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NP-6156

TECHNICAL REPORT 51

on

Contract NObs-65426

Index No. NS-200-021

TWO TUBE STEAM EVAPORATOR No. 3

W. Milich

E. A. Schultz

E. C. King

November 26, 1956

MSA

MINE SAFETY APPLIANCES COMPANY

Callery, Pennsylvania

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ABSTRACT

A two tube steam evaporator made of 2 $\frac{1}{4}$ % Cr - 1% Mo steel and having a gas-filled third fluid leak monitoring system (duplex tube), was tested and its performance compared with similar units constructed of types 304 and 347 stainless steel. Steam at 500 psig was generated, using a NaK inlet temperature of 850 F.

The highest value of 765 Btu/hr-sq ft-°F for the overall heat transfer coefficient, U, was obtained with a helium third fluid pressure of 200 psig. Lower coefficients were obtained at 20 and 600 psig. Using nitrogen, the optimum U occurred with a third fluid pressure range between 20 and 200 psig.

At the start of the program the U was found to be 660 Btu/hr-sq ft-°F at a NaK flow of 2450 lbs/hr-tube as compared to 610 Btu/hr-sq ft-°F at the completion of the program. This represents a 7 $\frac{1}{2}$ % drop in performance, with 75% of the drop occurring during the first 25% of the cyclic program. The overall drop in U for the type 347 stainless steel evaporator was 2%, and for the type 304 stainless steel evaporator was 37% before it failed.

The tubes in the present evaporator are to be re-expanded and the unit operated for an additional length of time to see if the original operating efficiency may be recovered.

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1. INTRODUCTION

A problem of major concern in the liquid metal heating of steam generators has been the lack of integrity of the steam generating equipment. Most of the failures have been attributed to chloride stress corrosion of the stainless steel on the water side. While rigorous water treatment programs have been set up in order to extend the life of present equipment, it was proposed to investigate the possibility of using 2 $\frac{1}{4}$ % Cr - 1% Mo steel as a material of construction. One advantage offered by such a steel lies in its resistance to chloride stress corrosion.

This report covers the tests at Callery of a two duplex tube evaporator constructed of 2 $\frac{1}{4}$ % Cr - 1% Mo steel by the Griscom-Russell Company, Massillon, Ohio, under the supervision of Knolls Atomic Power Laboratory, Schenectady, New York and the Bureau of Ships, Department of the Navy, Washington, D. C. The test included water conditions similar to those of the B&W Model Evaporator tests and both steady state and thermal cycling conditions as exemplified in the three major phases of the test program given below:

1. Operate the evaporator under steady state conditions prior to cycling to study the performance of the evaporator using first helium and then nitrogen as the third fluid medium in the duplex tube annuli.
2. Subject the evaporator to thermal cycling for a total of 11,200 cycles (10,000 regular cycles and 400 each of 3 special cycles using N₂ as the third fluid).
3. Perform steady state operation of the evaporator, after completion of the thermal cycling program, at various power levels (70, 60, 40, 30, 25 and 25% of full power using N₂ as the third fluid).

The heat source used for this test was hot circulating NaK (56% K).

2. DESCRIPTION OF THE SYSTEM

A flow diagram of the entire system is shown in Fig. 1. Except for the evaporator, which is constructed of 2 $\frac{1}{4}$ % Cr - 1% Mo, all water and steam piping is of type 304 stainless steel. The NaK piping is 1 in. schedule 40, type 304 stainless steel. Transition welds from the evaporator to the stainless steel were made using Inconel "A" rod.

Fig. 1 - Flow Diagram - Duplex Two Tube Steam Generator System
(2 1/4% Cr - 1% Mo)

2.1 Water-Steam System:

The evaporator, Fig. 2, contains two duplex tubes, initially bowed to handle thermal expansion. There are 36 grooves knurled into the outer surface of the inner tube, and equally spaced axially around the tube. When the inner tube was expanded into the outer tube to effect a mechanical bond between the tubes, the knurled grooves formed a third fluid leak detection system. Fig. 3, is a sketch showing tube to tube sheet details.

The pipe taps between the tube sheets are for introducing prepurified nitrogen or helium to the 36 grooves of the third fluid system, normally kept at a pressure intermediate between the steam and NaK pressures, to serve as a leak monitor.

The steam generated in the shell side of the evaporator (Fig. 1) flows through a 2 in. riser to two air cooled condensers; the condensate flows back to the evaporator by gravity. Provision was made for sampling the boiler water from the bottom of the evaporator.

The system was protected from excessive pressure buildup by a rupture disc sized for relief at 800 psig. A reseating safety valve down stream from the rupture disc served to maintain a back pressure should the rupture disc burst and thus prevent undue loss of water. An alarm was also installed to warn the operator if the steam temperature should fall outside prescribed operating limits.

2.2 NaK Systems

The liquid metal systems consisted of two independent NaK streams. The primary loop (Fig. 1) was used to transfer heat from a gas-fired furnace to the evaporator and the secondary loop was used to control the temperature of the primary NaK stream at the inlet to the evaporator, for cycling purposes, through the use of the double pipe heat exchanger. The secondary NaK stream was, in turn, air-cooled.

The NaK was pumped by an electromagnetic pump and the flow measured by a magnetic flowmeter. The NaK expansion and supply tanks were provided with pipe taps to introduce a cover gas such as prepurified grade nitrogen.

An alarm and automatic gas shut off to the furnace were incorporated in the system to protect the evaporator in case of loss of NaK flow or excessive NaK temperature.

FIG. 2 - TWO TUBE STEAM GENERATOR NO. 3

1ST PASS - HELIARC FUSION WELD
NO METAL ADDED

2ND PASS - HELIARC WELD
WITH FILLER ROD

3RD PASS - NO METAL ADDED
(ANGLE WELD TORCH)

Fig. 3 - Detail of Tube Joints

3. INITIAL STEADY STATE PROGRAM

3.1 Operation

At the start of the test program, steady state conditions were attempted, with NaK entering the evaporator at 850 F, and the steam pressure maintained at 500 psig. The nitrogen pressure over the primary loop was kept at 50 psig, but only a slight positive pressure was imposed on the secondary loop. Nitrogen at 200 psig was used as the third fluid. After four days of continuous operation at steady state conditions, the tubes in the evaporator were subjected to severe thermal shock when the main NaK pump was prematurely turned on after a power failure to the pump. As a result, the overall heat transfer coefficient, U , dropped from an original 650 Btu/hr-sq ft-°F to 550 Btu/hr-sq ft-°F. After conferring with R. Mantey of KAPL (wire dated March 8, 1956) testing was stopped.

