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S2G VALVE SODIUM FREEZE SEAL EVALUATION

PHASE II

By
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SIR EXPERIMENTAL ENGINEERING

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ABSTRACT

The design of the S2G 8-inch sodium stop valve freeze seal was evaluated under established conditions by cycling before and after a simulated bellows failure. The effectiveness of the freeze seal under severe ambient, water flow, and insulation conditions was also evaluated. The stop valve operated successfully under all test conditions.

INVESTIGATION

INTRODUCTION

A two-phase testing program was conducted to evaluate the performance of the S2G 8-inch sodium stop valves used in the inlet and outlet of the two coolant loops of the S2G reactor.

Phase I was a study of the possibility of the solidification of sodium in the bellows after a primary bellows failure. Complete bellows failure could then result during operation of the bellows as a result of abnormal stresses set up by the solidified sodium. Phase I and other supplementary tests are reported separately (Reference 1).

Phase II was an investigation of the performance of the valve after primary and secondary bellows failure under specified operating conditions. This investigation was intended to determine (A) if a sodium seal could be effected in the annulus after a secondary bellows failure and (B) if there was a significant change in the operating torque of the valve after the seal was established.

In Part A, the valve was cycled before and after a simulated primary and secondary bellows failure. In Part B, the freeze seal was evaluated after a simulated secondary bellows failure at the most severe ambient and coolant water temperatures anticipated in the lower reactor compartment of SSN575.

CONCLUSIONS

It is concluded that the S2G sodium stop valve can be made operable after a primary and secondary bellows failure.

It is three to five times more difficult to operate the valve when sodium is in the annulus.

A satisfactory seal was effected after a simulated secondary bellows failure at a pressure of 150 psig, ambient temperatures up to 250°F, and coolant water temperatures up to 150°F.

DESCRIPTION OF EQUIPMENT TESTED

Part A

The S2G sodium stop valve is an 8-inch split-stem, double-bellows valve. Included in the valve seal arrangement is a 30-35 mil freeze seal annulus whose outer wall consists of a coolant jacket. A cross-section of the valve is shown in Figure 1, Page 34. A 4-inch insulation jacket on the outside of the valve and a second insulation jacket remote from the first was utilized for maintaining an ambient temperature. A general view of the valve installed in the test facility is shown on Figure 2 and 3, Pages 35 and 36.

Part B

The test equipment was essentially the same as that used in Part A with the following exceptions: To simulate conditions aboard the SSN575; insulation was installed as shown in Figure 7, Page 40. To establish the higher ambients required, the ambient jacket was replaced by a heating box.

DESCRIPTION OF TEST FACILITIES

The test facilities consisted of the following:

1. Cooling Water System: constant temperature, constant rate, partially closed.
2. Ambient Flow System: constant temperature, constant gas composition.
3. Nitrogen System: for application of pressure or vacuum to sump or surge tank.
4. Sodium System: consisting of surge tank, sump tank, sodium valves, and calrod heaters.
5. Instrumentation:
 - 1 - Brown temperature recorder, 12 pt, 0-1000°F
 - 1 - Brown temperature indicator, 48 pt, 0-1000°F
 - 2 - F & P air flowmeters
 - 2 - Weston meat thermometers, roving, 0-150°F
 - 5 - Pressure gages, 4-0-100 psig, 1-0-200 psig
 - 1 - Vacuum pressure gage, 30-inch
 - 3 - Liquid level probes on surge tank, spark-plug type, 5-, 9-, 15-inch
 - 2 - Liquid level probes on sump tank, spark-plug type, 5-, 10-inch
 - 1 - Water flowrator, 0-10 gpm
 - 2 - Torque wrenches, 0-150, 0-600 ft-lb.

The water, ambient, and sodium systems are shown in Figure 5. The placement of the thermocouples, pressure gages, flowmeters etc. are shown in Figures 5 and 6 for Part A and Figure 7 for Part B.

DESCRIPTION OF TEST OPERATIONSPart A

The temperature of the sodium system was raised to 450°F. All sodium valves were closed and 15 inches of mercury was applied to the surge tank. With a pressure of 25-30 psig on the sump, valve #1A was opened and valve #1B was cracked, filling the inner bellows space until the lower surge light was lit. Additional heat was then supplied until the sodium source temperature reached 850°F. With the temperature controlled at 850°F, the coolant water flow was established through the jacket. The inlet water temperature was raised to 110°F at 1.5 gpm by means of the partially closed water loop. All temperatures and pressures were recorded at this point.

Temperatures were stabilized with the secondary bellows adapter temperature at 240°F and the ambient temperature was adjusted to approximately 175°F. The 8-inch valve was operated once (close and open) as shown in Figure 8, Page 41 to establish the approximate torque values that would be obtained. The secondary bellows adapter temperature was not affected by this cycle, while the valve closing did effect a general temperature rise (10-50°F) of the air annulus thermocouples. The source temperature increased slightly as a result of this cycle.

