's control cable. The other event was the failure of a valve to open due to the improper installation of a torque switch.

Event Summary

Within CREDO, events are classified as either primary or secondary. Primary events consist of component malfunctions due to failures within a defined component boundary. A secondary event is a malfunction caused by a device outside the boundary of the component. The valve component boundary consists of the valve, its operator, limit or torque switches mounted on the valve body or operator, and local control systems. Supply systems such as electrical power, pneumatic air, or hydraulic fluid are considered to be outside of the bounds of the component. Information regarding the failure origins, the root cause of the occurrence to the valve, documented in the reviewed event reports is compiled in Table 2. Failures of both types, primary and secondary, are compiled in this table. All secondary events of the valve are directly attributable to the controlling circuit board or electrical circuit to the valve. These events were included in this paper because they were considered to be important factors in the loss of function of the valve.

Table 2: Frequency of Event Origins Reported to CREDO

MOV Event Origins Reported to CREDO	Number
Torque or limit switch problems	13
Actuator malfunctions (including anti-feedback band failures)	3
Contamination on the valve seat causing leakage	3
Loose motor	1
Shear pin	1
Control circuit or electrical problems†	4
Bellows failure	3
Deterioration of packing resulting in leakage of lube oil	1
Lubrication related	1
Human initiated#*	6
Unknown	3
Total:	39

† The control circuit and electrical problems are considered secondary events.

These events include the following: two occurrences of a valve being installed improperly, one occurrence of a valve being operated in a cold sodium condition causing valve damage, an occurrence due to improper packing installation, a clutch installed out of specifications, and an improper connection of electrical leads.

* The improper connection of electrical leads is considered a secondary event.

As opposed to the event origin, which is the cause of the event, an event mode is what occurs as a result of the event. The event modes for the events reported to CREDO were grouped into six generic categories in Table 3.

Table 3: Frequency of Event Modes in Events Reported to CREDO	
MOV Event Mode	**Number**
Internal leak	5
External leak	4
Spurious operations#†	11
Plugged	0
Fail to open (on demand)*	14
Fail to close (on demand)	5
Total:	39

One spurious operation was a leakage of lubricating oil.

† Four spurious operations were due to secondary events.

* One fail to open on demand was due to a secondary event.

Fail to open and spurious operations were the most common event modes. Spurious operations is a "catch all" for any event modes which did not fit the other categories. Some examples of a spurious operation include loss of valve control, minor valve malfunctions, loss of position (open or closed) indication, etc.

Event Analysis

An event rate is an estimate of the number of failures a component will experience per unit time. Normally, an event rate is expressed in units of "number of events per 10^6 operating hours". The event rates, λ, for the MOVs were computed by dividing the number of events by the total time the components were operational[3],

$$\lambda = \frac{f}{T} \tag{1}$$

where f is the number of event occurrences in the component operating time interval T. This form of the event rate assumes the MOV events follow a classical Poisson distribution over the component's operating lifetime.

Confidence limits were calculated to identify ranges of parameter values that are consistent with the data to certain limits. For example, a 95% confidence limit for the event rate of X events per 10^6 hours would indicate that for event rates greater than X, the results are in the upper extreme 5% of possible outcomes. Values for the event rates less than X are much more consistent with the data. *Classical confidence limits have the property that, in repeated sampling, the probability the confidence interval will contain the parameter of interest is at least at the specified confidence level*[3]. The 100(1-α)% confidence limits (α = 0.05 in this case) can be computed using the chi-squared (χ^2) probability distribution function. The method of calculating the upper and lower confidence limits is given by Equations 2 and 3

$$\lambda_U(1-\alpha) = \frac{\chi^2(2f+2\,;\,1-\alpha)}{2T} \tag{2}$$

$$\lambda_L(1-\alpha) = \frac{\chi^2(2f\,;\,\alpha)}{2T} \quad . \tag{3}$$

Event Rates

Failure rates based on a Poisson distribution with 95% and 5% one-sided confidence limits were computed for the event origins listed in Table 2. These results are tabulated in Table 4 and graphically presented in Figure 1. The last row shows the failure rates and confidence limits computed for all 39 events.

