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CONTROL ROD DRIVE MECHANISM STATOR LOSS OF COOLANT TEST

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HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company
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Robert Ibatuan

April 1977

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ABSTRACT

This report documents the stator loss of coolant test conducted at HEDL on the lead unit Control Rod Drive Mechanism (CRDM) in February, 1977. The purpose of the test was to demonstrate scram capability of the CRDM with an uncooled stator and to obtain a time versus temperature curve of an uncooled stator under power. Brief descriptions of the test, hardware used, and results obtained are presented in the report. The test demonstrated that the CRDM could be successfully scrammed with no anomalies in both the two-phase and three-phase stator winding hold conditions after the respective equilibrium stator temperatures had been obtained with no stator coolant.

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CONTROL ROD DRIVE MECHANISM
STATOR LOSS OF COOLANT TEST

SUMMARY

The Control Rod Mechanism stator loss of coolant test was performed by Westinghouse-Hanford Company in the High Temperature Sodium Facility (HTSF) at the Hanford Engineering Development Laboratory (HEDL) Richland, Washington in February 1977. The primary test objective was to demonstrate the scram capability of the CRDM with an uncooled stator. A secondary test objective was to obtain a time versus temperature curve for an uncooled stator with either the two-phase or three-phase windings energized.

During the test, the CRDM was successfully scrammed with no anomalies in both the two-phase and three-phase stator winding energized hold conditions, after the respective equilibrium stator temperature had been obtained. Stator temperature stabilized at ∿775°F and ∿940°F for the two-phase and three-phase hold conditions, respectively. The time versus temperature curves obtained during the tests are presented in Figures 1 and 2. (Note: Because this report is short, all figures are grouped at the back of the report.)

Post-test operation of the stator and post-test electrical resistance measurements indicated that the damage to the stator was limited to minor damage to the stator winding insulation. Several reed switch connections on the position detector assembly had loosened, but since stator temperatures were above the reed switch solder melting temperature, failure of the reed switch connections was expected.

I. INTRODUCTION

In the Fast Flux Test Facility (FFTF) nine Control Rod Drive Mechanisms (CRDM's) are installed on the Fast Test Reactor (FTR) to lift, lower, or hold the reactor control rods. Reactivity is controlled by axially positioning the control rods within the active core in response to signals from an electrical control system. When the CRDM's are deenergized, the control rods drop to their lowest (least reactive) position. When the CRDM is energized, the control rods may be lifted to achieve criticality.

All the primary and secondary control rods have a common manifold which provides nitrogen cooling for the stator windings of the CRDM's. A failure of the manifold or supply system could result in loss of coolant to any one or to all nine of the active CRDM's. A failure of this type is most unlikely. However, to demonstrate that such a failure would not prevent the safe shutdown of the reactor, the stator loss of coolant test was performed on the lead unit CRDM that was being used in the control rod system maintenance tests underway in the High Temperature Sodium Facility (HTSF) at HEDL.

The primary purpose of the test was to confirm that the CRDM could be successfully scrammed should an abnormal condition occur which would result in a loss of coolant to the stator windings. Scram capability was to be confirmed with the stator windings energized in the two-phase or three-phase positions. A secondary objective of the test was to obtain a time versus stator winding temperature curve for the uncooled stator.

This report describes and presents the results of the stator loss of coolant tests conducted at HEDL.

II. DISCUSSION OF TEST

A. DESCRIPTION OF TEST EQUIPMENT

To conduct the stator loss of coolant test, two primary pieces of hardware were needed; the Control Rod Drive Mechanism (CRDM) and a control console to energize the CRDM stator. Brief descriptions of the hardware and instrumentation used in the test follow.

1. CRDM

The refurbished lead unit CRDM assembly, Figure 3, which had been life tested by the vendor, was used for the test. The assembly consisted of the stator jacket assembly, the motor tube rotor assembly, the position indicator housing, position indicator coil assembly, and the lower CRDM assembly. All the above units had been refurbished and used in the control rod system in-air maintenance demonstration tests conducted in HTSF.

The CRDM is used to position selected control rods in or out of the active core in response to signals from the electrical control system. The CRDM is capable of four modes of operation, i.e., latch, run, hold and scram. Latching is accomplished by creating a magnetic field around the segment arms at the upper end of the rotor assembly. The field draws the upper end of the segment arms outward, driving the lower end inward, causing the roller nuts at the lower end to engage with the threads of the leadscrew.

When current is applied to the motor phases in a programmed sequence, the rotor assembly rotates and the leadscrew and control rod is translated in either the in or out direction depending on the sequence of the applied pulses. In the "hold" mode, the rotor does not rotate, but the segment arms are held latched by the stationary magnetic field, thus maintaining the leadscrew at any position in the stroke. When stator power is interrupted, the segment arm springs force the lower end of the segment arms outward, releasing the leadscrew and allowing it to travel to the full in position. Scram is initiated by removing the electrical power to the stator.

The stator-jacket assembly, which was the primary subassembly being tested, consists of an electrical stator surrounded by a stator cooling jacket, a stator outer shell and a stator end cover. The stator assembly and rotor assembly form a 4-pole, 6-phase, reluctance-type stepping motor, in which the rotor poles tend to maintain alignment with a stepwise rotating stator field. The six phases of the stator windings are arranged in a 4-pole motor configuration. The phases are identified as A, B, C, AA, BB, and CC and are energized with direct current in a two-phase, three-phase sequence. The sequence is reversed to drive the CRDM leadscrew in the opposite direction.

2. CRDM Controller Maintenance Console Assembly

The control console used for the test consisted of the CRDM Controller Maintenance Console Assembly, Figure 4, which was designed to functionally test the CRDM primary Controller System controller drawers and the Relative Rod Position Indicator (RRPI) and Absolute Rod Position Indicator (ARPI) modules. Normally, the maintenance console is used with a resistive dummy load to check out a particular controller drawer or module. In this case, the dummy load was replaced with the lead unit stator assembly and the proper controller drawer and position indication module were installed in the console to provide a fully operational control rod system.

The maintenance console is a two-bay mobile test cubicle which supplies the voltage and external signals needed to energize the modules under test. The console also monitors the outputs of the modules. Basically, the console represents one channel of the controller system, one channel of the RRPI system, and one channel of the ARPI system.

3. Instrumentation

Instrumentation for the stator thermocouples consisted of a 12-channel multipoint recorder with a range of 0 to 1000°F. In operation, each channel was recorded at one-minute intervals, with 5 seconds between adjoining channels. A pyrometer (General Electric Model FH-1), was used to record the stator housing surface temperatures.

B. DESCRIPTION OF TEST

1. Test Preparation -- CRDM Hardware

In preparation for the subject test, the lead unit CRDM lower assembly extension shaft disconnect (ESD) was raised and blocked approximately 10 inches above its normal position when engaged with the Control Rod Disconnect Driveline (CRDD). This operation was performed to provide a positive stop for the extension shaft disconnect during the planned scram operations. The block was cushioned with soft rubber foam to reduce the impact of the ESD on the wooden block during a scram.

After installation of the motor tube, stator-jacket, and position indicator assemblies, the connecting of twelve thermocouples located in the CRDM stator windings was initiated. Since there were no records as to where the twenty-two thermocouples were positioned in the stator windings, or even whether these thermocouples were good, resistance measurements were first taken and recorded, as shown in Table 1. From these resistance measurements, twelve thermocouples were selected for measurement, four with high resistances, four with low resistances and four in between the extremes, so that the top, middle and bottom stator winding temperatures might be recorded. The actual thermocouples selected are also shown in Table 1.

2. Test Preparation -- CRDM Controller Maintenance Console Assembly

Since the CRDM controller maintenance console assembly had never been unpackaged after arrival from the vendor's plant, the console assembly was shipped to HTSF, unpackaged, and inspected. In addition, a complete checkout of the console was performed, using the dummy resistive load to verify that the console was operational.

Following checkout of the console, the console was connected to the stator, as shown in Figure 5, for the test. The position indicator detector was also connected to the console to record rod position.

TABLE 1

THERMOCOUPLE RESISTANCE MEASUREMENTS AND RECORDER CHANNEL IDENTIFICATION

(IRON-CONSTANTAN THERMOCOUPLES)

Thermocouple Identification	Resistance Measurements (ohms)	Recorder Channel
1	2.66	5
2	3.82	12
3	2.31	
4	2.70	6
5	Open	
6	3.40	
7	3.70	9
8	1.86	4
9	2.64	
10	3.55	
11	2.50	
12	1.56	3
13	3.71	11
14	1.50	2
15	2.65	
16	3.10	
17	2.85	7
18	3.70	10
19	3.00	8
20	3.30	
21	1.50	1
22	3.20	

C. TEST OPERATIONS

1. Preliminary Scram Test

The initial test consisted of verifying that the CRDM mechanical and electrical components were operationally sound by performing an in-air scram test. This was accomplished by setting the motor phase voltage at 237 volts and latching the CRDM leadscrew. Then the motor phase voltage was reduced to 194 volts and the CRDM extension shaft raised six inches. Scram was then initiated and occurred as expected, with no hesitation or anomalies noted. The stator winding temperatures were recorded during the sequence and are presented in Table 2 and Figure 6.

Note that thermocouples on recorder channels 3, 7, and 8 were selected for most of the temperature vs time plots. Channel 3 was selected since this particular thermocouple, along with channel 9, appeared to be located in the nitrogen cooling exit nozzle. Both channels were considerably lower in temperature and more sensitive to nitrogen coolant flows than the other channels. The other two selected channels, 7 and 8, were picked to represent the high and low extremes of the remaining temperature parameters. Temperatures on recorder channels 4, 5 and 6 and 10, 11 and 12 were observed to be normally grouped together between channels 7 and 8. Channel 1 was essentially the same as channel 7.