The temperatures were again stabilized and test cycling was started, using the 0-150 ft-lb torque wrench. Twelve full cycles (fully closed to fully open) were run. The temperatures followed the same pattern as that of the one-cycle test shown in Figure 8. Torque versus time values for breakaway, running and close, for open and close of the valve were noted. No binding or irregular friction characteristics of the valve was evident. The valve was left in the fully open position less one hand wheel turn, and the sump was then pressurized in an attempt to increase the surge level. The surge was then filled until the

top light remained lit. Then the heat was increased to raise the surge and piping temperatures to 850°F. The secondary bellows adapter temperature increased to approximately 325°F and the air annulus thermocouples leveled off over a 125°F to 225°F range. Three hours later, the surge and piping temperatures were at 850°F, and the surge tank was then pressurized to 150 psig using the regulator on the nitrogen source, adjusted to hold a constant pressure of 150 psig. To simulate a secondary bellows failure (using pre-established safety precautions), valves #3A and #5 were then opened. No immediate effects were observed and a satisfactory seal appeared to have been established. At this point, the secondary bellows adapter temperature was approximately 275°F* and cycling was started, using the 0-600 ft-lb torque wrench. The latter temperature again was not affected during cycling while the source temperature varied by $\pm 150^\circ\text{F}$, decreasing when the valve was being opened. The temperature profiles of all the recorder thermocouples during cycling are shown on the recorder chart, Figure 9, Page 42. During cycling, the pressure at the nitrogen cylinder varied from 147 psig at "open" to 162 psig at "close". After the last cycle, the valve was left fully open less one hand wheel turn.

During the cycling, the torque-versus-time readings of operation of the valve for "open" and "close" were again taken for each cycle. All temperatures and pressures were recorded throughout the cycling. The sodium was then drained into the sump and all heat secured except that of the sump calrods. Throughout the cycling, there was no indication of leakage. It was observed that closing the valve required more torque and time than opening it. After having stripped the lagging from the test, some evidence of sodium leakage was found. The extent of the leakage can be seen in Figures 10 and 11, Pages 43 and 44. The amount

* Specifications called for a secondary bellows adapter temperature of 213°F or greater before cycling.

of leakage was considered comparatively small and a satisfactory seal was apparently effected. This leakage is explained under Discussion, Page 16.

Part B

The test operations of Part B were similar to those of Part A except that the valve was not cycled, the ambient was at 250°F, and the insulation had been changed to more closely simulate the S2G installation.

Since the valve already had sodium in its secondary bellows from previous tests, filling was not necessary. Therefore, the source temperature was brought to 850°F with water flow through the bypass section. When a temperature of 850°F was reached, water was started through the freeze seal and a flow of 1.5 gpm was established. The ambient temperature was then brought to 250°F by energizing the calrod heaters in the ambient box. To represent the most severe condition possible, a nitrogen bleed into the box had been established for two days prior to the test so that it could be assumed that the oxygen concentration in the freeze seal annulus was less than 5%.

Valve #3A was then opened, allowing sodium to penetrate as far as Valve #5. After raising the drain line temperatures to 850°F, the water to 110°F, and allowing the secondary bellows adapter temperature to reach equilibrium at 322°F, a constant pressure of 150 psig was applied to the surge tank. Valve #5 was then opened allowing sodium to enter the outside of the secondary bellows, simulating a secondary bellows failure. The fact that sodium had been introduced was evidenced by a drop in the level of the surge tank (the upper liquid level light went off) and a sudden rise in temperature of the secondary bellows adapter temperature. No immediate leakage effects were observed and a satisfactory seal was apparently established. The water temperature was permitted to rise to 150°F to establish whether leakage would occur. Meanwhile, the secondary bellows adapter temperature decreased from 366°F to 295°F after which all heat and water was secured. No leakage was observed at any time. The source temperature varied about 20°F during this period. Figure 12, Page 45 depicts the temperature profiles.

DATE

OPERATING TORQUESNo Sodium In Annulus

Cycle No.	<u>OPEN</u> Torque (Ft-Lbs)				<u>CLOSE</u> Torque (Ft-Lbs)			
	Time (sec)	Break	Ave. Running	Close	Time (sec.)	Break	Ave. Running	Close
1	50	15	21.7	-	50	5	10.0	15
2	55	15	7.0	10	60	5	5.0	15
3	65	15	8.8	5	60	0	3.0	15
4	52	15	7.0	15	60	15	3.8	15
5	45	15	10.0	15	55	15	5.0	15
6	48	15	6.7	15	50	15	3.8	15
7	45	10	5.0	15	55	15	12.5	20
8	45	10	0.0	5	55	10	7.6	20
9	45	5	10.0	15	50	10	8.8	20
10	45	5	10.0	15	40	5	11.7	15
11	40	5	12.5	15	40	5	9.0	15
12	45	5	12.5	15	50	5	11.7	20