The evaporator was removed from the loop, washed, dried and leak tested with the mass spectrometer. No leak was evident. The evaporator was sealed and returned to Griscom-Russell Co., for retubing (March 12, 1956). In rebuilding the evaporator the following refinements in fabricating techniques were employed.

1. The outer surface of the inner tube was cleaned and polished prior to heat treatment and ball expansion. The cleaning and polishing removed any high spots on the tube surface caused by the knurling operation.
2. The heat treatment was performed in a hydrogen atmosphere to prevent the formation of an oxide film on the tube surfaces.
3. A larger diameter ball (0.558 in. as compared with 0.554 in. diameter) was used for expanding the rebuilt unit, resulting in a better mechanical bond.
4. Argon gas was circulated through the third fluid space during ball expansion of the rebuilt unit to help prevent oxidation.

With the rebuilt evaporator installed, steady state operation was resumed. On April 18, 1956 a pump failure resulted in loss of NaK flow. Natural circulation of the NaK caused high temperature transients at the inlet and outlet to the evaporator, Fig. 4. On May 22 a second high temperature incident occurred when the power was cut off during an electrical storm while at 40% NaK flow. The plot of temperature vs time for this incident is found in Fig. 5.

Following these two incidents, the overall heat transfer coefficient had dropped about 2% which could be attributed to possible stress relieving of the mechanical bond between the tubes. The reason the damage (if any) to the bond from these later incidents was so slight as compared with the initial incident (2% vs 15%) was because, in the first case, the hot slug of NaK was carried through the entire length of the tube. In the latter two cases, the flow of hot NaK was by natural circulation only and was thereby only sufficient to maintain a large temperature difference a short distance into the evaporator before it was cooled by the boiling water.

Fig. 4 - High NaK Temperature Incident 4-19-56 During Operation of G-R Two Tube Steam Evaporator No. 3

Fig. 5 - High NaK Temperature Transient Due to Power Failure 5-22-56
During Operation of G-R Two Tube Evaporator No. 3

It may be noted from Fig. 4 that both the inlet and outlet of the evaporator were subjected to hot NaK. This incident resulted from loss of NaK flow but the NaK cooler remained in operation to cool the NaK. It was successful in reducing the maximum temperature but caused a flow reversal since it cooled the hot leg below the cold leg temperature. This phenomenon did not occur during power failure when flow through the NaK-NaK exchanger was also lost (see Fig. 5).

The chronological history for the steady state operating conditions is shown in Table 1 for the initial evaporator and in Table 2 after the evaporator had been repaired.

The maximum NaK operating conditions for the test apparatus were determined while operating at 500 psig steam pressure. The rated NaK flow for the evaporator had been set at 3500 lbs/hr-tube by KAPL. However, the maximum flow rate for these tests was established as 70% of 3500 lbs/hr-tube or 2450 lbs/hr-tube. This latter flow rate represented the maximum safe power level at which the equipment (furnace, pumps, etc.) could be operated continuously. During these tests an attempt was also made to correlate the variation of the heat transfer coefficient, U , with the pressure and nature of the third fluid gas, and with the rate of flow of NaK. Helium and nitrogen were both used.

During all electrical storms, the evaporator power load was lowered to 30% to prevent damage to the unit, should a power failure occur while operating at the higher loads.

Table 1 - Chronological History of Operation
Prior to Rebuilding the Evaporator

Date	Operation
Feb. 24	During initial start up, the 600 - 650 psig blow out disc prematurely ruptured at 450 psig. The relief valve failed to reseat resulting in loss of 2-3 in. of water from the evaporator. No damage inflicted to the evaporator. The disc and relief valve were replaced and make up water added to the boiler to operating level, (1 in. above top tube).
Feb. 27	Operation resumed and after 3 hours of operation there was an increase in system pressure to 580 psig which ruptured the blowout disc rated 623 psig at 575 F. There was no increase in steam temperature (465 F) with this increase in system pressure. The relief valve prevented undue loss of the water.
Feb. 28	System examined to determine cause of pressure rise. Cause undetermined. Preparations made to resume operation.
Feb. 29	Operation resumed. Attempt made to reach rated temperature conditions.
Mar. 1	After 24 hours of operation the unit was shut down to inspect the pump and try to increase the primary NaK flow as the evaporator appeared to perform considerably beyond the predicted range. A 240 F temperature drop across the generator could not be maintained with a NaK inlet temperature of 850 F. After over-hauling the pump, the system was again put into operation.
Mar. 2 - 7	Operation was continuous except as noted below. On 3/5/56 at 3:00 P.M. the primary NaK pump stopped for a short time due to overloading of the circuit breaker when attempting to increase the flow. The temperature of the NaK in the furnace rose to approximately 1500 F and, when the pump was prematurely turned on, a hot slug of NaK entered the evaporator. Operation was continued to study the damage of the shock to the heat transfer bond. On 3/6/56 at 6:00 A.M. a small steam leak occurred in the water system on the return line to the evaporator near the boiler feed line from the pump. The unit was shut down for three hours while repairing the steam leak. Operation was then resumed. The unit was shut down on 3/7/56 for clean-up and returned to Griscom-Russell to be re-tubed.

Table 2 - Chronological History of Operation
After Rebuilding the Evaporator

Date	Operation
April 16 - 18	Initial operations at steady state: NaK inlet to steam generator 850 F Steam temperature 467 F Nitrogen third fluid 200 psig NaK flow 55, 60, 71%
April 18(9:00 am-3:00 pm)	Shut down to replace blow out disc.
April 18(3:00 pm-6:30 pm)	Steady state at 70% flow.
April 18 (6:30 pm) - 21 (10:00 am)	Shut down - loss of NaK flow caused by bus bar dropping off at silver solder joint.
April 21 - May 10	Steady State conditions: Varied NaK flow 20 to 80% with variable nitrogen and helium third fluid pressures. (Vac. to 600 psig)
May 10 - 18	Shut down to repair steam leak and rebuild the NaK furnace which was badly cracked.
May 18 - 20	Steady state: Varied NaK flow and helium pressure on third fluid.
May 20	Shut down to repair steam leak at T.C. weld.
May 21 - 22	Steady state conditions: Varied NaK flow and helium third fluid pressure.
May 22	Down for 4 hours - power failure caused by electrical storm.
May 22 - 29	Steady state conditions: Varied NaK flow and third fluid nitrogen and helium pressures.
May 29 - 31	Steady state at 30 and 70% flow, 200 psig N ₂ , ran trial cycles.
Total Time: (4/16/56 tp 5/31/56)	
Steaming - steady state operation	787 hours
Cycling - trial cycles	5 hours
Down time - repairs, etc.	294 hours

3.2 Results - Steady State Conditions

A summary of the results obtained on the evaporator prior to being rebuilt is found in Table 3, and after rebuilding in Table 4.