2. Two-Phase Hold Test

Following the successful preliminary scram, the CRDM leadscrew was again latched and raised six inches. At this point, the console HOLD button was energized with the phase sequence in the two-phase position. This condition was then maintained $\sim$3-1/2 hours until the stator winding temperatures were essentially stabilized at approximately 775°F. Scram was then initiated and successfully completed. During scram, the position indicator went from 20.5 inches to 37.5 inches, indicating an open circuit and probable failure of the Position

TABLE 2

TEMPERATURE READINGS (°F) FOR CRDM STATOR 2-PHASE HOLD TEST

TIME (MIN)	RECORDER CHANNEL 1	2	3	4	5	6	7	8	9	10	11	12	REMARKS
0	75	75	75	75	75	75	75	75	75	75	75	75	Stator Test No. 1, 2-Phase
1	75	78	77	94	91	87	155	115	74	121	113	115 ←	"Prelim." Scram Data to
2	207	143	76	131	121	135	213	153	78	135	132	146	check Mechanics.
3	222	160	81	143	146	157	230	169	84	151	156	164	Scram -
4	221	167	82	142	155	162	192	159	92	138	151	162	
5	174	154	95	139	151	155	159	147	95	138	149	150	
6	153	152	99	140	147	147	151	146	100	140	142	143	
7	147	145	101	141	142	143	145	143	102	140	140	141	
8	142	142	105	140	141	140	141	140	103	137	137	138	
9	140	140	104	141	141	141	140	139	103	140	140	140	
10	139	138	105	140	140	139	139	137	105	140	140	140 ←	0940 - Start of Stator Test No. 1, 2-Phase Hold
11	137	137	105	139	140	139	138	136	103	138	138	138	
12	138	136	105	139	139	137	137	137	105	155	153	153 ←	0942 - Raising Leadscrew
13	191	154	105	167	156	161	214	171	105	173	167	173	
14	210	185	105	180	182	188	240	192	107	177	195	201	
15	242	198	110	181	207	214	247	202	110	187	215	220	Latch & Hold in 2-Phase
16	255	207	112	191	226	230	261	213	115	196	232	235	
17	265	220	120	205	238	242	271	226	121	210	246	247	
18	276	231	125	216	251	256	282	237	129	224	256	259	
19	289	241	132	229	267	266	294	247	139	235	268	272	
20	297	252	138	241	275	277	304	258	139	245	280	280	
30	391	352	201	348	375	374	396	355	204	350	377	376	
40	459	424	237	422	443	443	463	425	220	426	445	445 ←	Steam observed out of Exit Port
50	509	476	287	479	493	493	511	479	277	480	492	495	
60	551	517	297	520	530	532	553	579	250	521	533	533	
70	582	550	314	555	566	565	586	551	281	555	565	565	
80	613	580	348	587	594	590	615	582	294	587	593	593	
90	635	605	297	613	622	622	638	606	305	614	618	616	
100	657	625	320	634	641	634	659	626	310	635	642	639	
110	680	645	439	651	661	658	680	647	438	657	663	661	
120	696	664	451	672	677	676	697	664	445	675	678	676	
130	710	677	467	690	695	691	712	677	462	688	696	692	
140	725	690	482	705	710	705	727	691	479	705	708	705	
150	736	702	488	715	721	716	736	703	496	715	722	720	
160	748	715	500	727	730	730	749	717	506	727	731	728	
170	757	724	511	737	742	737	756	725	505	739	740	738	
180	765	732	514	746	751	745	765	732	521	749	749	748	
190	774	740	528	752	756	752	774	740	523	755	756	755	
200	776	748	523	760	761	760	777	748	527	760	768	760	
210	785	754	534	765	769	766	785	754	530	767	768	764	
220	788	760	536	772	773	769	791	758	540	771	774	771	
221	790	760	535	770	774	768	787	755	534	770	760	762 ←	Scram (manual)
222	772	749	533	765	755	755	760	743	542	764	750	749	
223	750	742	539	762	745	741	741	737	538	759	741	736	
224	736	735	532	755	736	732	732	730	536	751	732	729	
225	729	727	536	749	727	724	724	723	534	747	725	721	
235	662	660	507	681	662	660	660	657	507	680	660	657	
245	604	599	321	623	607	607	601	596	318	620	606	605 ←	Adding N_2 Cooling Flow
255	424	418	192	523	526	535	416	406	187	517	521	529	
265	320	316	185	407	425	429	327	326	215	405	423	427 ←	N_2 Shut off
275	362	360	297	386	399	400	363	360	298	387	398	398	

Indicator (P.I.) detector reed switch circuit. Therefore, the position indicator module was shut off for the remaining tests. Damage to the P.I. detector was later confirmed when the P.I. detector was removed for examination.

Nitrogen cooling was introduced into the stator upon completion of the test to cool the winding temperatures and hardware for the next test. Up to this point, only vapor had been observed leaving the stator exit nitrogen port and the off-gassing was attributed to drying of the stator windings. Upon introduction of the nitrogen cooling, after scram, a white smoke was observed billowing from the stator coolant exit port. The smoke had a distinct odor and was recognized to be from the stator winding insulation. Velocity of the nitrogen gas was minimized to prevent possible damage to the winding insulation due to the gas flow.

Table 2 and Figure 1 present the temperature data obtained during the two-phase hold test. Table 2 lists the temperatures recorded for all recorder channels and Figure 1 presents a temperature vs time plot for channels 3, 7 and 8. Variations in the channel 3 temperature vs time plot early in the test are attributed to vapor off-gassing, thereby intermittently cooling the thermocouples in the nitrogen cooling exit. Nitrogen cooling of the stator following scram was significant in reducing stator winding temperatures.

Figure 7 presents the current and voltage for the energized phases B and C vs time. Note that six stator phase windings exist; they are identified as A, B, C, AA, BB, and CC. Currents to the phase B and C windings were not reduced below 5.2 amps and the neutral current was not reduced below 10.9 amps as the stator was heated. Voltage increased slightly as the amperage was reduced.

3. Three-Phase Hold Test

Relatch of the CRDM leadscrew for the three-phase hold test was attempted at various temperatures as the stator cooled to determine the highest temperatures at which the relatch could be obtained. Relatch was attempted at average stator winding temperatures of 400°F, 350°F, 325°F, and 300°F. Relatch was not successfully obtained until the 300°F temperature was obtained.

Once relatch was obtained, the CRDM leadscrew and disconnect assembly was raised six inches, and the HOLD button energized with the phase sequence in the three-phase position. This condition was maintained for approximately 2-1/2 hours until the average stator winding temperature had essentially stabilized at 940°F. At this point, scram was again initiated and successfully completed with no hesitation or other anomalies. Cool-down of the stator assembly was accomplished normally without the introduction of nitrogen cooling.

Table 3 and Figure 2 present the temperature data obtained during the three-phase hold test. The effect of latching and nitrogen cooling on the stator temperatures can be observed in the early portion of the test in Figure 2. The 15-minute to 25-minute time period is shown in greater detail in Figure 8 to better show the relationship between the different temperature parameters during one of the latch attempts. Figure 9 presents the current and voltage for the energized phases A, B, and CC vs time for the three-phase hold test. Current to each phase decreased to $\sim$4.9 amps and the neutral current decreased to $\sim$14.9 amps as the stator was heated to a temperature of $\sim$940°F. Voltage increased slightly as the currents decreased.

During both the two-phase and three-phase hold tests, the external CRDM surface temperatures were monitored using a dual range pyrometer. These temperatures and location of measurements are shown in Table 4.

TABLE 3

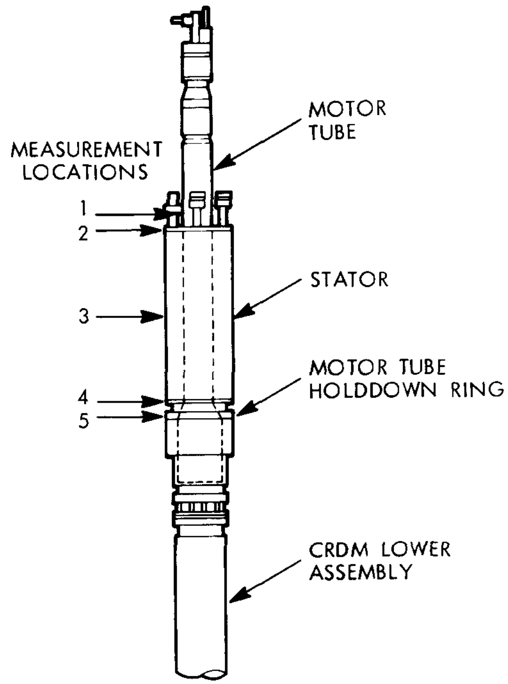
TEMPERATURE READINGS (°F) FOR CRDM STATOR 3-PHASE HOLD TEST

TIME (MIN)	RECORDER CHANNEL 1	2	3	4	5	6	7	8	9	10	11	12	REMARKS
0	380	367	311	389	392	394	422	382	308	396	400	406	
5	402	391	323	400	405	408	397	388	227	400	402	406	← Start N_2 Cooling
10	348	340	176	385	386	390	342	336	173	382	384	386	
16	307	302	162	359	363	367	304	299	160	357	364	365	
18	300	293	157	350	358	360	296	289	157	346	356	358	
19	294	288	155	343	355	356	292	287	157	343	352	356	← Prior to Latch
20	295	295	198	365	370	373	357	322	227	354	364	369	← Start Latch
21	330	310	222	365	370	373	357	322	227	354	364	369	← Latch
22	343	317	164	350	363	368	327	307	106	348	361	365	← Start Cooling
23	314	299	153	347	357	362	304	292	152	343	353	358	
25	287	278	149	335	348	350	283	275	147	335	345	348	
29	262	257	140	317	327	332	260	255	138	312	326	329	
30	260	253	139	312	325	327	257	250	138	308	321	325	← Prior to 2nd Latch Attempt
40	234	236	153	282	297	298	255	254	168	286	312	314	← Latch and Hold
50	492	430	265	442	460	471	499	437	271	445	464	476	
60	590	542	338	547	553	562	596	537	340	550	558	565	
70	659	607	391	620	620	627	662	608	393	625	625	628	
80	713	662	431	680	675	676	717	665	433	682	676	678	
90	761	711	468	728	717	717	765	707	467	728	720	720	
100	800	743	497	764	755	755	804	744	498	766	758	755	
110	833	775	520	798	787	784	835	775	522	798	790	785	
120	862	801	533	825	814	808	863	802	540	827	816	810	
130	887	825	560	848	837	831	890	825	551	850	837	832	
140	910	842	577	867	853	847	910	842	577	868	854	847	
150	922	855	591	881	867	861	922	858	590	883	867	862	
160	932	869	604	890	878	861	935	870	603	894	877	874	
170	946	878	616	905	888	880	944	879	616	904	887	883	
180	956	887	627	917	897	892	957	890	628	915	896	892	
190	967	895	636	925	905	899	967	895	636	923	908	899	
195	973	900	641	928	911	901	973	899	642	927	912	904	← Scram
200	867	848	633	877	857	850	862	843	630	872	852	843	
210	786	771	600	798	777	772	782	767	600	795	772	768	
220	722	707	572	728	708	705	718	708	572	730	710	707	
230	671	662	548	680	662	661	668	660	548	678	661	660	
240	627	620	523	636	620	618	624	618	523	632	617	617	
250	589	583	493	596	583	582	586	581	495	593	581	581	
260	554	550	476	559	548	547	552	547	473	557	547	547	
270	524	520	454	528	518	517	523	518	451	526	517	517	