Sodium In Annulus

Cycle No.	<u>OPEN</u> Torque (Ft-Lbs)				<u>CLOSE</u> Torque (Ft-Lbs)			
	Max.	Min.	Avg.	Time (Sec)	Max.	Min.	Avg.	Time (Sec)
1	20	0	7.3	80	80	10	47.8	305
2	40	10	23.0	105	90	10	55.6	195
3	45	10	16.8	100	120	30	70.0	150
4	50	0	13.6	100	70	10	48.4	155
5	55	10	21.0	100	75	10	38.0	225
6	50	20	30.8	95	100	20	35.8	130
7	45	15	24.7	150	100	20	58.7	200
8	55	20	26.3	115	120	25	61.1	210
9	70	40	44.0	90	90	20	60.6	160
10	45	20	27.5	115	85	50	61.2	110
11	70	20	31.0	110	70	40	53.8	145
12	70	20	28.9	105	95	60	78.4	195

OPERATING CONDITIONS

	Source OF	Water OF	Ambient OF	Wt. % O ₂	Surge Press psig	H ₂ O Flow gpm	Cycling
1	850	170	175	6.38	147-162	1.5	Yes
2	850	170-150	250	0.00	150	1.5	No

RESULTS

Part A

1. A satisfactory seal was effected in the S2G valve sodium freeze seal after a secondary bellows failure was simulated at 150 psig.
2. The valve operating torques are tabulated as follows:

<u>Conditions</u>		<u>Ft-Lbs Torque</u>	
		<u>Open</u>	<u>Close</u>
No sodium in annulus	Breakaway	10.83	8.75
	Running	9.27	7.66
	Close	12.73	16.67
	Time-Sec.	48.33	52.08
Sodium in annulus	Maximum	51.3	91.3
	Minimum	15.4	23.8
	Average	24.6	55.8
	Time-Sec.	105.4	181.7

3. The average shear stresses were as follows:

Open 27.4 psi
Close 80.5 psi

Part B

A satisfactory seal was effected in the annulus after a secondary bellows failure was simulated at ambient temperatures up to 250°F and water coolant temperatures up to 150°F.

DISCUSSION

Part A

The purpose of Part A tests was twofold: (1) to determine if a sodium seal could be effected in the annulus after a secondary bellows failure had been simulated; and (2) to determine if there was a significant change in the operating torque of the valve after the seal had been established.

The first condition was satisfied by visual observation, i.e. no significant sodium leakage was found at 150 psig, as shown in Figure 10 and 11, Pages 43 and 44. Sodium solidified in the seal. The comparatively small amount of leakage was probably due to the physical movement of the sodium and/or sodium oxide along the annulus as a result of the cycling action of the valve. The second condition was considered in the calculation section of this report. The results indicate that a significant change did take place in operating torques.

Although the test was not designed for a statistical approach, the average running torque values, in the first part, have been compared to the mean torque average in the second. The justification for this is that the number of readings taken when sodium was in the seal was greater than when there was no sodium in the seal. That is, even though the maximum and minimum values were included in the average values when sodium was in the seal, their effect is overshadowed by the large number of readings taken.

The "open" and "close" running torques in the first case were statistically the same and they were averaged: Avg. Running = 8.47 ft-lb. In the second, the "open" and "close" averages were statistically different so that:

$$\frac{\text{Average close with seal}}{\text{Average open with seal}} = 2.27$$

This difference in torque between "open" and "close" of the valve when sodium is in the annulus can be explained by the following phenomena:

1. Probably the most important factor in the above difference is the temperature of the annulus can and valve shaft. It is evident in Figure 8 that when the valve was closed, temperatures along the annulus increased. Thus, the sodium in the annulus increased in temperature and its viscosity was decreased. When the hot can was drawn out again, the hot sodium offered little resistance to its motion. As soon as the can was out (valve open), however, the surface temperature dropped to near the ambient temperature (175°F). Thus, when the can went in again, with its temperature decreased, it faced frozen sodium in the annulus. Overcoming this barrier gave higher torque values.
2. When closing the valve, the gas trapped inside and outside the bellows was compressed. This movement acted against the 150 psig surge tank pressure and therefore further increased the "close" torque. Upon opening, this effect was reversed and the built-up pressure tended to reduce the operating torque.

Thus the "open" torques were significantly lower than "close" torques. Also

$$\frac{\text{Average close torque with seal}}{\text{Average running torque - no seal}} = \frac{55.8}{8.47} = 6.59$$

$$\frac{\text{Average open torque with seal}}{\text{Average running torque-no seal}} = \frac{24.6}{8.47} = 2.90$$

The derivation of these values is shown in the Calculations, Page 22 .

The running torque values are more reliable than the seat & breakaway torque values. Here the arbitrary choice was made of just seating the valve with no extra effort. The "seat" values could be, of course, as high as desired, and for comparative reasons, the above standard was chosen. The breakaway values are dependent upon the "seat" values so again the numbers are somewhat arbitrary and the possibilities of error increased.

These factors are hidden in the maximum, and average torque values when sodium is in the annulus. The maximum values were almost always at the "break" or "seat" position of the valve, introducing the arbitrary standard and possible error. The average values included these "break" and "seat" values. The minimum readings were not affected by any external factors. In both Part A and Part B, no irregular friction characteristics or binding of the valve were observed.