From data obtained during operation of the rebuilt evaporator, the overall heat transfer coefficient, U , was computed for various third fluid pressures, using first helium then nitrogen as the third fluid, Fig. 6. When using helium, the highest heat transfer coefficients calculated were at a third fluid pressure of 200 psig indicating that the optimum pressure should be around the 200 psig. When nitrogen was used, the same values were obtained at third fluid pressures of 20 and 200 psig, indicating a maximum heat transfer rate between these two pressures.

Fig. 7 is a plot of the variation in overall heat transfer coefficient with variation in power level of the evaporator before the start of the thermal cycling program. The average value for the overall heat transfer coefficient at 30% power was about 480 Btu/hr-sq ft-°F, while at 70% power the overall coefficient was about 660 Btu/hr-sq ft-°F.

Table 3 - Summary - Initial Steady State Results

<u>Date</u> <u>1956</u>	<u>Boiler Water Analyses</u>						<u>NaK Temp. °F</u>		<u>Steam</u> <u>Temp.</u> <u>°F</u>	<u>NaK</u> <u>Flow</u> <u>lb/hr-</u> <u>tube</u>	<u>q=Btu/hr</u>	<u>U</u> <u>Btu/hr-</u> <u>sq ft-°F</u>	<u>Comments</u>
	<u>pH</u>	<u>PO₄⁻³</u> <u>ppm</u>	<u>SO₃⁻²</u> <u>ppm</u>	<u>O₂</u> <u>ppm</u>	<u>Cl⁻</u> <u>ppm</u>	<u>Solids</u> <u>ppm</u>	<u>Inlet</u>	<u>Outlet</u> ¹					
2/27	10.8	100	90	< 0.05	< 0.1	583	689.8	509.7	462.0	2161.8	92,274	460.5	not at equilibrium
2/29	10.9	105	33	< 0.05			829	545	466.5	2362.9	159,434	623.3	
3/1	10.7	80	28	< 0.05			806.2	551.5	465.3	2759.9	166,597	653.8	
3/2							842.6	561.4	466.9	2791.0	186,005	663.7	
3/3							830.3	568.2	466.0	3040.2	188,851	665.7	
3/4	10.8	105	35	< 0.05			848.4	573.5	468.0	2027.8	197,265	668.8	
3/5	10.8	105	35	< 0.05			837.5	564.0	467.5	2878.2	186,562	666.7	
3/5	10.9	90	36	< 0.05			816.5	570.4	467.3	3239.2	188,653	681.0	
3/5							865.0	612.4	466.8	3295.7	196,053	567.2	
3/6							842.6	596.2	465.0	3046.5	177,906	555.7	
3/7	10.7	105	45	< 0.05			830.7	598.8	465.0	3214.7	176,680	556.8	shut down to return generator

¹ The NaK temperatures of the top tube and bottom tube were essentially the same.

Table 4 - Steady State Heat Transfer Data on Two Tube
Steam Generator No. 3,
Obtained During Initial Steady State Operation

Date 1956	NaK Temp °F		Steam Temp °F	NaK Flow		q = Btu/hr	U Btu/hr-sq ft-°F	Third Fluid Pressure-psig	
	Inlet	Outlet		lb/hr-tube	% of 3500 lb/hr-tube			N ₂	He
4/16	857.8	520.9	465	1870	53.3	150,000	630	120	
	871	523	464	1870	53.3	155,000	627	200	
4/17	867	527	464	1940	55.4	157,000	625	190	
	866	530	465	1950	55.6	155,500	610	190	
	850	535	465	2130	61.0	162,000	637	195	
	852	534	465	2120	60.6	160,000	631	195	
	850	548	467	2420	69.0	173,600	650	190	
	855	548	467	2440	69.8	178,000	659	195	
	851	548	467	2460	70.3	176,500	656	195	
	854	549	466	2490	71.0	180,000	663	195	
4/18	856	551	465	2480	71.0	179,200	645	195	
	867	571	466	2500	71.5	175,300	576	195	
4/22	826	528	465	1950	55.8	138,000	587	185	
4/23	809	525	463	1930	55.2	130,500	575	180	
	871	551	464	2490	71.1	189,000	660	200	
	854	550	464	2490	71.1	179,500	650	195	
	838	548	465	2490	71.1	171,500	646	195	
	846	550	465	2490	71.1	174,500	643	195	
	855	551	465	2490	71.1	179,500	650	195	
	847	561	465	2820	80.6	191,200	673	195	
	848	561	465	2860	81.6	195,000	685	195	
	847	562	465	2870	82.0	194,000	679	195	
	850	566	465	2880	82.1	195,500	662	595	
	850	566	465	2870	82.0	193,000	660	595	
	851	567	465	2880	82.1	193,500	660	595	
	856	588	465	2890	82.5	183,100	575	5 mm Hg abs	
4/24	854	588	465	2870	82.0	180,500	570	5 mm Hg abs	
	855	588	464	2865	82.0	181,000	564	5 mm Hg abs	
	849	560	465	2830	80.8	193,800	681	195	
	850	549	465	2460	70.3	175,000	645	200	
	840	479	465	771	22.0	65,000	430	195	
	845	475	464	692	19.8	62,500	434	195	
4/25	845	471	463	604	17.3	55,300	413	190	
	852	473	464	604	17.3	55,000	397	180	
	850	494	464	1115	31.9	94,800	496	185	
	856	495	463	1120	32.0	97,000	488	200	
	853	514	467	1170	42.0	118,700	537	200	
4/26	853	570	464	1140	41.0	118,000	533	190	
	852	511	465	1140	41.0	118,000	533	195	
	855	496	463	1115	31.9	95,700	480	195	
	848	496	465	1115	31.9	93,900	488	195	
	844	499	465	1110	31.7	91,500	466	595	
	845	498	464	1110	31.7	92,000	465	595	
	855	500	465	1110	31.7	94,000	469	605	

Table 4 - Steady State Heat Transfer Data on Two Tube
Steam Generator No. 3,
Obtained During Initial Steady State Operation
(continued)