TABLE 4

CRDM EXTERNAL TEMPERATURES (°F) DURING STATOR LOSS OF COOLANT TESTS

TIME (MIN)	PYROMETER MEASUREMENT LOCATIONS 1	2	3	4	5
2-PHASE HOLD TEST					
115	205	300	550	360	145
150	200	350	630	400	160
180	240	360	650	450	200
220	260	375	690	475	240
3-PHASE HOLD TEST					
94	200	300	600	400	200
109	200	300	650	450	200
135	260	390	760	510	250
190	275	425	800	550	260



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4. Post-Test Verification Tests

As a post-test inspection and equipment verification, the stator insulation resistance was checked and CRDM leadscrew assembly was cycled. The leadscrew was cycled 12 times over a six-inch distance while maintaining the average stator temperature below 500°F with nitrogen cooling. At the end of 12 cycles, the CRDM was successfully scrammed with no anomalies noted during the scram or cycling operation. The insulation resistance was measured at 100 Megohms before and after the leadscrew cycling and scram, indicating that there was no significant degradation of the insulation during the stator loss of coolant tests or the post-test inspection.

Table 5 and Figure 10 present the stator temperature vs time data obtained during the post-test CRDM leadscrew cycling test. Although nitrogen cooling was being applied (amount of flow unmeasured), the flow was too low to remove the heat being generated in the stator and a gradual heatup of the stator occurred until scram was initiated.

Upon completion of the testing and post-test operations, the position detector assembly was removed for inspection to determine what damage had occurred when the unit was subjected to the elevated temperatures and scram operations during the stator loss of coolant tests. During the two-phase hold test, the position indication detector system failed, indicating an open circuit. The position indicator module was not used after the failure. When inspected after disassembly, the resistor ladders were intact, but some reed switches were no longer attached to the ladder (see Figures 11 and 12). The ladders operated satisfactorily with the missing reed switches when attached to the position indicator module and actuated by a magnet. The open circuit indication in the two-phase hold test scram was not explained.

Following the examination of the position indicator, the CRDM stator and motor tube were removed for examination. As observed in

TABLE 5

CRDM STATOR TEMPERATURES (°F) DURING CRDM LEADSCREW CYCLE TEST

TIME (MIN)	RECORDER CHANNEL 1	2	3	4	5	6	7	8	9	10	11	12
0	75	75	75	75	75	75	75	75	75	75	75	75
3	239	151	78	137	143	148	253	163	81	146	155	162
6	272	195	99	177	207	210	287	205	100	188	211	217
9	334	250	115	234	250	255	337	257	117	242	255	263
12	371	293	137	279	292	297	375	300	140	287	297	303
15	401	328	157	321	328	332	407	334	158	326	334	338
18	430	362	176	357	362	363	435	365	177	362	365	368
21	457	390	193	388	390	392	460	393	196	392	396	397
24	478	416	211	417	417	418	483	418	212	420	400	422
27	502	440	228	442	442	442	505	443	231	447	444	444
30	522	462	247	466	463	462	526	465	247	468	465	466
33	455	442	257	454	445	444	445	437	258	453	442	440
36	425	422	263	443	430	425	422	419	262	440	427	421

CRDM Leadscrew cycled in and out in 6-inch strokes for 12 complete cycles over a period of + 6 minutes to + 27 minutes. Scram was actuated at + 31 minutes. Nitrogen cooling was used throughout test.

Figures 13 through 15, both units were discolored due to the 940+°F temperatures and some deterioration of winding insulation is apparent by observing the condition of the stator windings and external surfaces of the motor tube.

III. CONCLUSIONS

The completion of the CRDM stator loss of coolant test verified that the CRDM could be scrammed without difficulty when a loss of nitrogen cooling occurred and the stator winding energizing sequence was in either the two-phase or three-phase hold condition. With loss of coolant, the stator winding temperatures increased steadily in both the two-phase and three-phase hold conditions until the equilibrium temperatures were obtained -- $\sim$775°F for the two-phase hold condition and $\sim$940°F for the three-phase hold condition. Scram was successfully demonstrated in both cases after the static windings had reached the respective equilibrium temperature. Stator phase currents did not reduce to a value low enough during stator heat-up to cause inadvertent unlatching of the control rod.

Post-test operation of the stator and post-test electrical resistance measurements indicated that the damage to the stator was limited to minor stator winding insulation damage. Loosening of several reed switch connections on the position detector assembly had occurred, but since stator temperatures were above the reed switch solder melting temperature, failure of the reed switch connections was expected.

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K. M. Beadell
W. F. Bisley
H. L. Anderson
J. C. Moore

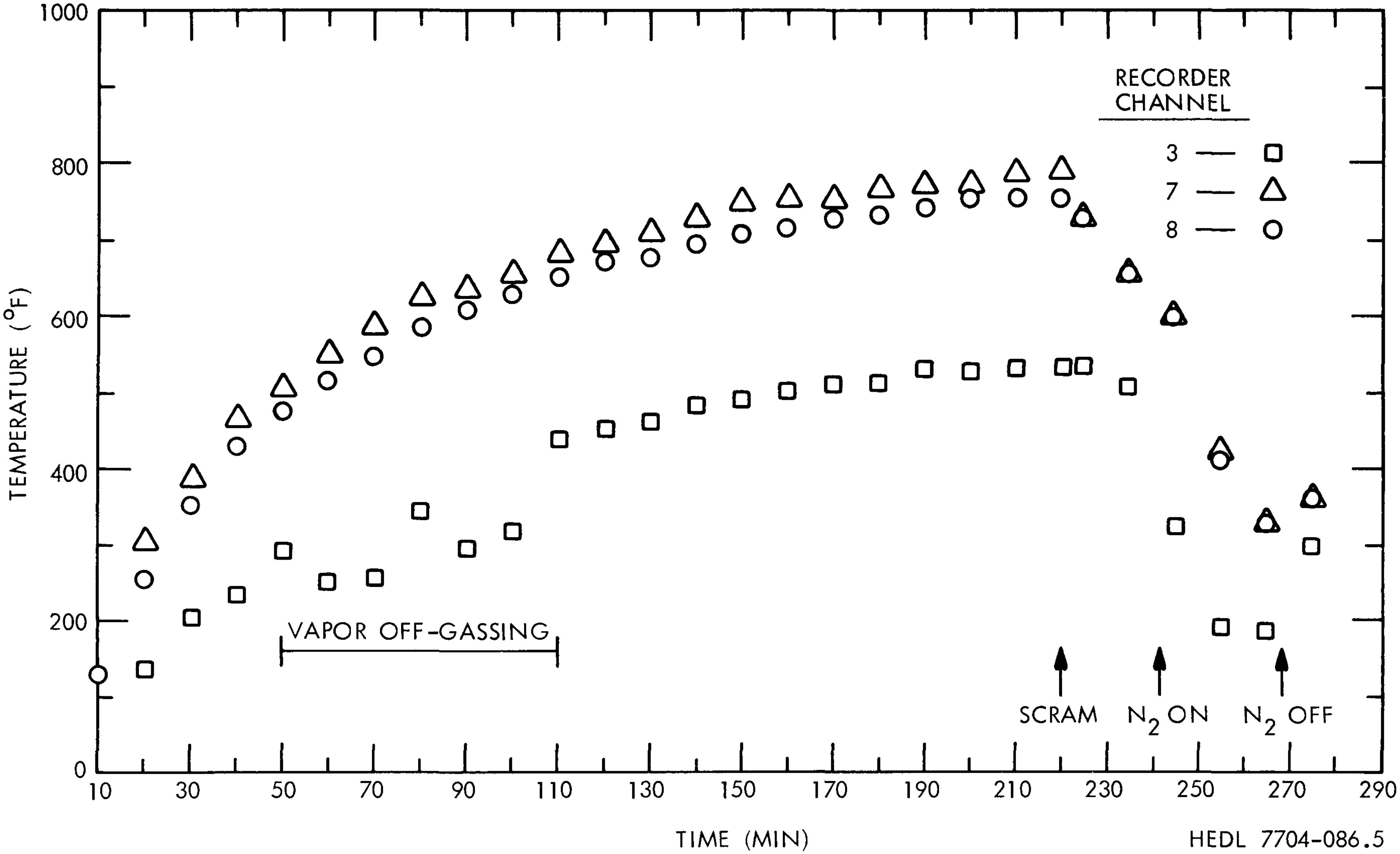


FIGURE 1. CRDM Stator Temperatures vs Time -- 2-Phase Hold.