Statistically, for the condition of no sodium in the annulus, the time to open and time to close were the same, and thus averaged: Average time = 50.21 sec. The ratios of (Average open time with seal/average no seal time = 2.10 and average close time with seal/average no seal time = 3.62) indicate that when sodium is in the annulus, it takes more than twice the time to open the valve and more than 3.5 times the time to close the valve. The ratio:

$$\frac{\text{close time with seal}}{\text{open time with seal}} = 1.72$$

also indicates that sodium in the annulus makes

closing time greater than open time, and compares favorably with the torque ratio previously shown (2.27).

Since the valve was operated by hand using a torque wrench, the times indicated on the data listed are arbitrary (the faster the valve is turned, the lower the time). During operation of the valve, a constant rate of turning was attempted so that a basis of comparison would result. Thus, it is important to note that the time data are only valid for the relative comparisons as shown and should not be considered as absolute values.

Different torque wrenches were used in parts A and B and they were calibrated against each other and checked at 25, 50, and 100 ft-lbs.

The error in torques introduced was due to the difficulty found in visually reading the torque wrenches when they were in motion.

In general, it can be said that for these test conditions, it is about three to five times more difficult to operate the S2G freeze seal valve when sodium is in the annulus than when it is not. The torques involved were not excessive.

Shear calculations were made in order to determine if the increase in operating torque of the valve, after injection, was due primarily to sodium shearing in the annulus. To accomplish this, it is necessary to calculate the shear stress that would result from the actual force transmitted to the stem. It is assumed that the zero point or initial torque readings can be subtracted from the final readings since the former represent only gear friction, compression of the bellows, etc. The difference between the initial and final torque readings should then represent the torque required to shear sodium in the annulus. The shear values calculated were representative (order of magnitude) of sodium shearing stresses at corresponding temperatures, as shown in Reference 4. It is important to note at this point that the torque values (from which the shear stresses were found) in this report are not absolute values since shear stress varies with shear velocity. This is shown in Reference 4. The curve as given is:

The actual numerical values on this plot cannot be used. The two tests differed in shaft diameter, depth, nature, and length of shear. The diameter of the shaft was one inch, the annulus was 50 mils, the shear was rotational and the shearing length was 17 inches. However, the plot does indicate that such a variation exists and gives the freeze seal test results in order of magnitude values.

The values from Reference 4 can be tabulated as follows:

<u>% Shear Area 150°F</u>	<u>Shear Stress - psi</u>
55.0	75
81.4	83
94.0	95

Now since approximately 70% of the freeze seal annulus was less than 150°F, the shear values calculated (80.5 and 27.4 psi) can be considered representative of sodium shear. Hence, the increased torques can be attributed to sodium in the annulus. Other points established by Reference 4 were:

- a. Sodium shear values decrease with repetitive cycling.
- b. Healing of sheared sodium occurs after approximately 40 hours. This healing is temperature-dependent.
- c. Sodium wetting occurs at greater than 580°F.

From point c, it can be deduced that in the Freeze Seal Test, no wetting occurred and therefore the shear occurred on the outside diameter of the can (inside diameter of the annulus) due to the smaller surface area.

During cycling, the pressure at the nitrogen cylinder varied from 147 psig at "open" to 162 psig at "close" indicating the possible existence of gas in the annulus. The constant 150 psig $\pm$ 3 psi pressure that was applied to the surge tank is transmitted to the inner (and outer) bellows. Upon closing the valve, the total volume of this system is reduced due to the collapsing of the bellows, and since the resulting increased pressure cannot be vented across the regulating valve, the increase was registered on the system pressure gage.

Part B

The chief purpose of the Part B test was to determine whether the freeze seal would hold under high ambient and inlet water temperatures. Most of the air annulus thermocouples had been removed so that a temperature distribution along that annulus was not obtainable. However, a new thermocouple was placed on the stem at the bonnet side of the bonnet flange to give an indication of the heat flux along the stem. Also, this temperature was requested because of the possibility of lubricant breakdown at the high temperatures.

After the injection (see Figure #12, Temperature Profile), the inlet water was permitted to rise to 150°F to determine whether leakage would result. No leakage occurred and a satisfactory seal was apparently established.

In Part A, the fully insulated condition was considered. The insulation for Part B was designed to simulate conditions on SSN575. There was a possibility that higher annulus temperatures would result from the change in insulation and the higher ambients.

The rise in temperature of the secondary bellows adapter, indicated in Figure 11, was due to the 850°F sodium that was injected into a point in the valve where temperatures were in the 500°F-700°F range. This caused an additional heat flux along the valve and stem and raised the secondary bellows adapter temperature. When this additional perceptible heat was dissipated and the system again approached equilibrium, the secondary bellows adapter temperature slowly fell to its original value.

If no oxygen was present in the atmosphere in the box, no oxide could form to plug the annulus. Thus, keeping a constant nitrogen bleed of 20 psig through the box, the reduction in insulation, the higher ambients, and the higher water temperatures helped to establish the most severe conditions for the test.

Visual observation of the external parts of the tester was possible at all times through a window installed on the ambient box.

CALCULATIONSAmbient Oxygen Concentration ((Part A)

The necessary 4-10% by weight oxygen ambient was obtained by mixing service nitrogen (dry) and service air, and sending the mixture through the ambient shell at a rate determined by the ambient temperature ($175^{\circ}\text{F} \pm 5^{\circ}\text{F}$). The arrangement is shown on Figure 2.