Date 1956	NaK Temp °F		Steam Temp °F	NaK Flow		q = Btu/hr	U Btu/hr-sq ft-°F	Third Fluid Pressure-psig	
	Inlet	Outlet		lb/hr-tube	% of 3500 lb/hr-tube			N ₂	He
4/27	864	497	464	1105	31.6	97,000	476	20	
	853	496	464	1115	31.8	95,200	483	20	
	857	496	464	1115	31.8	96,200	485	20	
	852	496	464	1120	32.0	95,300	484	20	
4/28	851	524	465	1145	32.8	89,000	372	5 mm Hg	abs
	849	527	464	1165	33.3	89,000	362	5 mm Hg	abs
	849	528	464	1152	33.0	87,700	356	5 mm Hg	abs
	846	528	463	1160	33.1	87,500	354	5 mm Hg	abs
	846	528	465	1160	33.1	87,300	357	5 mm Hg	abs
4/29	850	497	464	1160	33.1	97,700	495	190	
	848	496	462	1160	33.1	97,000	486	190	
4/30	849	496	463	1150	32.8	97,000	492	185	
	851	498	465	1160	33.1	97,700	494	190	
	847	496	464	1130	32.3	95,000	488	195	
	855	525	465	1740	49.7	136,200	562	195	
	854	524	465	1730	49.4	135,500	563	195	
5/1	849	523	465	1740	49.6	134,500	568	195	
	853	525	464	1780	51.0	138,000	570	200	
	855	525	464	1780	51.0	139,500	571	200	
	848	523	464	1740	49.7	134,200	562	200	
	850	524	465	1735	49.6	134,200	560	200	
	843	539	465	2118	60.4	152,500	595	200	
	850	539	465	2100	60.0	155,000	600	200	
	851	540	466	2105	60.1	155,500	598	200	
	849	542	465	2110	60.2	153,500	583	595	
	847	542	465	2100	60.0	152,000	577	595	
	849	543	465	2120	60.5	153,900	583	590	
	850	541	465	2160	61.6	158,200	604	35	
	850	542	465	2180	62.2	159,300	605	20	
	850	543	465	2165	61.8	158,000	597	30	
	851	541	465	2110	60.3	155,100	592	20	
5/2	856	561	465	2102	60.1	147,100	507	5 mm Hg	abs
	850	561	464	2102	60.1	144,000	500	5 mm Hg	abs
	851	566	464	2150	61.5	145,300	494	5 mm Hg	abs
	851	568	465	2160	61.7	145,000	492	5 mm Hg	abs
	853	565	465	2105	60.1	143,800	492	5 mm Hg	abs
	844	537	465	2110	60.3	154,000	606	200	
	845	537	465	2100	60.0	153,600	602	200	
	852	537	465	2909	59.8	156,200	605	200	
	846	556	465	2655	75.6	182,500	653	198	
	843	557	466	2700	77.2	183,000	667	195	
5/4	844	556	465	2700	77.27	184,300	663	195	
	844	555	465	2685	76.8	184,000	665	190	
	850	557	466	2685	76.8	187,000	667	205	
	848	558	465	2660	76.0	183,000	650	20	
	850	558	465	2660	76.0	184,000	651	20	
	848	560	464	2720	77.7	185,900	651	20	

Table 4 - Steady State Heat Transfer Data on Two Tube
Steam Generator No. 3,
Obtained During Initial Steady State Operation
(continued)

Date 1956	NaK Temp °F		Steam Temp °F	NaK Flow		q = Btu/hr	U Btu/hr-sq ft-°F	Third Fluid Pressure-psig	
	Inlet	Outlet		lb/hr-tube	% of 3500 lb/hr-tube			N ₂	He
5/4	846	556	464	2720	77.5	186,800	666	195	
	848	556	464	2710	77.5	187,700	667	195	
	847	555	465	2700	77.2	187,000	662	195	
5/5	842	558	465	2780	79.5	187,600	672	185	
5/6	843	558	464	2780	79.3	187,200	667	200	
5/7	850	503	464	1228	35.0	101,800	488	197	
	849	501	463	1228	35.0	102,200	493	195	
	854	550	464	2470	70.5	178,000	643	195	
	849	579	464	2520	72.0	161,000	525	5 mm Hg	abs
	849	558	464	2085	59.6	144,000	507	5 mm Hg	abs
	849	558	465	2090	59.7	144,000	507	5 mm Hg	abs
	851	559	465	2100	60.0	145,300	508	5 mm Hg	abs
	851	560	464	2165	61.8	149,500	520	5 mm Hg	abs
5/9	852	562	464	2170	62.0	149,000	513	5 mm Hg	abs
	850	562	464	2165	61.8	148,000	512	5 mm Hg	abs
	853	561	465	2120	60.6	146,700	509	5 mm Hg	abs
	848	510	463	2090	59.8	168,800	762	595	
	845	511	463	2100	60.0	167,500	755	595	
	849	510	463	2665	59.0	167,200	754	595	
	845	509	462	2075	59.3	166,500	755	595	
	849	509	463	2072	59.2	168,000	763	200	
	850	510	464	2080	59.5	168,800	765	200	
	849	511	464	2100	59.9	169,300	763	200	
	848	518	463	2115	60.4	166,000	710	20	
5/10	848	519	463	2140	61.2	167,000	713	20	
	853	520	465	2070	59.2	164,000	699	20	
	850	519	464	2070	59.1	163,000	700	20	
	849	511	465	2080	59.5	168,000	765	200	
	852	511	465	2065	59.1	168,500	765	200	
	857	549	463	2065	59.0	151,000	543	5 mm Hg	abs
5/20	849	494	465	1470	42.0	124,800	660	200	
	846	496	467	1480	42.3	124,000	659	200	
5/22	846	515	465	1510	43.2	119,200	532	200	
	848	515	465	1555	44.4	123,300	547	200	
	848	517	465	1541	44.0	121,500	526	195	
5/23	853	517	467	1541	44.0	123,300	545	200	
	851	515	466	1510	43.2	121,000	540	200	
	786	539	466	2415	69.0	141,500	615	200	
	859	555	467	2550	72.8	183,000	646	200	
5/24	848	554	467	2640	75.3	183,900	672	200	
	849	551	466	2580	73.8	182,500	668	200	
	843	493	465	1060	30.3	88,800	480	200	
5/25	845	493	464	1080	30.9	90,900	483	200	
	854	492	465	1060	30.3	92,000	492	200	
	854	491	464	1049	29.95	91,200	488	200	
5/26	847	480	467	1080	30.09	95,300	636	200	
	847	480	467	1080	30.09	95,300	636	200	
	847	480	467	1080	30.09	95,300	636	200	
	846	469	464	704	20.01	44,100	536	200	
5/27	838	464	459	697	19.95	62,900	527	200	
	835	461	456	697	19.95	62,800	528	200	
5/28	840	478	465	703	20.01	61,200	413	200

Fig. 6 - Overall Heat Transfer Vs. 3rd Fluid Pressure
for G-R Two Tube Evaporator No. 3

Fig. 7 - Heat Transfer Performance of Duplex Tube at Several Power Levels of G-R Two Tube Evaporator No. 3

4. CYCLIC PROGRAM

4.1 Specifications

The conditions for the cyclic program are tabulated in Table 5. At the start of the program 1600 standard (No. 2) cycles were to be run first. Then the three special cycles were to be introduced, running seven No. 2 cycles between each of the 3 special cycles.