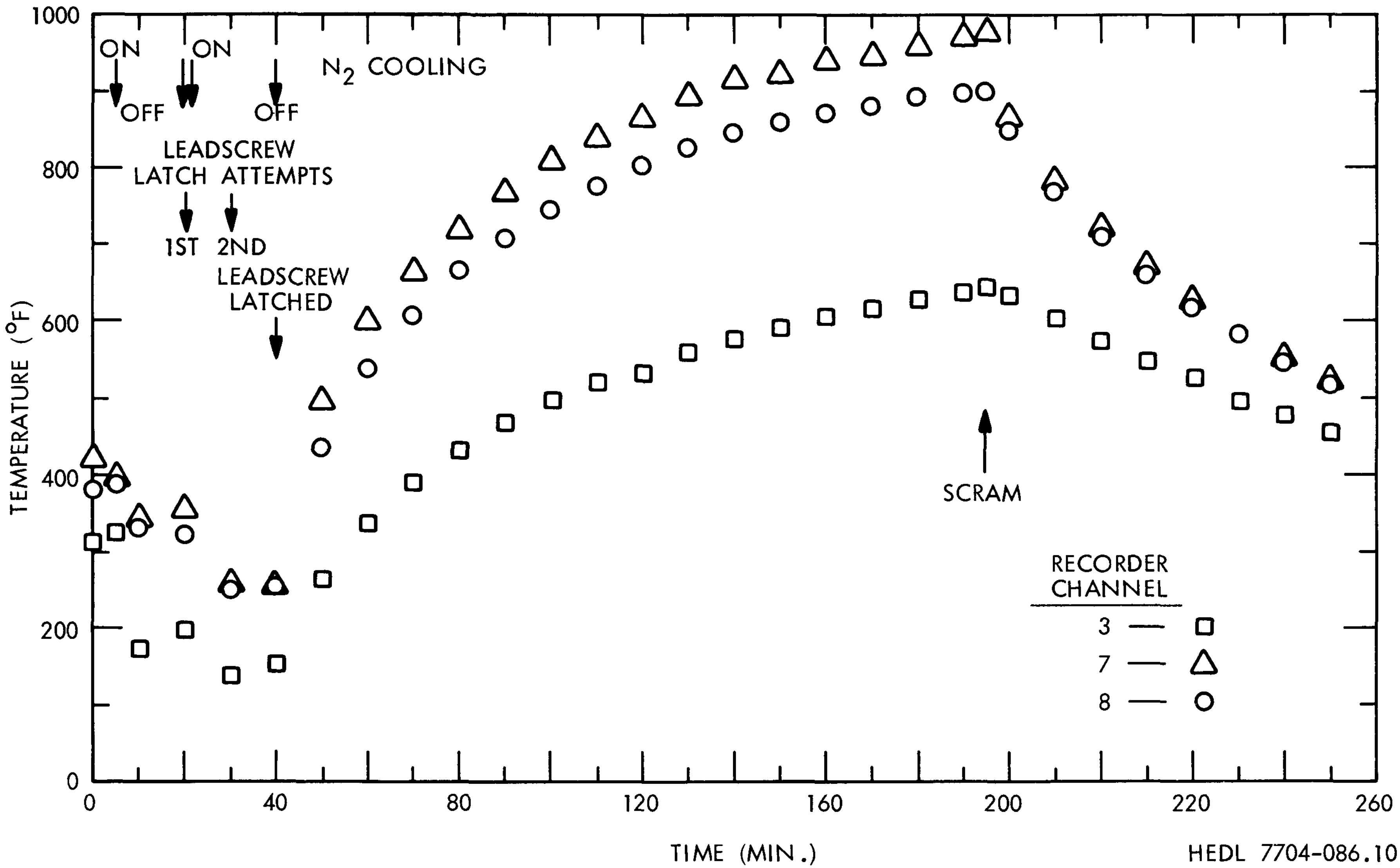


FIGURE 2. CRDM Stator Temperatures vs Time -- 3-Phase Hold.

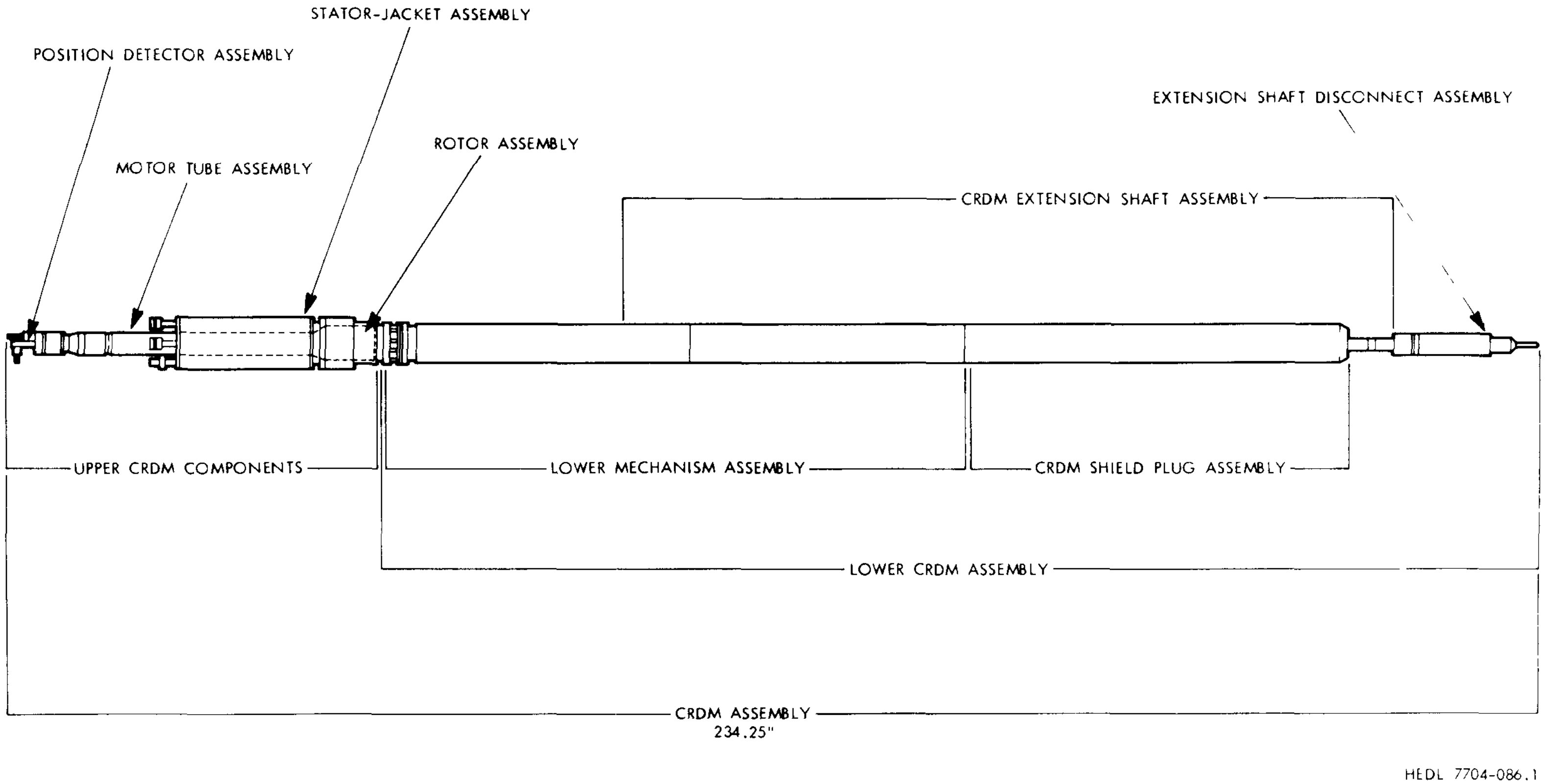


FIGURE 3. Control Rod Drive Mechanism Configuration -- Nomenclature.