Table 4: Event Rates for Each Failure Origin Reported to CREDO

Failure Origin	5% C.L. (events / 10^6 hours)	Event Rate (events / 10^6 hours)	95% C.L. (events / 10^6 hours)
Torque or limit switch problems	0.88	1.49	2.37
Actuator malfunctions	0.09	0.34	0.89
Valve seat contamination	0.09	0.34	0.89
Loose motor	0.01	0.11	0.54
Shear pin	0.01	0.11	0.54
Control circuit or electrical	0.16	0.46	1.05
Bellows failure	0.09	0.34	0.89
Deterioration of packing	0.01	0.11	0.54
Unknown	0.09	0.34	0.89
Lubrication related	0.01	0.11	0.54
Human initiated	0.30	0.69	1.36
Event rate for all causes:	3.36	4.47	5.83

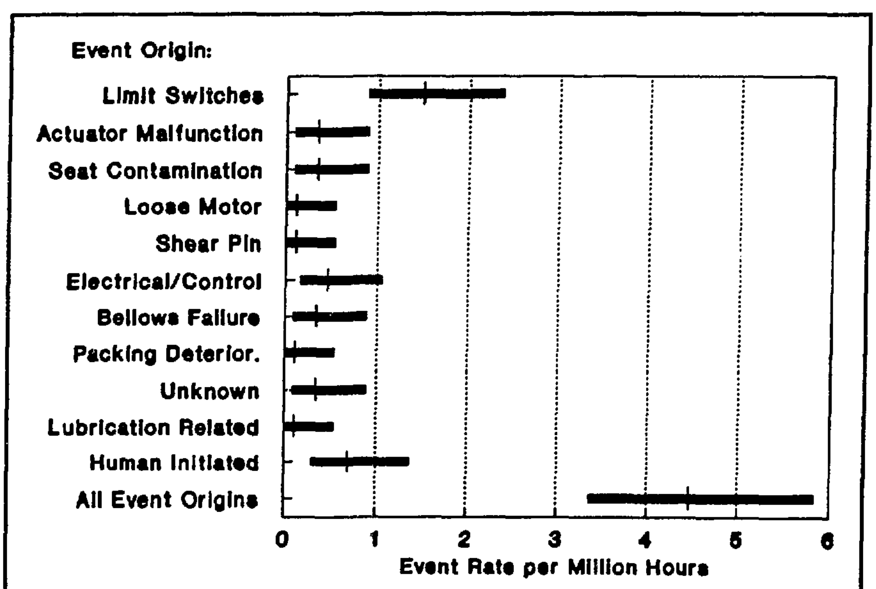

Figure 1: MOV Event Rate Distribution for Each Event Origin

The breakdown of event rates for each event mode tallied in Table 3 is shown in Table 5 and graphically illustrated by Figure 2. Notice that although there were no events that fit the plugged category, it is possible to attain a 95% Confidence Limit value by applying Equation 2.

Table 5: Event Rates for Each Event Mode Reported to CREDO

Event Mode	5% C.L (events / 10^6 hours)	Event Rate (events / 10^6 hours)	95% C.L (events / 10^6 hours)
Internal leak	0.23	0.57	1.26
External leak	0.16	0.46	1.05
Spurious operations	0.71	1.26	2.09
Plugged	0	0	0.34
Fail to open	0.97	1.60	2.51
Fail to close	0.23	0.57	1.26
Event rate for all modes:	3.36	4.47	5.83

Fail to open is the most probable event mode encountered with an event rate of 1.60 events per 10^6 hours. This correlates to a probability of 1.4% chance of failure in a year of operation. The high frequency of this failure mode is attributed to the fact that limit/torque switches have high failure rates (1.49 events per 10^6 hours). Often when a limit/torque switch fails, a valve will seat too tightly resulting in a fail to open event mode.