4.2 Operation

Steady state heat transfer data was obtained daily by leveling out operations at 70% power and using a Leeds and Northrup precision potentiometer for thermocouple readings. A nitrogen third fluid pressure of 200 psig was used with 50 psig nitrogen cover gas. A chronological history of operation during the cyclic program is given in Table 6.

4.3 Results

Fig. 8 shows the change in overall heat transfer coefficient, U , as the cycling program progressed. At first, there was a rapid drop in U from about 660 to about 630 Btu/hr-sq ft-°F when the special thermal cycles were introduced. The further drop in U to about 610 Btu/hr-sq ft-°F over the remainder of the cycling program was much more gradual.

Plots of conditions typical of each of the four thermal cycles used in the program are shown in Fig. 9, 10, 11 and 12. Fig. 13, is a typical 24 hour chart of the NaK temperature at the evaporator inlet during the cycling program. A tabulation of the steady state heat transfer data obtained after the start of the thermal cycling program is shown in Table 7.

On June 19, a faulty relay caused a short circuit and loss of power, at the top of a standard (No. 2) cycle. The plot of NaK temperature and steam temperatures within the evaporator during this high temperature excursion is found in Fig. 14. This incident occurred just at the time of the introduction of the special thermal cycles (No. 1, 3 and 4) to the cycling program. Since the slope of the curve of U vs cycle numbers immediately before and after the power failure did not change, and since shortly thereafter the slope did decrease, it is difficult to state conclusively that any possible damage to the unit was attributable to this incident or to the co-current special thermal shock program.

Table 5 - Cyclic Program for Two Tube Steam Evaporator No. 3

Cycle No.	Inlet NaK Temp. (°F)	Time Sequences (Sec)	NaK Flow % of 3500 lb/hr-tube	Steam Pressure Psig	Cycles Required	Method of Control
1	850 946 850	Balance 30 up 300 hold 300 down Balance	70	500	400	Reduce primary NaK flow to ~43%. Reduce secondary loop flow to minimum steady flow.
2	850 740 850	30 down 180 hold 30 up 180 hold	70	500	10,000	Primary NaK flow reduced to ~28%. Cool with secondary NaK loop.
3	850 1050 850	Balance 120 up 300 hold 300 down Balance	As necessary	500	400	Primary NaK flow reduced to ~27%. Secondary NaK loop at minimum flow.
4	850 650 850	Balance 2 down 300 hold 300 up Balance	70	500	400	Primary NaK flow constant at ~68.8%. Cool with secondary NaK loop.

Table 6 - Chronological History of Two
Tube Steam Generator No. 3
During Cycling Program

Date	Operation
June 1 - 3	Cycling Condition 2 - Daily heat transfer $\sim$ 70% steady state - 1 hr.
June 4 - 5	Replace sight glass - 70% steady state, cycling, 30% steady state.
June 6 - 20	Cycling Condition 2 - at 70% steady state for heat transfer and 30% during storms. Made adjustments for special cyclic conditions 1, 3 and 4.
June 21 - 30	Special cycles introduced running a series of 7 No. 2 cycles between each No. 1, 3 and 4 cycle. Ran 70% steady state to adjust instruments, and 30% during storms.
July 1 - 3	Down for repair of Secondary NaK exchanger. Small secondary NaK to air leak at bellows. New charge of water added to boiler.
July 4 - 11	Back in operation and cycling except when necessary to be at 70% steady state during heat transfer readings and adjustments in instrumentation. Operation at 30% during storms.
July 12 - 13	Down for repair of secondary NaK exchanger. Small secondary NaK leak to air at bellows again. Redesign exchanger with bellows at cold end with protective sleeve and shroud.
July 14 - 15	Cycling except for 70% operation for adjustments and heat transfer.
July 16 - 20	Steady state operation at 70 and 30% flows. Repairing automatic cycling instrumentation.
July 21 - 31	Cycling operations except 70% daily heat transfer and adjustments. Operation at 30% during storms.
Aug. 1 - 7	Cycling, except for 70% operation for daily heat transfer and 30% for storms.
Aug. 8	Down for repair of premix bearings.
Aug. 9 - 17	Cycling, except for 70% operation for daily heat transfer and 30% operation during storms.
Aug. 18 - 25	Down for repair of NaK leak in secondary exchanger. New exchanger installed featuring hairpin design to eliminate bellows.
Aug. 26, - Sept. 9	Cycling except for adjustments to instrumentation. 70% operation for daily heat transfer and 30% operation during storms.
Sept. 9	Completed 10,000 standard cycles and 400 each of the special cycles. End of cycling program.

Fig. 8 - Heat Transfer Performance of Griscom-Russell Two Tube Steam Evaporator No. 3

Fig. 9 - Cyclic Condition I of Griscom-Russell Two Tube Steam Evaporator No. 3

Fig. 10 - Cyclic Condition II of Griscom-Russell Two Tube Steam Evaporator No. 3

Fig. 11 - Cyclic Condition III of Griscorn-Russell Two Tube Steam Evaporator No. 3

Fig. 12 - Cyclic Condition IV of Griscom-Russell Two Tube Steam Evaporator No. 3

NOTE:
CYCLIC CONDITION III
PEAK TEMPERATURES AS NOTED
LEVELING OFF TEMPERATURES ~ 1050 F

Fig. 13 - Chart Showing NaK Inlet Temperature to Steam Generator No. 3

Table 7 - Heat Transfer Steady State Test Data (during cycling program)
Two Tube Evaporator No. 3 (200 psig Nitrogen Third Fluid)