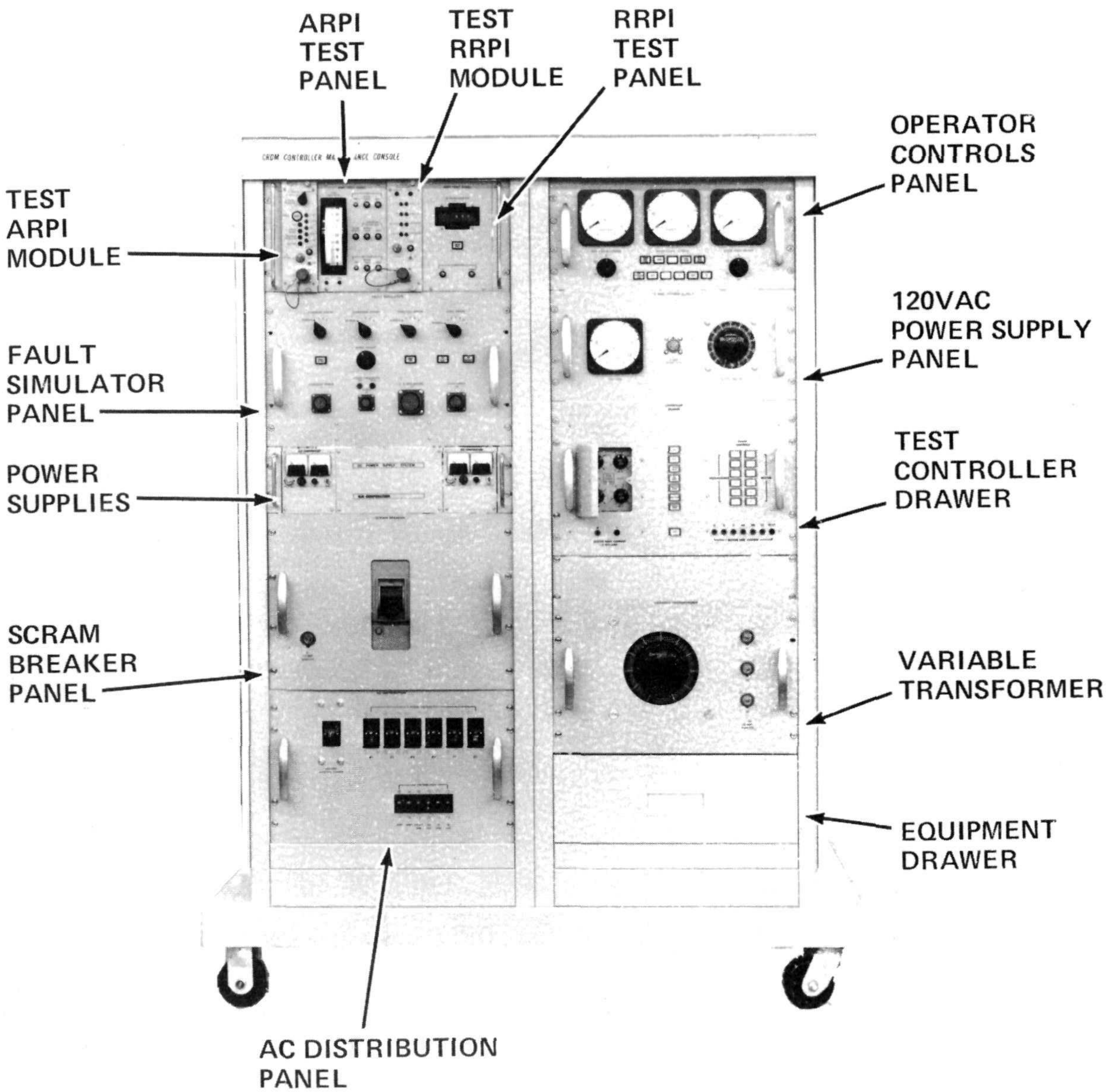


FIGURE 4. CRDM Controller Maintenance Console.

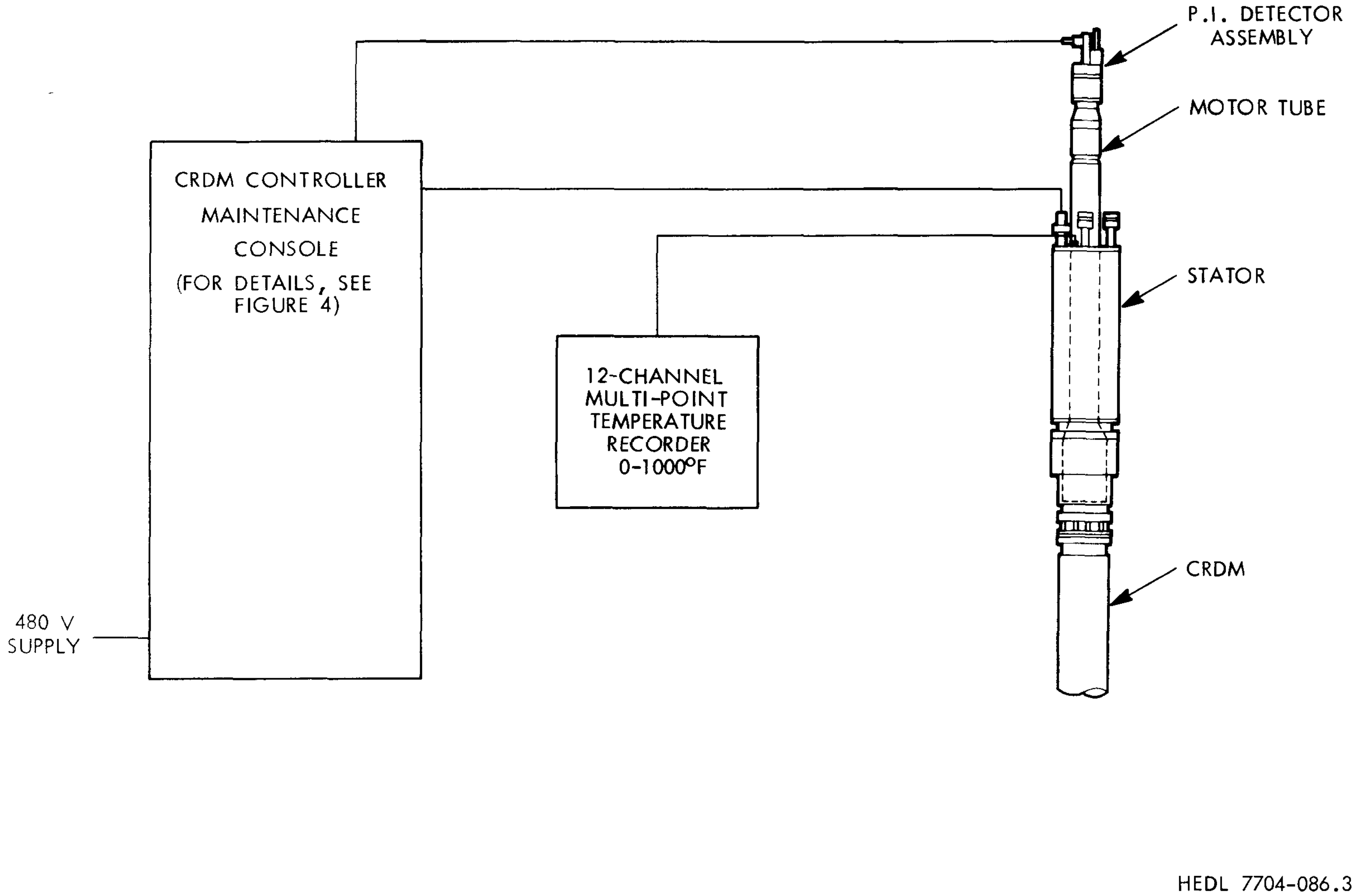


FIGURE 5. Stator Loss of Coolant Test Configuration.

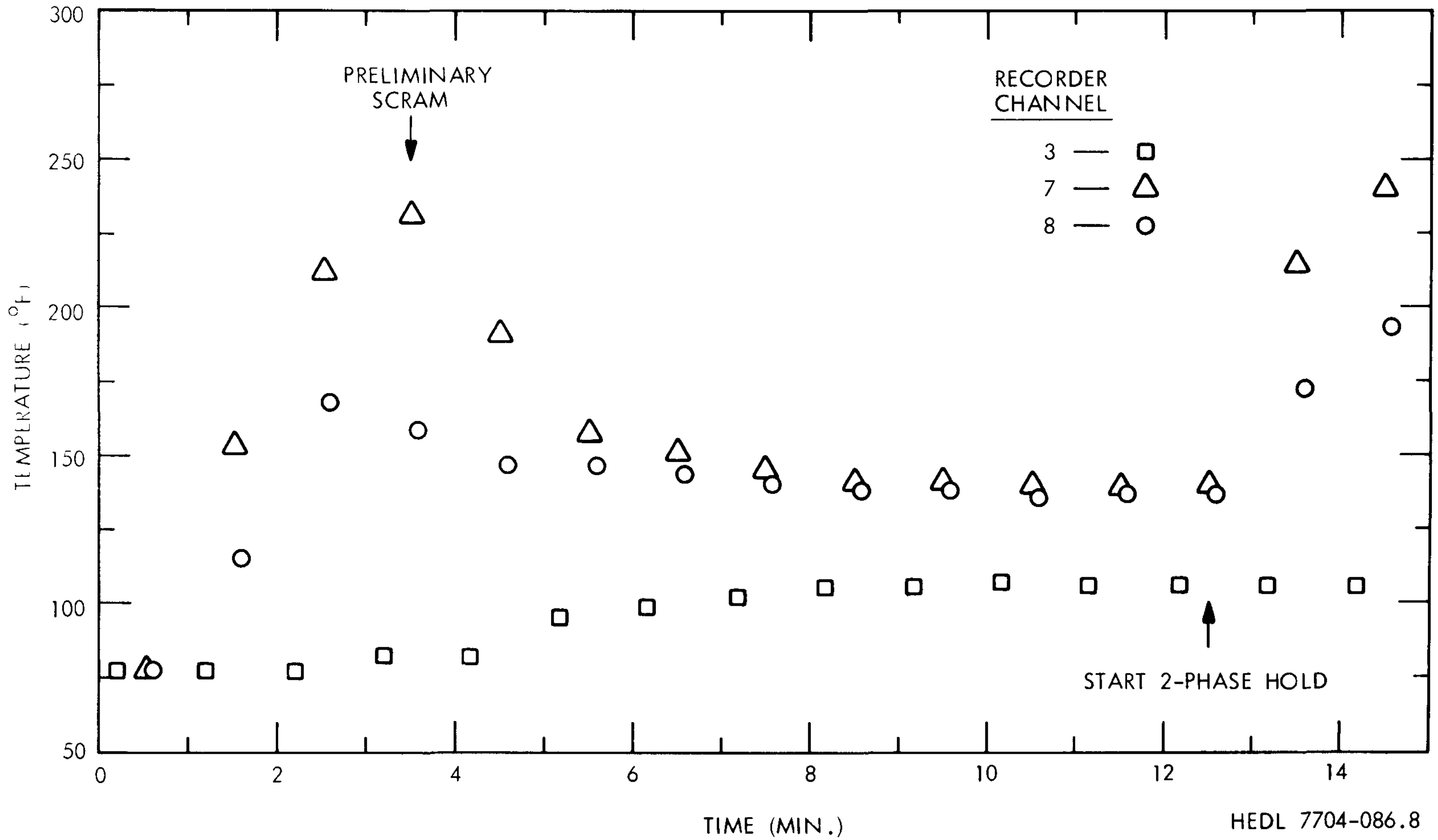


FIGURE 6. CRDM Stator Temperatures vs Time -- Preliminary Scram & 2-Phase Hold.