From Linde Air Products Company, Albany, New York, KAPL's service nitrogen supplier, the following assay was obtained.

Volumetric Composition

O ₂	20 ppm
H ₂ O	15 g/1000 ft ³
H ₂	5 ppm
HC	5 ppm
He	5 ppm
Ne	15 ppm
A	50 ppm

This corresponds to a maximum total impurity of 0.01% by weight. Therefore, the gas can be considered 100% nitrogen.

A sample of the building service air was analyzed by the Chemical and Metallurgy Analysis group. The mass-spectral analysis was as follows:

	<u>Volume %</u>	<u>Weight %</u>
H ₂ O	0.3	0.02
N ₂	78.7	75.28
O ₂	20.1	21.97
A	0.9	1.23
CO ₂	0.1	1.50

Now, oxygen = 21.97% and let the inerts = 78.03%. Combining this information with that previously found (service nitrogen = 100% nitrogen) let:

1. X = pounds air

2. Y = pounds nitrogen and

3. Z = % oxygen

$$4. \quad Z = \frac{\text{pounds oxygen}}{\text{pounds oxygen} + \text{pounds inerts}} \times 100 = \frac{0.2197X}{0.2197X + 0.9803X + Y} \times 100$$

Rearranging equation 4 by dividing the numerator and denominator of the right-hand term by X gives:

$$5. \quad Z = \frac{0.2197}{1 + Y/X} \times 100$$

Converting this to cfm gives:

$$6. \quad Z = \frac{0.2197}{1 + \frac{Q_{N_2}}{Q_{\text{air}}}} \times 100$$

An order of magnitude test at conditions of 850°F sodium, 110°F water, 1.5 gpm water, etc., showed that the ambient will be approximately 175°F when the flow indicated on rotameter #1 (nitrogen) is 40 cfm. Since the nitrogen and air rotameters chosen at the location were for other gases at different pressures, a calibration is necessary*.

The correction factors are:

$$7. \quad \text{For nitrogen: } Q_A = 0.422 Q_I$$

$$8. \quad \text{For air: } Q_A = 0.262 Q_I$$

Applying equations 7 and 8 to the above test, the total flow to obtain 175°F should be close to:

$$9. \quad Q_I = 0.422 \times 40 \text{ or:}$$

* These correction factors may be obtained by using the general equation:

$$Q_{\text{actual}} = Q_{\text{indicated}} \sqrt{\frac{S.G. \times P_A \times T}{S.G.A \times P_I \times T_A}} \text{ which is derived from the perfect gas law}$$

10. $Q_1 = 16.88 \text{ cfm}$

For a maximum air meter (#2) reading from the correction factors:

11. $Q_{\text{air}} = 17.8 \text{ (100\% scale) (0.262) or:}$

12. $Q_{\text{air}} = 4.66 \text{ cfm}$

and for a nitrogen meter (#1) reading of 26:

13. $Q_{N_2} = 0.422 \text{ (26) or}$

14. $Q_{N_2} = 10.99 \text{ cfm}$

Therefore,

15. Total flow = $10.99 + 4.66 = 15.65 \text{ cfm}$ which is close enough to the order of magnitude test result of equation 10. Any temperature differences due to this lower flow can be made up by adjusting the ambient heaters.

Knowing the nitrogen and air flow rates, substitution of equations 12 and 14 into equation 6 gives:

16. $Z = \frac{0.2197}{\frac{10.99}{4.66} \times \frac{29}{28} + 1} \times 100 \text{ or:}$

17. $Z = 6.38\%$ weight oxygen, the actual oxygen content of the ambient with the above gas flows.

Statistical Analysis of Valve Cycling Data

The data obtained during the valve cycling phase of the program was treated statistically to establish whether a significant change in operator torque resulted from the introduction of sodium to the annulus.

The following table was obtained from the cycling data by averaging over 12 full cycles.

		Quantity	Symbol	Open	Close
No sodium in Annulus	Time	Mean	$\bar{T}$	48.33	52.08
	Sec.	Variance	S_T^2	42.78	43.61
	Sec.				
	Breakaway	Mean	$\bar{B}$	10.83	8.75
	Ft-lbs	Variance	S_B^2	20.21	25.52
	Running	Mean	$\bar{R}$	9.27	7.66
	Ft-lbs	Variance	S_R^2	24.19	10.86
	Seat	Mean	$\bar{S}$	12.73	16.67
	Ft-lbs	Variance	S_S^2	0.45	5.44
Sodium in Annulus	Time	Mean	$\bar{T}$	105.4	181.7
	Sec.	Variance	S_T^2	276.3	2480.9
	Max.	Mean	$\bar{M}_a$	51.3	91.3
	Ft-lbs	Variance	$S_{M_a}^2$	187.1	253.9
	Min.	Mean	$\bar{M}_1$	15.4	23.8
	Ft-lbs	Variance	$S_{M_1}^2$	106.6	302.3
	Avg.	Mean	$\bar{A}$	24.6	55.8
	Ft-lbs	Variance	S_A^2	80.6	134.9