C	Nak Temp °F		Steam Temp °F	Nak Flow		q = Btu/hr	Heat Flux q/A = Btu/hr-sq ft	U Btu/hr-sq ft-°F	Cycle No.	ΔT °F
	Inlet	Outlet		lb/hr-tube	% of 3500 lb/hr-tube					
2	835	542	464	2450	70.0	170,800	124,200	600	173	188
3	844	545	463	2505	71.7	177,500	129,000	662	240	195
4/5	850	548	467	2420	69.2	173,100	126,000	646	378	195
5	856	545	461	2450	70.0	180,800	131,500	653	378	201
6	850	544	463	2395	68.3	173,900	126,800	646	460	196
7	850	545	464	2395	68.3	173,000	125,800	643	652	195
8	853	545	463	2395	68.3	175,000	127,300	641	785	198
9	855	545	462	2420	69.2	178,000	129,500	647	876	200
10	822	542	464	2460	70.2	163,200	118,800	646	1050	184
11	824	540	465	2350	67.2	159,000	115,500	635	1238	182
12	851	550	464	2410	68.8	172,000	125,000	644	1430	194
13	854	545	463	2425	69.3	178,000	129,500	653	1587	198
	850	546	463	2425	69.3	174,600	126,900	641	1607*	149
	850	501	349	1246	35.6	103,800	75,600	517	1607	198
6/15	854	547	462	2470	70.5	179,800	130,900	650	1617	201
6/16	846	543	463	2430	69.5	174,500	126,900	654	1640	194
6/17	850	547	463	2460	70.3	176,800	128,500	646	1642	198
6/18	846	540	460	2382	68.2	173,000	125,900	647	1642	194
6/19	848	550	463	2418	68.9	170,800	124,000	620	1694	200
6/20	849	551	463	2418	69	161,000	124,500	618	1694	202
	850	550	462	2417	68.8	171,500	125,000	620	1694	202
	853	553	469	2418	69	172,000	125,100	633	1694	197
	852	550	465	2392	68.3	171,300	125,000	627	1694	199
6/20	851	501	467	1148	32.8	95,900	69,700	487	1721	143
6/21	851	494	466	808	23.1	71,100	51,700	431	1721	120
	840	547	466	2362	67.5	164,700	119,500	623	1721	192
6/22	852	552	468	2420	69.3	172,800	125,500	635	1851	198
6/25	850	552	466	2390	68.3	168,500	122,700	615	2038	199
6/26	849	552	466	2475	70.6	174,200	126,800	635	2142	199
6/27	847	547	465	2375	67.7	169,000	123,000	629	2258	195
6/28	861	553	468	2450	70.0	179,000	130,200	648	2444	201
6/29	851	553	469	2440	69.7	172,200	125,200	636	2605	197
7/4	851	554	468	2440	69.7	172,000	125,000	629	2732	199
7/5	848	545	465	2300	65.7	165,300	120,500	621	2732	194
7/5	849	552	465	2400	68.5	169,000	123,000	615	2732	200
7/6	850	554	469	2355	67.2	165,000	120,000	610	2810	197
7/6	852	552	468	2355	67.2	167,200	121,800	616	2848	197
7/7	851	554	469	2410	68.8	170,000	123,600	625	2973	198
7/8	861	558	471	2420	69.0	173,800	126,300	626	3055	202
7/9	858	551	465	2360	67.5	172,000	125,000	620	3147	202
7/10	855	550	468	2330	66.5	168,500	122,700	623	3263	197
7/14	855	557	467	2420	69.2	170,900	124,100	609	3403	204
7/20	833	549	462	2500	71.5	168,500	122,700	626	3508	196
7/21	854	555	469	2405	68.7	170,900	124,300	625	3628	199
7/22	848	552	465	2386	67.7	170,400	124,000	623	3805	199
7/23	856	556	469	2400	68.5	170,800	124,300	617	3981	201
7/24	850	553	468	2380	68.2	168,000	122,300	620	4324	198
7/25	849	553	467	2405	68.7	169,000	123,000	622	4150	197
7/26	858	554	467	2390	68.3	171,200	124,800	620	4492	202
7/27	857	547	464	2280	65.2	168,000	122,300	614	4537	199
7/28	850	549	465	2380	68.1	170,200	124,000	625	4639	198
7/29	851	549	467	2245	64.2	161,000	117,000	598	4768	196
7/30	847	552	466	2318	66.1	162,100	118,000	594	4797	198
7/31	848	549	465	2385	68.1	169,500	123,200	623	4973	198
8/1	853	552	468	2395	68.5	171,000	124,000	630	5134	197
8/2	852	552	468	2340	66.8	166,500	121,000	616	5306	197
8/3	848	550	462	2359	67.3	166,600	121,200	604	5477	201
8/4	847	550	467	2350	67.0	165,200	120,000	614	5645	195
8/6	856	550	466	2320	66.1	168,400	122,700	613	5798	200
8/7	855	552	303	2330	66.6	167,500	121,800	614	5946	198
8/10	853	553	468	2315	66.1	165,000	120,000	606	6269	198
8/11	857	553	467	2360	67.5	170,300	124,000	617	6445	201
8/12	844	552	468	2380	68	165,000	120,300	617	6611	194
8/13	849	551	469	2350	67.2	166,100	121,000	620	6793	195
8/14	848	553	468	2345	67.1	164,100	119,300	607	6975	196
8/15	848	551	468	2370	67.7	167,000	121,500	621	7145	195
8/16	849	552	468	2350	67.2	165,500	120,300	612	7324	197
8/17	851	551	469	2355	67.2	167,200	121,700	620	7489	196
8/26	844	555	468	2400	68.8	164,800	119,900	609	7780	197
8/27	852	553	468	2350	67.3	166,900	121,500	615	7925	197
8/28	844	554	468	2360	67.5	162,500	118,300	605	8067	196
8/29	844	554	468	2349	67.3	162,100	118,000	600	8201	196
8/30	848	553	466	2360	67.5	165,500	120,500	605	8365	199
8/31	852.5	556	467.5	2390	68.4	167,700	122,100	607	8540	201
9/1	848	555	468	2390	68.2	166,000	120,800	608	8694	198
9/2	850	556	468	2400	68.5	167,200	121,800	610	8881	200
9/3	848	551	463	2400	68.5	169,200	123,000	610	9046	201
9/4	850	540	465	2380	68.0	170,000	123,700	625	9220	198
9/5	840	551	468	2380	68.0	168,000	122,700	622	9394	196
9/6	850	550	464	2360	67.3	167,900	122,000	610	9568	200
9/7	853	555	467	2380	67.9	168,000	122,500	609	9713	201
9/8	820	552	465	2405	68.8	158,000	115,000	595	9899	193
9/9	844	554	465	2449	70.0	168,300	122,500	613	10000	200

*Start of special cycles 1, 3, 4.