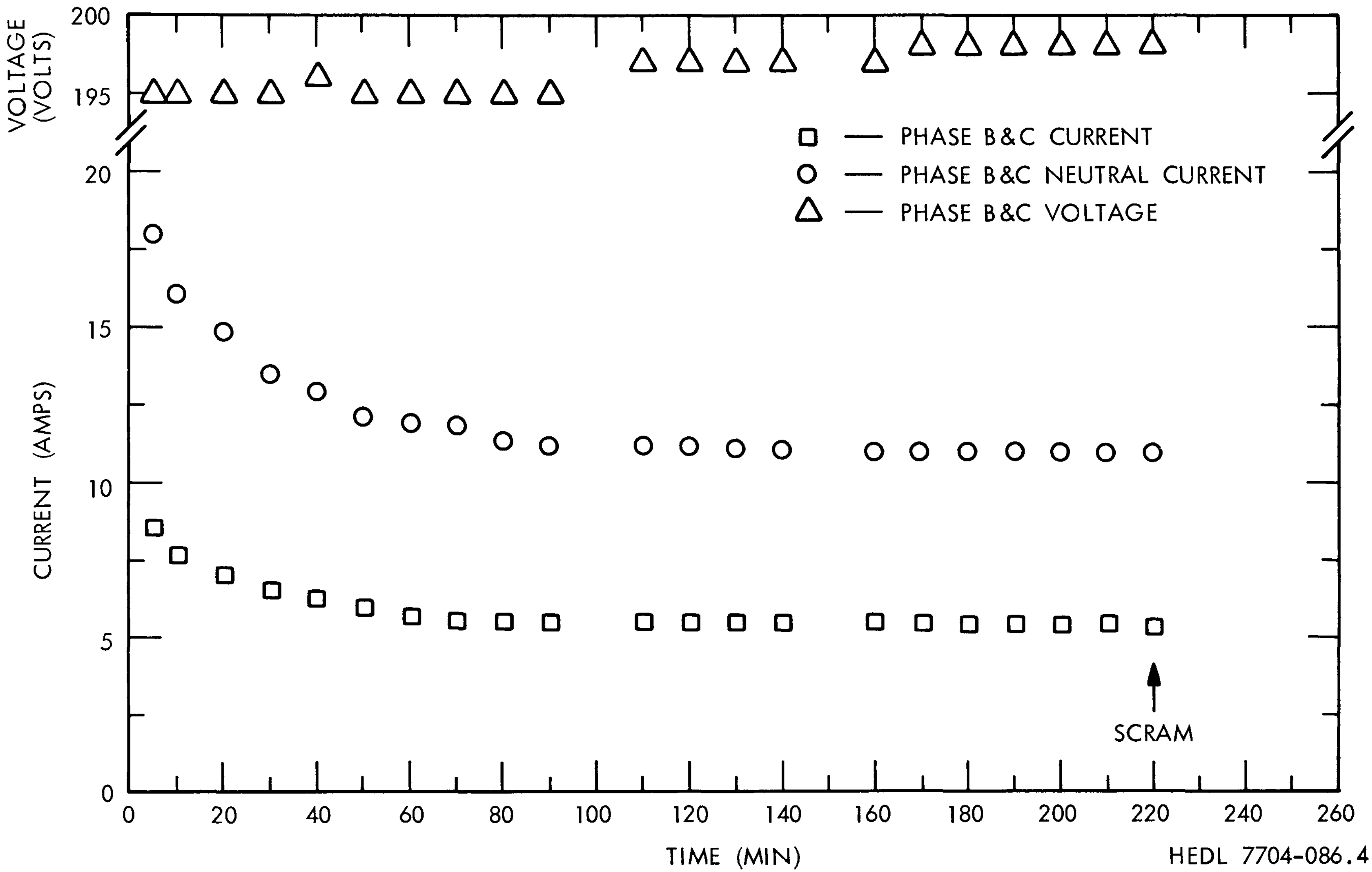


FIGURE 7. CRDM Stator 2-Phase Voltage & Current vs Time.

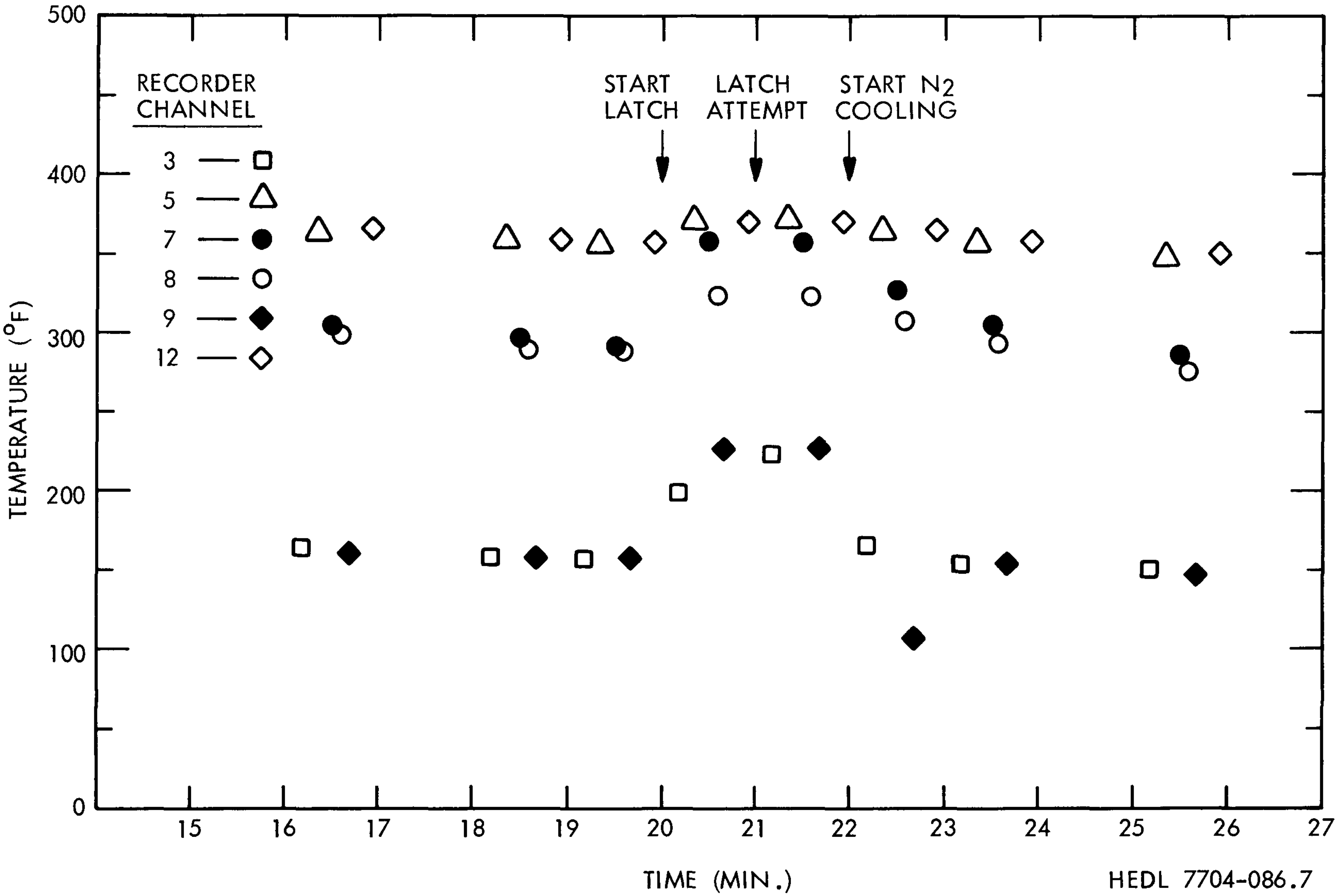


FIGURE 8. CRDM Stator Temperatures vs Time -- First Latch Attempt - 3-Phase Hold.

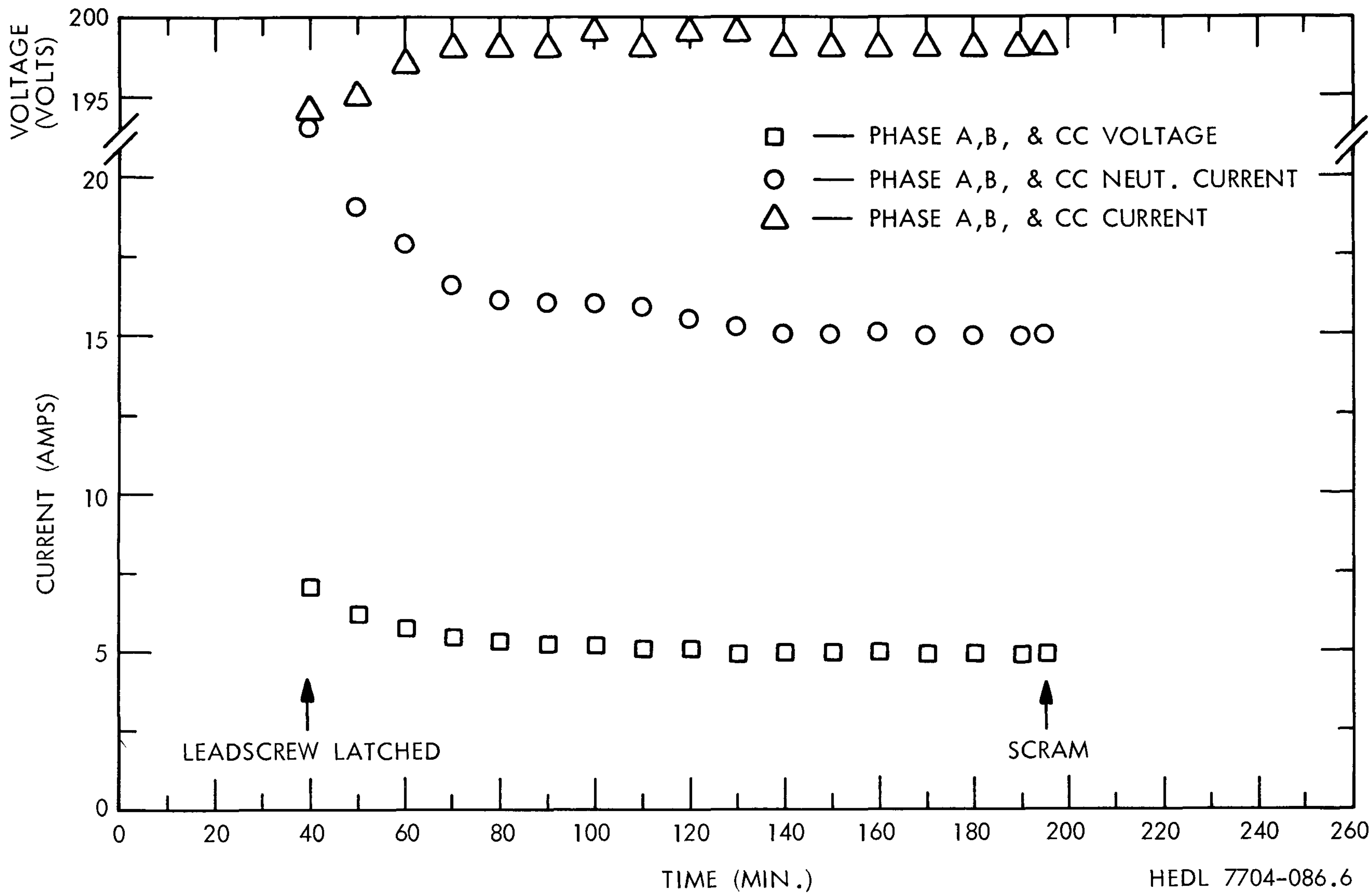


FIGURE 9. CRDM Stator 3-Phase Voltage & Current vs Time.