Now applying a t-test to the following hypothesis for all tests:

18. $H_0: M_2 - M_1 = 0$ and assuming a significance level:

19. $\alpha = 0.05$ for all tests and since all sample sizes are the same:

20. Degrees of freedom = $n_1 + n_2 - 2 = 22$ From the t-statistic tables

Reference 5, $t = 2.07$

21. The following tables show the values obtained from substitution in the equation for the t-statistic (see appendix):

No sodium in annulus

<u>H₀</u>	<u>"t" calc.</u>	<u>Result</u>
$\bar{T}_c - \bar{T}_o = 0$	1.34	Accept
$\bar{E}_c - \bar{E}_o = 0$	1.02	Accept
$\bar{R}_c - \bar{R}_o = 0$	0.89	Accept
$\bar{S}_c - \bar{S}_o = 0$	5.39	Reject

Sodium in annulus

$\bar{T}_c - \bar{T}_o = 0$	4.82	Reject
$\bar{M}_{1c} - \bar{M}_{1o} = 0$	6.30	Reject
$\bar{M}_{1c} - \bar{M}_{1o} = 0$	1.38	Accept
$A_c - A_o = 0$	7.03	Reject

Gross comparisons between above tables:

<u>H₀</u>	<u>"t" calc.</u>	<u>Result</u>
$\bar{T}_{ONa} - \bar{T}_o = 0$	10.62	Reject
$\bar{T}_{ONa} - \bar{T}_c = 0$	9.88	Reject
$\bar{T}_{CNa} - \bar{T}_o = 0$	8.81	Reject
$\bar{T}_{ONa} - \bar{T}_c = 0$	8.56	Reject
$\bar{A}_{ONa} - \bar{R}_o = 0$	4.96	Reject
$\bar{A}_{ONa} - \bar{R}_c = 0$	5.86	Reject
$\bar{A}_{CNa} - \bar{R}_o = 0$	12.22	Reject
$\bar{A}_{CNa} - \bar{R}_c = 0$	13.26	Reject

From the previous tables, the following evaluations can be made.

Since the open and close times for "no sodium in annulus" are not significantly different ($\bar{T}_c - \bar{T}_o = 0$ was accepted), the two valves will be averaged to obtain a best estimate of the true population mean.

$$22. \text{ Average time } -(\text{no seal}) = \frac{52.08 + 48.33}{2} = 50.21 \text{ sec.}$$

The same reasoning holds true for the running values so that:

$$23. \text{ Average running } -(\text{no seal}) = \frac{9.27 + 7.66}{2} = 8.47 \text{ ft-lbs.}$$

For the case of "sodium in annulus", the following ratio may be taken:

$$24. \frac{\text{Average close with seal}}{\text{Average open with seal}} = \frac{55.8}{24.6} = 2.27$$

Both open and close times and torques for sodium in the annulus are significantly greater than open and close times and torques for no sodium in the annulus.

25. Cross-comparison of

$$\frac{\text{Open time with seal}}{\text{Average no seal time}} = \frac{105.4}{50.21} = 2.10 \text{ and}$$

$$26. \frac{\text{Close time with seal}}{\text{Average no seal time}} = \frac{181.7}{50.21} = 3.62$$

Thus giving a comparison of the valve operating time with and without sodium in the annulus.

This statistical treatment of the data gives the best estimates only of the values concerned. It does not give absolute numbers upon which further rigid calculations can be made.

Stress Considerations

Cross sectional drawing Figure 13A shows that movement of the valve stem results in a shear of sodium between two concentric cylinders. The relative motion occurs between the outside casing and the inner portion of the annulus.

When the inner cylinder moves relative to the outer, a shear is set up in the sodium filled annulus. The torque necessary to operate the valve (friction etc.) when there is no sodium in the seal may be considered a zero point. When sodium is in the annulus, a shear will be established across the sodium, resulting in higher operating torques. This is substantiated by the Data, Page 14.

As the temperature of the sodium increases, the viscosity decreases and the shear will decrease approaching the zero point, when the sodium approaches its melting point.

27.
$$S_s = \frac{F_s}{A_s}$$

28. Where: A_s = π DL or the outside and inside surfaces of the cylinders

To calculate translational force (transmitted force) in terms of the applied torque values on the spur gears, consider:

The connection between 3 and 4 is a 1 3/8" o.d. 4-pitch left hand screw, 29°, modified ACME threader.

29. $D_1 = 1.375$ in.

30. $D_2 = 4.000$ in.

31. $D_3 = 10.000$ in.

32. $D_4 = 1.375$ in.

33. $W_1 = W_2$ since they are connected.

34. $W_2 = \frac{D_3}{D_4} W_3$ or

35. $W_2 = 2.5 W_3$

When gear 3 makes one revolution bar 4 moves a distance equal to the pitch.