Fig. 14 - High NaK Temperature Incident 6/19/56 Two Tube Steam Evaporator No. 3

5. FINAL STEADY STATE OPERATION

5.1 Operations

Upon completion of the cyclic program, steady state heat transfer data was obtained with the evaporator operating at 70%, 60%, 40%, 25% and finally 20% of full power. In collecting data at each power level, the unit was first allowed to attain steady state conditions for an hour, then three readings were taken at half hour intervals.

5.2 Results

The overall heat transfer coefficient, U , was calculated over the range of power levels, and shown in Table 8. These have been plotted and are shown in Fig. 15, along with a copy of the curve of Fig. 7 for easy comparison. The effect of the thermal cycling upon the performance of the evaporator was a lowering of the heat transfer coefficient rather uniformly over the whole range of operation. U for 30% power was lowered from 480 to about 443 Btu/hr-sq ft-°F while at 70% power was lowered from 660 to about 610 Btu/hr-sq ft-°F.

After this series of data was obtained, the unit was operated for an additional day at low power in anticipation of further testing instructions. On Sept. 13, 1956, no further word having been received, the furnace was secured and the steam system blanketed with dry nitrogen at 25 psig.

Table 8 - Heat Transfer Data At Different Power Levels After
Completion of Cycling Program

Date 1956	Hour	Evaporator NaK Temp °F		Steam Temp. °F	NaK Flow lb/hr-tube	Flow % of 3500 lb/hr-tube	Q = Btu/ hr-tube	Heat Flux		Δ T °F
		Inlet	Outlet					Q/A=Btu/hr -sq ft-tube	U	
9/9	4:15 PM	844	554	465	2455	70.2	168,800	122,900	615	200
9/10	1:30 AM	853	557	466	2450	70	172,000	125,000	613	204.4
	9:15 AM	852	554	465	2400	68.5	169,600	123,500	610	202.6
	11:00 AM	844	553	465	2413	68.9	166,600	121,200	609	199
	12:30 PM	842	541	464	2065	59	147,600	107,600	569	189
	1:30 PM	849	542	465	2065	59	150,200	109,500	574	191
	2:30 PM	850	542	464	2060	58.8	150,600	109,800	570	192.5
	4:00 PM	846	513	465	1388	39.6	110,200	80,300	499	160.7
	5:00 PM	846	513	465	1389	39.7	110,500	80,400	500	160.8
	6:00 PM	850	513	464	1388	39.65	111,800	81,300	497	163.5
	9:30 PM	849	492	465	864	24.6	74,000	53,800	400	134.4
	10:30 PM	848	494	465	865	24.7	73,250	53,400	388	137.3
9/11	3:00 AM	847	482	465	697	19.9	61,110	44,500	373	119.2
	7:30 AM	851	481	464	692	19.75	61,400	44,600	377	118.3
	11:00 AM	852	490	464	857	24.5	74,400	54,100	404	134
9/12		851	500	465	1061	30.3	89,000	64,800	443	146.2
9/13		850	500	464	1060	30.3	88,880	64,590	443	145.9

Fig. 15 - Heat Transfer Performance of Duplex Tube at Several Power Levels of G-R Two Tube Evaporator No. 3 Before and After Cycling Program

6. EVAPORATOR WATER

Inasmuch as the purpose of this experiment was to test the choice of the material of construction and the operating conditions as a means for minimizing the effects of chloride stress corrosion, a strict boiler water quality control was maintained throughout the program.

Before charging with water, the steam system was cleaned by circulating a solution of 15% HCl and 0.2% inhibitor at 150 F for several hours, then the system was rinsed with demineralized water, purged with nitrogen and vacuum dried. The water was charged into an evacuated system and during all times when not steaming, the system was blanketed with nitrogen.

Table 9 shows the water analyses determined throughout the program and the prescribed specifications. A point-to-point record of each analysis over the entire test program is shown in Fig. 16.

Table 9 - Boiler Water Analysis and Specifications
for Two Tube Steam Generator #3

	<u>Water Sample Analyses</u>		<u>Specifications</u>
	<u>Minimum</u>	<u>Maximum</u>	
pH	10.7	11.1	10.6 - 11.2
SO ₃ (ppm)	17	60	> 15*
PO ₄ (ppm)	75	150	50 - 300
Hardness (ppm CaCO ₃)	0	< 0.05	< 10
O ₂ (ppm)	**	**	< 0.005
Cl (ppm)	0.01	0.09	< 0.1
Total solids (ppm)	411	950***	< 1000

* KAPL water specifications do not specify sulfite content. This is an MSA specification to insure sulfite presence and absence of oxygen.

** The presence of sodium sulfite in the evaporator water precluded the existence of free oxygen in the evaporator. For this reason the presence of excess sodium sulfite is assumed to maintain free oxygen within specifications.

*** Water was changed when 950 ppm value was reported. Total solids of new water charge reached a maximum of 580 ppm, and Cl reached 0.06 ppm.

Fig. 16 - Water Analysis During Operation of
G-R Two Tube Steam Evaporator No. 3

7. OVERALL RESULTS AND DISCUSSIONS

7.1 Comparison of Data on This Test

The performance of the evaporator was appreciably higher ($\sim 28\%$) when helium instead of nitrogen was used as the third fluid in the annuli spaces of the duplex tubes at 200 psig. A comparison at 60% and 30% NaK flow conditions indicates that U will be 765 and 633 Btu/hr-sq ft- $^{\circ}$ F respectively for the helium condition as compared to 602 and 492 respectively for the nitrogen condition. These differences are most likely due to the higher thermal conductivity of helium over that of nitrogen (~ 0.5 to 1).

The increase in U with an increase in the third fluid gas pressure is very definite at low pressures up to about 2 atmospheres (see Fig. 6, p.17). This is expected as the number of molecules of gas in the third fluid system to conduct heat is increased. However, between 2 and 20 atmospheres there is very little change in overall U , presumably because in this pressure range, a change in pressure has very little effect on the thermal conductivity of the gas, and the increase pressure may cause a loss of mechanical bond between the outer and inner tubes.

A complete summation of the operating time of the evaporator at different conditions is given in Table 10.

There was very little change in U during the initial steady state studies even though tests were made over a 6 week period.

During the cyclic program U dropped from 660 to 610 Btu/hr-sq ft- $^{\circ}$ F, a 7.5% drop, with 74% of the drop occurring the first 25% of the cyclic test (see Fig. 8, p 22). Fig. 15 shows that there seems to be a break in the U vs per cent NaK flow curve at 40% power following these cyclic tests. These findings may be due to a slight separation of the mechanical bond due to stress relieving and would be exemplified at low power loads. As the load is decreased the inner tube becomes more nearly equal to the outer tube in temperature and thus contracts more. At loads below 40% the differences in expansion may just cause a gas gap to appear between the two tubes. Above 40% loads, the two tubes may again come into contact and further expansion of the inner tube with respect to the outer tube with increased temperature difference would contribute very little to added heat transfer.