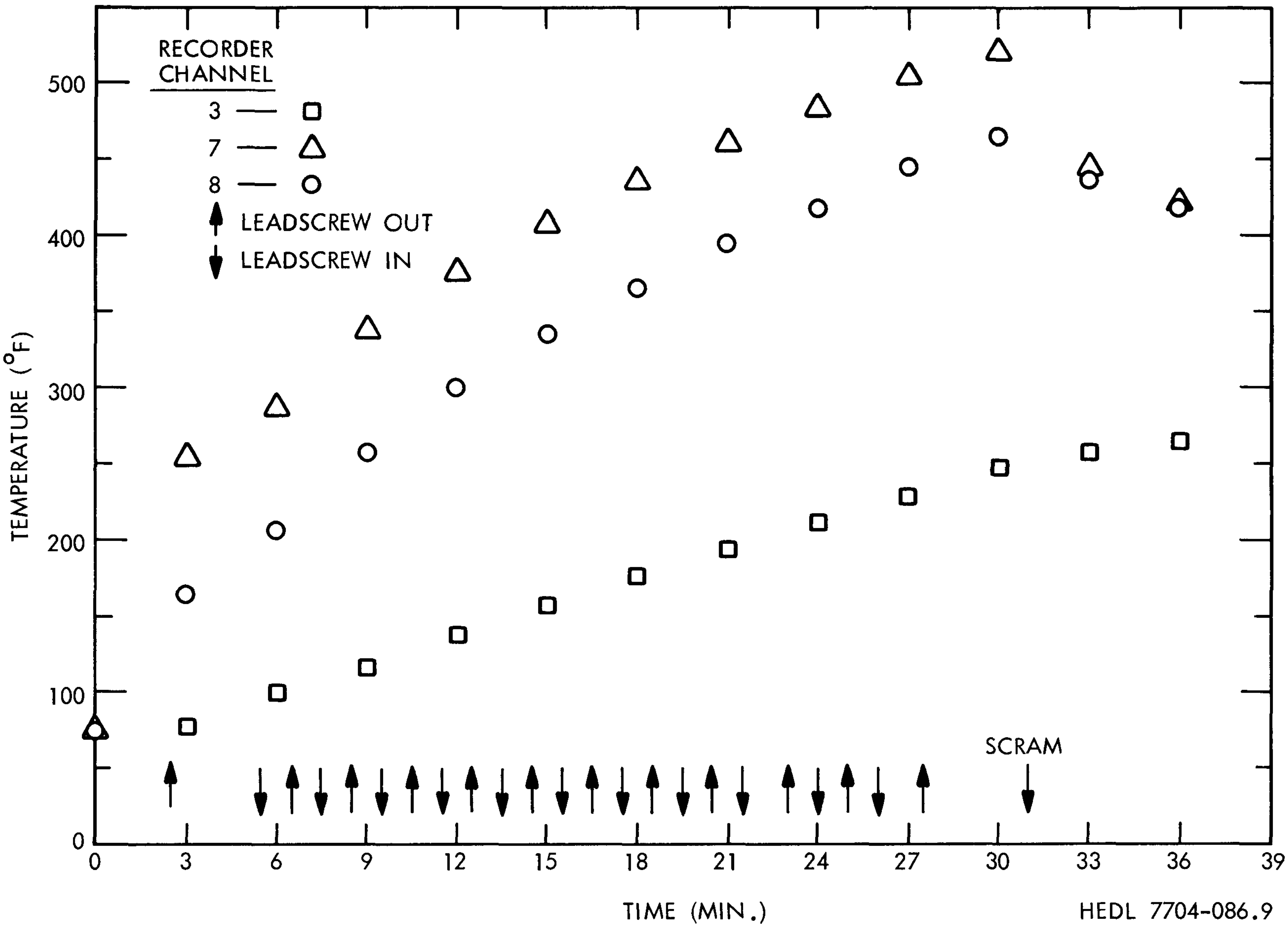


FIGURE 10. CRDM Stator Temperatures vs Time -- CRDM Leadscrew Cycle Test.

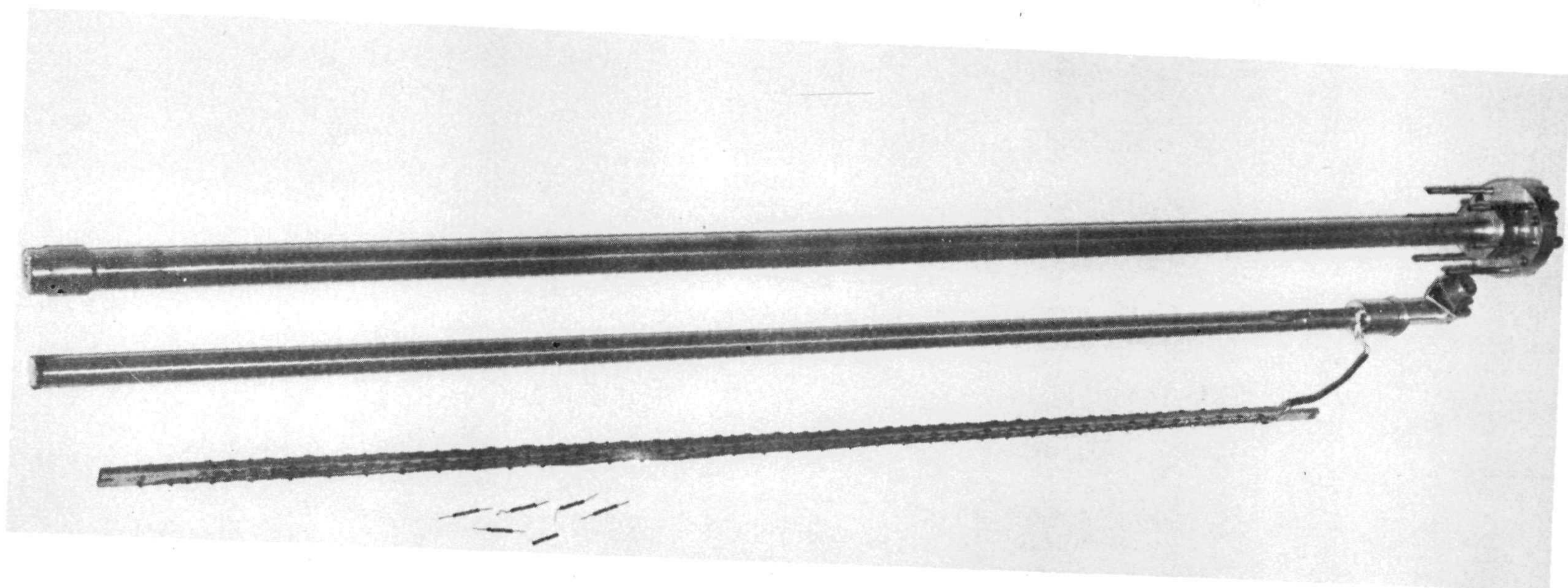


FIGURE 11. Position Detector Assembly.