From the law of conservation of energy:

36. $E_3 = E_4$ or:

37. $T_3 \times \theta_3 = F_4 \times P_4$

From equations (33) and (35) and the law of conservation of energy:

38. $T_3 = 2.5T_2 = 2.5T_1$

From the above statement:

39. $\theta_3 = 2\pi$ radians

40. $P_4 = \text{pitch} = \frac{1}{4}$ "

Substitute equations 38, 39, and 40 into equation 37:

41. $2.5T_1 \times 2\pi = F_4 \times \frac{1}{4}$ or:

42. $F_4 = 20\pi T_1$ For M_1 in ft-lbs:

43. $F_4 = 20\pi \times 12 \times T_1$ or:

44. $F_4 = 753.6 T_1$

Assuming that the friction loss between the spur gears is negligible compared to the friction loss at the 3-4 connection, the efficiency of the gears can be approximated from the following equations (Reference 3) The average between the values of efficiency for square threads and for V-threads will be used since Acme threads have properties common to both and are an approximate average of the two. For square threads with an opposing load:

$$45. \quad e = \frac{\tan b}{\tan (a \& b)}$$

$$46. \quad \text{Where } f = \tan a \text{ and:}$$

$$47. \quad \tan b = \frac{\text{Pitch}}{\pi D_m}$$

For V threads with an opposing load:

$$48. \quad e = \frac{\tan b (1 - f \tan b \sec d)}{(\tan b + f \sec d)}$$

$$49. \quad \text{Where } c = \frac{3}{2} \text{ between threads}$$

$$50. \quad \sec d = \sec c \sqrt{1 - (\sin b \sin c)^2}$$

The friction factor f depends on the metals at the threading and whether there is lubrication or not. No lubrication on the tester exists (California G-2D Grease is normally used as the lubricant) and the threading is Cast Manganese-Bronze versus Corrosion resistant steel (stem) - ASTM A-182

F-G. Applying these facts to reference 2.

$$51. \quad f = 0.30$$

From this and the following:

$$52. \quad D = \frac{D_o + D_i}{2} = \frac{1.375 + 1.375 - 2(0.135)}{2} = 1.24 \text{ in.}$$

$$53. \quad \text{Pitch} = 1/4"$$

$$54. \quad c = 1/2 (29) = 14.5^\circ$$

Substitution into equations 45 and 48 using equations 46, 47, and 50 gives:

$$55. \quad e = 0.173 \text{ for square threads and:}$$

56. $e = 0.168$ for V-threads

Since the accuracy of f is only to two significant places, let:

57. Gear Efficiency = 0.17

Now applying equation 57 to equation 44 gives:

58. $F_4 = (0.17) (753.6) T_1$ or:

59. $F_4 = 128 T_1$ which is the same as:

60. $F \text{ shear} = F \text{ trans.} = 128 T \text{ app.}$

Substituting equations 28 and 60 into equation 27 gives:

61. $S_s = \frac{128 T \text{ applied}}{DL}$

Now: $L = 6" = 1/2 \text{ ft.}$

$D = 4" = 1/3 \text{ ft.}$ so that:

62. $S_s = \frac{128 T \text{ applied}}{(3.14) (1/3) (1/2)} \frac{\text{#ft}}{\text{ft}^2} = \frac{128 T \text{ applied} \times 3 \times 2}{3.14 \times 1/4} \frac{\text{#ft}}{\text{in}^2}$

63. or: $S_s = 1.70 \text{ applied psi}$

From the data:

64. Average running = 8.47 ft-lbs - No sodium

65. Average open = 24.6 ft-lbs - Sodium in

66. Average close = 55.8 ft-lbs - Sodium in

The average running value for no sodium can be assumed to be the torque required to overcome the friction of the gearing and the compression of sodium inside the bellows. After sodium was injected, greater torques were required and these can be assumed as due to shearing of the sodium in the annulus. The average running value may be considered as a zero point and included in the second set of readings. These values already contain the gear friction, etc, factors and therefore the former value can be subtracted out. In this way only, the effect of sodium in the annulus is being measured.

67. Average open avg. = average running = $24.6 - 8.5 = 16.1 \text{ ft-lbs}$

68. Average close avg. - avg. running = $55.8 - 8.5 = 47.3$ ft-lbs

From equation 63

69. S_s open = 27.4 psi

70. S_s close = 80.5 psi

APPENDIX

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Calculation of Sample Variance	47
Nomenclature	49

34

35

GENERAL VIEW OF TEST FACILITY

KS-9046
UNCLASSIFIED

36

KS-9047
UNCLASSIFIED

GENERAL VIEW OF TEST FACILITY

643 035

S2G 8" Freeze Seal Test Facilities

37

Part A

- (32) Room Ambient
1A } Westons -
1 } Roving Ambient

Notes:

1. All T.C.'s here are on the indicator
2. Diagram not to scale
3. $\frac{1}{2}$ " piping on cooling water system
4. Cu tubing on all gas lines
5. Na lines = 1"
6. Na valves on thickend Na lines

KAPL-MED-1120
Fig. 1, Page 37

L.M.P. 236
5/17/56
P.K.L.