The present evaporator is to have the inner tubes re-expanded and the test continued to see if the original operating efficiency can be recovered.

7.2 Comparison of This Evaporator With Two Made of Stainless Steel

MSA Technical Report No. 28¹ describes the tests and results performed on two previously built evaporators, the first made of Type 347

¹ Andrews, R. C., King, E. C., Effects of Thermal Cycling and Chloride Corrosion on Stainless Steel Steam Generators, Technical Report 28, (Contract NObs-65426) Mine Safety Appliances Co., July 30, 1954.

Table 10 - Operational History of Two Tube Generator No. 3
500 psig Steam - 200 psig N₂ Third Fluid

Operating Condition	Operating Time, Hours			Total
	4/16/56 to 5/31/56 Initial Steady State	6/1/56 to 9/9/56 Cycling Program	9/9/56 to 9/13/56 Final Steady State	
70%* flow (steady state)		350	35	385
60% flow (steady state)			3	3
40% flow (steady state)			3	3
30% flow (steady state)		301	48	349
25% flow (steady state)			7	7
20% flow (steady state)			10	10
Cycling		1334		1334
Changing of power level (estimate)		72		72
Total Hours Steaming	792	2057	106	2955
Down Time	294	392		686

* Based on 100% = 3500 lbs/hr-tube

S S (No. 1) and the second made of Type 304 (No. 2). The cycling program for evaporators No. 1 and No. 2 are found in Tables 11 and 12. A tabulation of the important data for all these units is found in Table 13. Fig. 17 is a comparison of the performance of the 3 evaporators. Evaporators No. 1 and 2 were tested using synthetic sea water in the feed water system while S2G water was used in No. 3.

Evaporator No. 2 failed, presumably by chloride stress corrosion. Evaporator No. 1, Type 347 S S, did not show the percentage decrease in U that evaporator No. 2 did. However, whereas the U calculated for evaporator No. 3 at 70% power was 610 Btu/hr-sq ft-°F at completion of the test program, U for evaporator No. 1 at the start was only 575. With helium as the third fluid in evaporator No. 3 the coefficient was even higher. Evaporator No. 3 did show a greater drop in coefficient than did No. 1 but the test was for 10,000 cycles whereas No. 1 was only 1,000 cycles. If only the first 1,000 cycles of operation of evaporator No. 3 are considered, then that unit suffered a drop of only 3% in U. This compares well with the 2% drop in U experienced with evaporator No. 1 during 1,000 cycles.

It should be expected that thermal cycling would have the effect of accelerating creep. It remains for metallographic examination to determine the extent of any creep, or other strain in the No. 3 evaporator, and to determine if any structural weakness exists.

Table 11 - Cyclic Program For Steam Generator No. 1

<u>Cycle No.</u>	<u>Inlet NaK Temp. (°F)</u>	<u>Time Sequences (Min)</u>	<u>NaK Flow % of 7000 lbs/hr</u>	<u>Steam Pressure Psig</u>	<u>Cycles Required</u>	<u>Method of Control</u>
1	820 700 820	$\frac{1}{2}$ up $14\frac{1}{2}$ hold $\frac{1}{2}$ down	71.5	500	1000	Reduce primary NaK flow rate to 28.2% or normal. Cool with secondary loop.
2	850 650 850	1/30 down 15 hold 3 up	71.5	500	20	Primary NaK flow rate constant. Cool with secondary loop.
3	850 1400 850	5 up 15 hold 10 down	71.5	500	4	Reduce primary NaK flow rate.
4	850 1080 850	1 up 15 hold 3 down	71.5	500	4	Reduce primary NaK flow rate.
5	850 1400 850	1 up 15 hold 5 down	71.5	500	4	Hold inlet NaK initial condition with secondary loop, then turn off secondary loop and reduce primary loop flow rate simultaneously.

Table 12 - Cyclic Program for Steam Generator No. 2

Cycle No.	Inlet NaK Temp. (°F)	Time Sequence (Min)	NaK Flow % of 7000 lb/hr	Steam Pressure Psig	Cycles Required	Method of Control
1	850 946 850	$\frac{1}{2}$ up $14\frac{1}{2}$ hold 3 down	63.8	500	100	Reduce primary NaK flow to obtain temp. Secondary loop turned off.
2	850 740 850	$\frac{1}{2}$ up $14\frac{1}{2}$ hold $\frac{1}{2}$ down	63.8	500	2500	Primary NaK flow reduced to ~12%. Cool with secondary loop.
3	850 1150 850	2 up 5 hold 5 down	63.8	500	100	Reduce primary NaK flow to obtain temp. Secondary loop turned off.
4	850 650 850	1/30 down 5 hold 3 up	63.8	500	100	Primary NaK flow constant. Cool with secondary loop.
5	850 470 850	10 down 5 hold $1\frac{1}{2}$ up	63.8 3.2	500	100	Primary flow reduced to ~5%. Cool with secondary loop. Temp. and flow returned within prescribed time.

Table 13 - Operating Conditions of Evaporators No. 1, 2 and 3

	<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>
No. of cycles	1000	2500	10,000
No. of special cycles	32	400	1,200
U at start	575	480	660
U at completion	565	305	610
ΔU	2%	37%	7.5%
NaK flow rate for steady state readings, lbs/hr-tube	2500	2225	2450
Flow rate at % of 3500 lbs/hr tube	71.5	63.8	69.1
Third fluid gas	He	He	N ₂
System pressures, psig			
Third fluid	200	200	200
NaK	50	50	50
Steam	500	500	500
NaK inlet temperature to evaporator	820 F	850 F	850 F
Evaporator material	347 S.S.	304 S.S.	2 $\frac{1}{4}$ % Cr - 1% Mo steel

Fig. 17 - Comparison of G-R Two Tube Evaporators

8. CONCLUSIONS

The 2 $\frac{1}{4}$ % Cr - 1% Mo steel evaporator compared favorably with the type 347 stainless steel evaporator and out-performed the type 304 stainless steel evaporator which failed before completion of the testing program. If metallographic tests show that the evaporator is structurally sound, then advantages to be had in using this latest design include cheapness of material of construction, higher thermal conductivity and freedom from dependence on chloride free water as the alloy is not as susceptible to chloride stress corrosion.

Advantages, such as material cost and space may be had by using helium in the third fluid system rather than nitrogen, since a unit using helium would reduce the size by $\frac{1}{4}$ for a given rated power output.