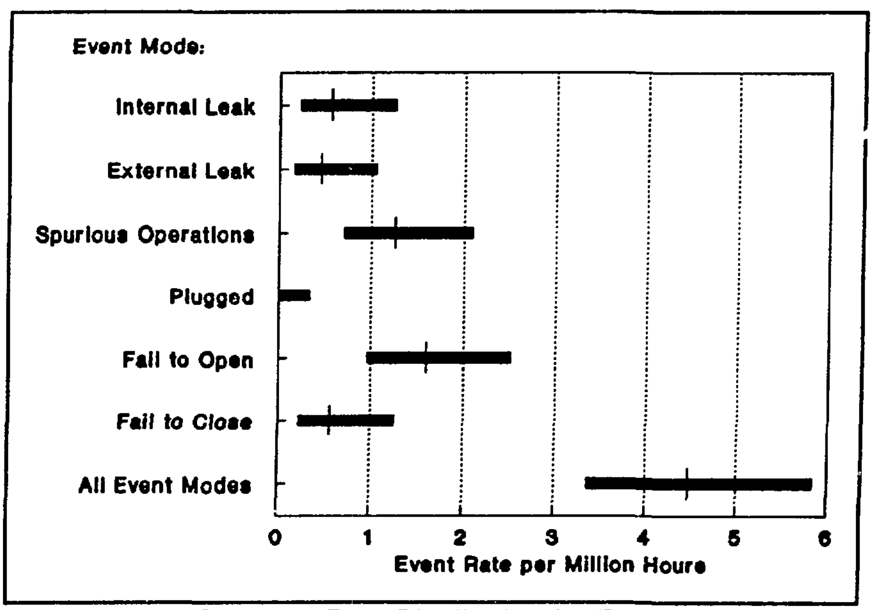

Figure 2: MOV Event Rate Distribution for Each Event Mode

Data Comparison

The failure rate for all modes, 4.47 events per 10^6 hours, compares well to failure rate data from MOVs operating in light water reactors (LWR). Table 5 contains failure rate data from three different LWR sources. For example, the results from Brookhaven (Source C, Table 5) are conservative compared with the calculations from CREDO, and the failure rate results from the ANSI/IEEE Standard 500 and the Tills report (Source B) compare favorably with the CREDO results.

Table 5: Failure Rates for LWR MOVs

	Source	Event Rate (events / 10^6 hours)
A	ANSI/IEEE Standard 500[4]*	4.20
B	EPRI NP/GS-6327[5]	5.39
C	EGG-SSRE-8875[6] and NUREG/CR-2815[7]	10.3

* Motor operated 4 - 11.99 inch globe valves.

In examining the event dates for the CREDO data, it was found that more events occurred earlier in the plant's life than later, thus showing decreasing failure rates for the sodium valves over time. This may be a result of better maintenance procedures brought about from increasing awareness of frequent problems. Tills noted a similar decrease in the rate of LWR MOV failures over time for the valves analyzed in his report.

Thirty three percent of the MOV events in the CREDO data base are attributed to limit or torque switches. When compared to the 52% of the failures of LWR MOVs attributed to limit or torque switches in the Tills report, it appears that maintenance procedures in the test facilities reporting to CREDO are thorough.

Conclusions

Data for 179 motor-operated globe valves in a liquid sodium environment from three reactors and five test facilities were analyzed. Problems with limit or torque switches accounted for 33% of the reported failures to these valves. One potential solution to this recurrent problem is to calibrate the settings on these switches more frequently to minimize over-seating problems caused by inaccurate signals from faulty limit switches. The environment the valve operates in should not have a significant effect on the performance of limit and torque switches, so the liquid metal reactor community should take advantage of the vast amount of data available on these problems reported to data bases such as NPRDS or documented in reports like Tills[4]. Another 15% of the failures reported to CREDO were attributed to human initiated problems. This problem should be addressed by site management. Ten percent of valve problems were due to the control circuit and electrical problems. Two of the three events that caused the actuator to malfunction are a result of failures of the anti-feedback band, another potential problem to monitor. The primary event type that can be directly attributed to the sodium environment is the contamination of particles on the valve seat causing seat leakage. Only 8% of the events were attributed to this cause. This problem could be avoided if higher sodium quality was maintained by the system cold traps.

The event rate calculated for all modes was 4.47×10^{-6} events per hour. This correlates to a 4% chance that a MOV event will occur in a year. The 5% and 95% confidence limits were computed as 3.36×10^{-6} and 5.83×10^{-6}, respectively, for an event to occur for all modes. The results mean that only 5% of operating valves will have an event rate lower than 3.36 events per 10^6 hours (2.9% chance per year) and only 5% of the operating valves will have event rates higher than 5.83 events per 10^6 hours (5.1% chance per year). Consequently, 90% of the operating valves at these plants have between a 2.9% and a 5.1% chance of an event occurring in the next year of operation. These results compare similarly to data from motor-operated valves in light water reactors.

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