TITLE MADE FOR REFERENCES

S.O. SCALE

BY ISSUED MATERIAL

S2G 8" FREEZE SEAL TEST FACILITIES PART B

NOTES

- 1- ENCIRCLED T.C'S ARE ON THE INDICATOR. ALL OTHERS ARE ON THE RECORDER.
- 2- 1/2" PIPING ON COOLING WATER SYSTEM
- 3- CU TUBING ON ALL GAS LINES
- 4- NA LINES - 1"
- 5- NA VALVES ON THICKEND NA LINES

LMP.253
8/6/56

679 037

S2G 8" Freeze Seal
Thermocouple Locations
Mounted Internally

39

Part A

32-Room Ambient

Encircled T.C.'s are on the recorder. The rest on the indicator.
 Not to scale.

KAPL-M-EDL-124
 Fig. 6, Page 39

L.M.P.-235
 4/30/56
 P.K. L.

679 038

40

Blue line shows insulated area.

INSULATION, PART B

PART A, TEMPERATURE PROFILE, PRELIMINARY CYCLING, NO SODIUM IN ANNULUS

PART A, TEMPERATURE PROFILE, FINAL CYCLING, SODIUM IN ANNULUS

KS-9044
UNCLASSIFIED

PART A, SODIUM LEAKAGE, TOP VIEW

44

PART A, SODIUM LEAKAGE, SIDE VIEW

TEMPERATURE PROFILE, SIMULATED SECONDARY BELLOWS LEAK

46

A. POINT OF SODIUM SHEAR

B. TYPE OF SHEAR

679-045

8-30-56
P.K.S.
L.M.P.-246

SAMPLE VARIANCE

Values of the mean found in the calculation section of this report came from the equation:

$$\bar{X} = \sum_{i=1}^N X_i / N$$

Where: N = Sample size = 12 in this case. The sample variance of each group is obtained from the equation:

$$S_x^2 = \frac{1}{N} \sum_{i=1}^N X_i^2 - (\bar{X})^2$$

The data may be compared by means of a t-test, which will reveal any significant differences in the data. The t-statistic for testing the difference between two samples means is given by:

$$t = \left[\frac{(\bar{X}_2 - \bar{X}_1) - (M_2 - M_1)}{(N_1 S_1^2 + N_2 S_2^2)^{1/2}} \right] \left[\left(\frac{N_1 N_2 (N_1 + N_2 - 2)}{N_1 + N_2} \right)^{1/2} \right]$$

Where: $\bar{X}_1, \bar{X}_2$ = sample means

N_1, N_2 = sample sizes

S_1^2, S_2^2 = sample variances

M_2, M_1 = population means

It is assumed that the data comes from a normal population. The t-test is illustrated in this case by the following diagram.

As the number of degrees of freedom increases, this curve approaches the normal distribution curve. The 2.5% on either tail equals the area in the shaded section, the sum of which equals α (the significance level).

The total area under the curve is equal to 1 (one). Now the null hypothesis under test (for all tests) is:

$$H_0: M_2 - M_1 = 0 \text{ or:}$$

$$H_0: M_2 = M_1$$

When a value of t calc. falls to the right of t_{α} or to the left of $-t_{\alpha}$ as does t calc.₂, the above hypothesis can be rejected with $(1 - \alpha) = 95\%$ certainty. If the value falls within these two values, t calc., the hypothesis cannot be rejected. When not rejected, no certainty limits on the hypothesis can be made, but it is assumed in this problem that non-rejection means acceptance.

NOMENCLATURE

H.C.	= Hydrocarbons in gaseous range
X	= Pounds air
Y	= Pounds nitrogen
cfm	= Cubic feet per minute
Q	= Flow - cfm
A	= Actual
I	= Indicated
Z	= Weight % oxygen
$\bar{T}$	= Mean of time values - sec
$\bar{B}$	= Mean of Breakaway values - ft-lbs
$\bar{R}$	= Mean of Running values - ft-lbs
$\bar{C}$	= Mean of Close values - ft-lbs
$\bar{M}_a$	= Mean of Maximum values - ft-lbs
$\bar{M}_i$	= Mean of Minimum values - ft-lbs
$\bar{A}$	= Mean of Average values - ft-lbs
s^2	= Sample variance - seconds or ft-lbs
$\bar{X}$	= Mean of sample of random variable X
X_i	= The i'th value of the random variable X
N	= Sample size
M	= Population mean
t	= tee-statistic
H ₀	= Hypothesis
α	= Significance level
c	= close subscript
o	= open subscript

$f_x(x)$ = Probability density function
 V = Degrees of freedom = $N_1 + N_2 - 2$
 D = Diameter ft
 L = Length - ft.
 S_s = Shear stress - psi
 F_s = Shearing force - ft-lbs
 A_s = Shearing area - square inches
 T = Torque - ft-lbs
 SBA = Secondary bellows adaptor
 E = Energy - ft-lbs
 θ = Angle of rotation - degrees
 F = Force
 P = Pitch - $\frac{\text{inches}}{\text{Thread}}$
 f = friction factor
 D_1 = Root diam - In.
 D_o = Outside thread diam. - in.
 D_m = Mean diameter = $\frac{D_o + D_1}{2}$ Inches
 e = efficiency
 w = angular velocity - $\frac{\text{radians}}{\text{sec.}}$