Neg. No. 771940-3

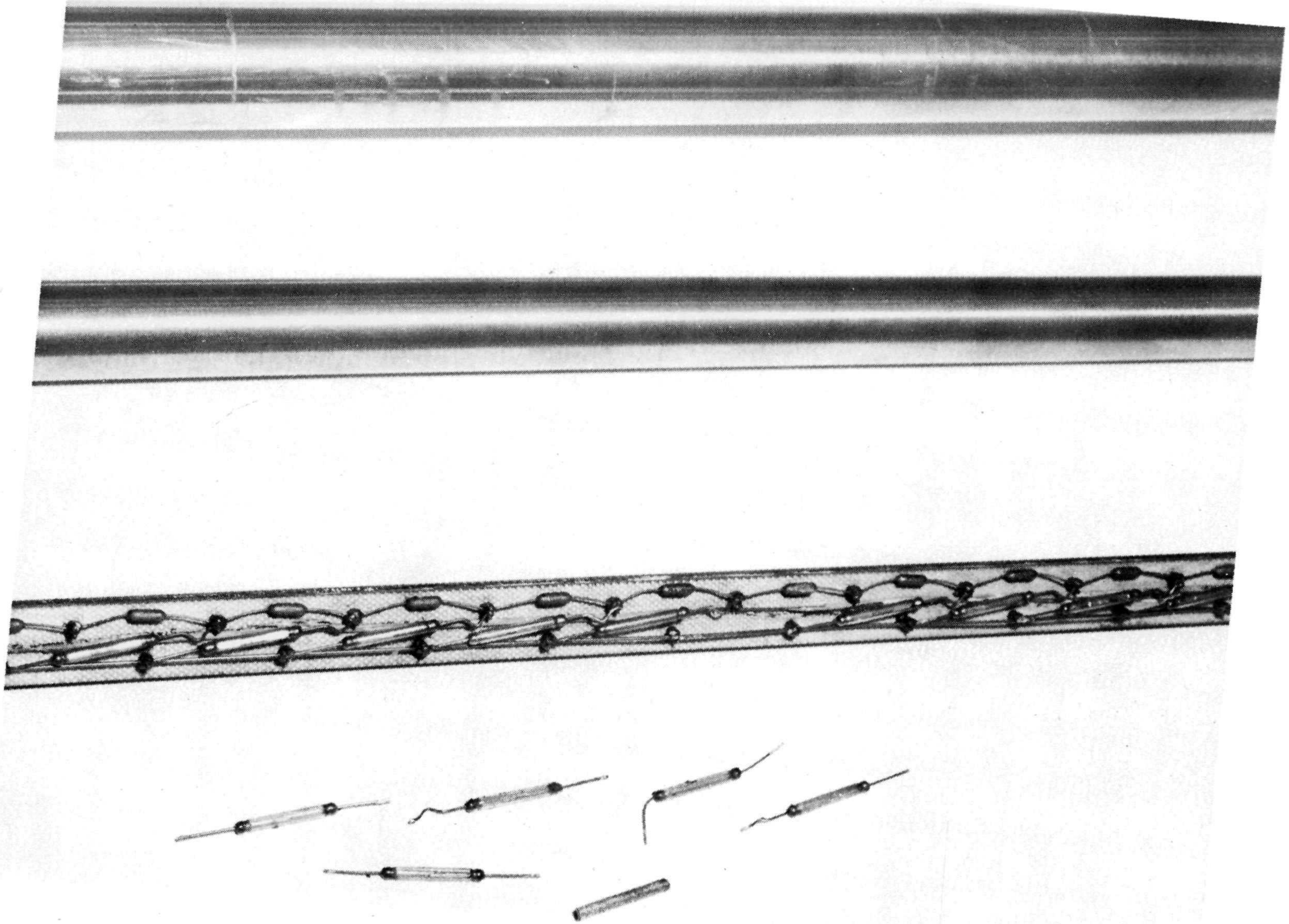
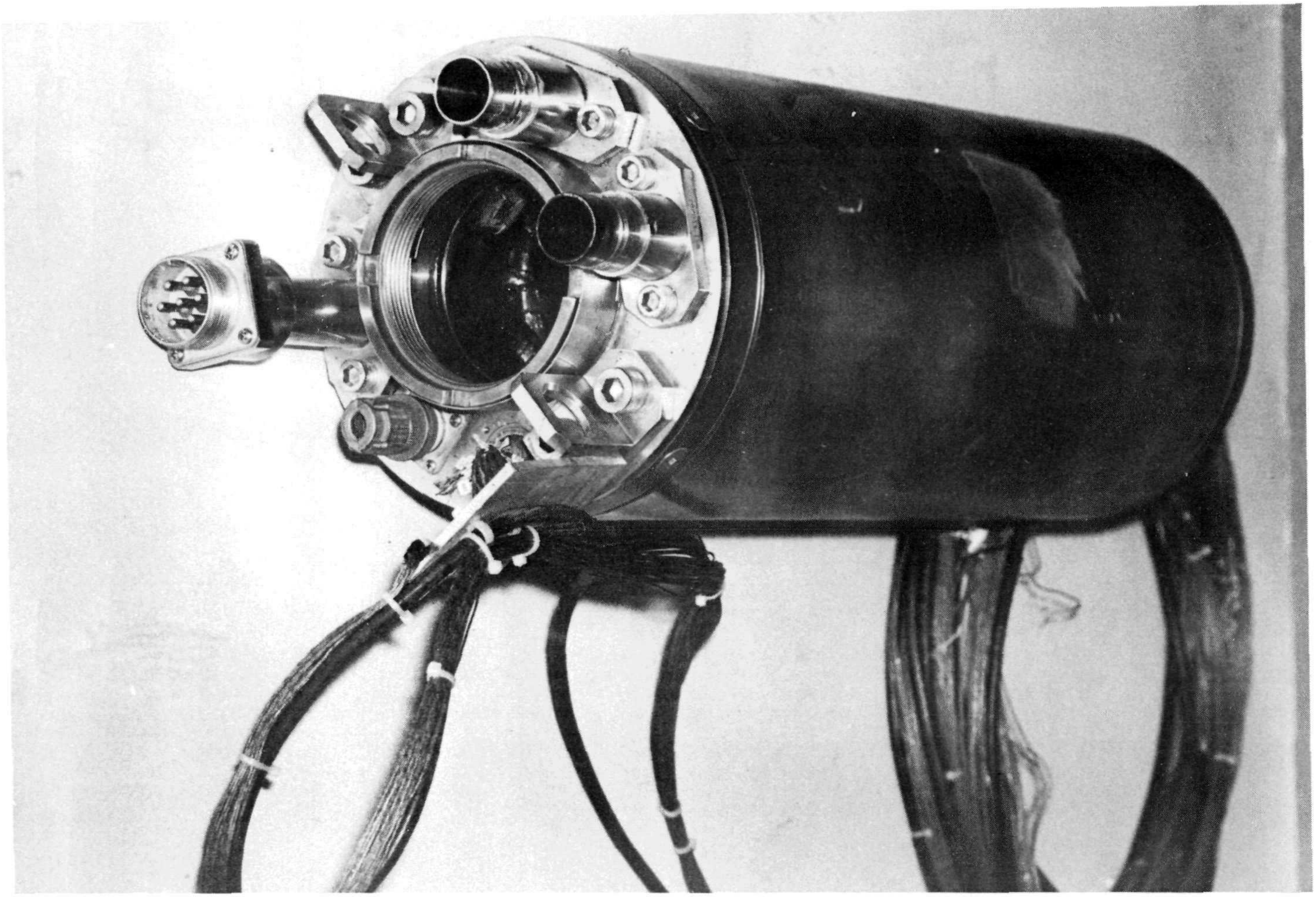


FIGURE 12. Position Detector Assembly.

Neg. No. 771940-4



Neg. No. 771918-11

FIGURE 13. CRDM Stator Assembly.

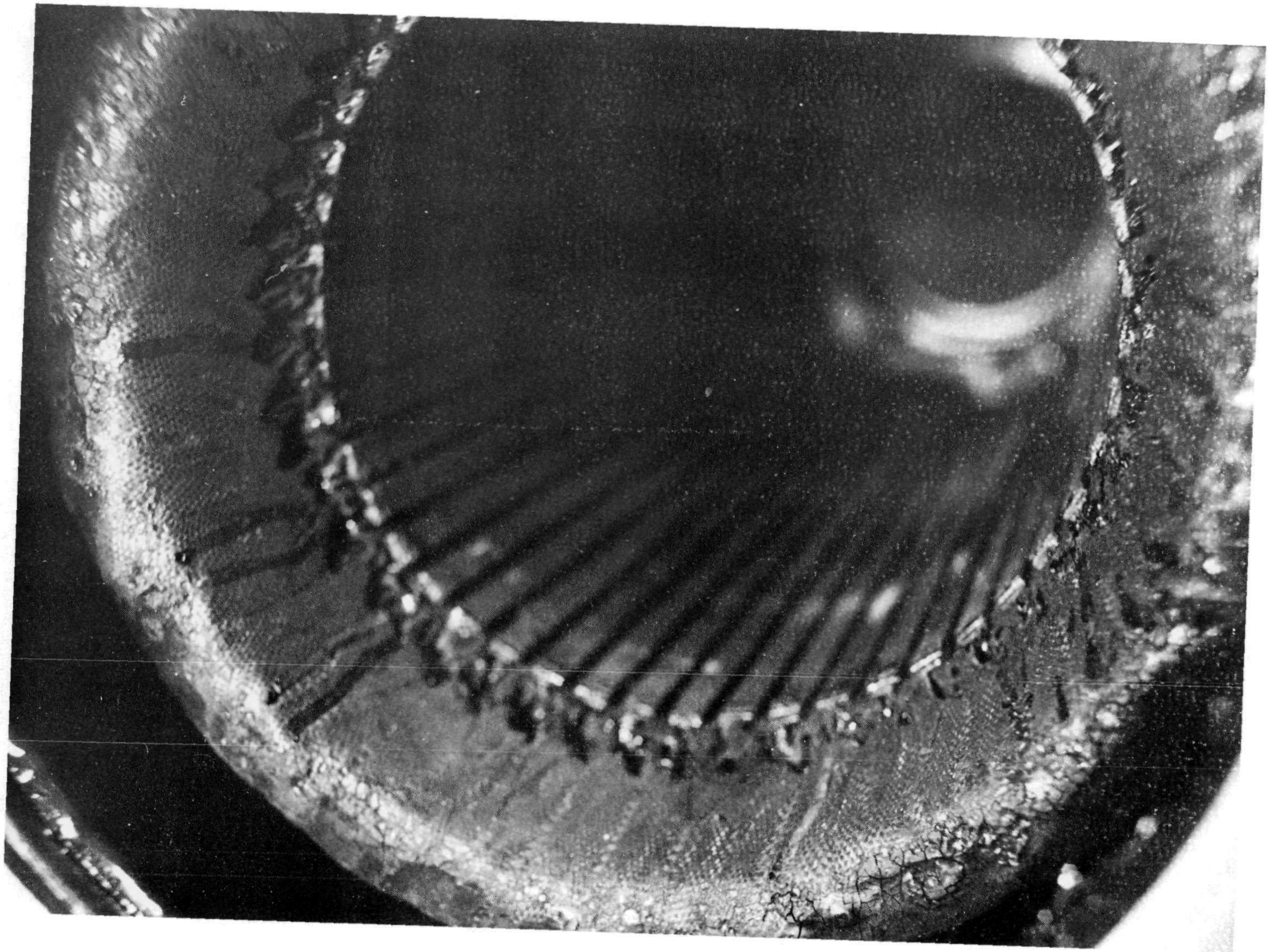
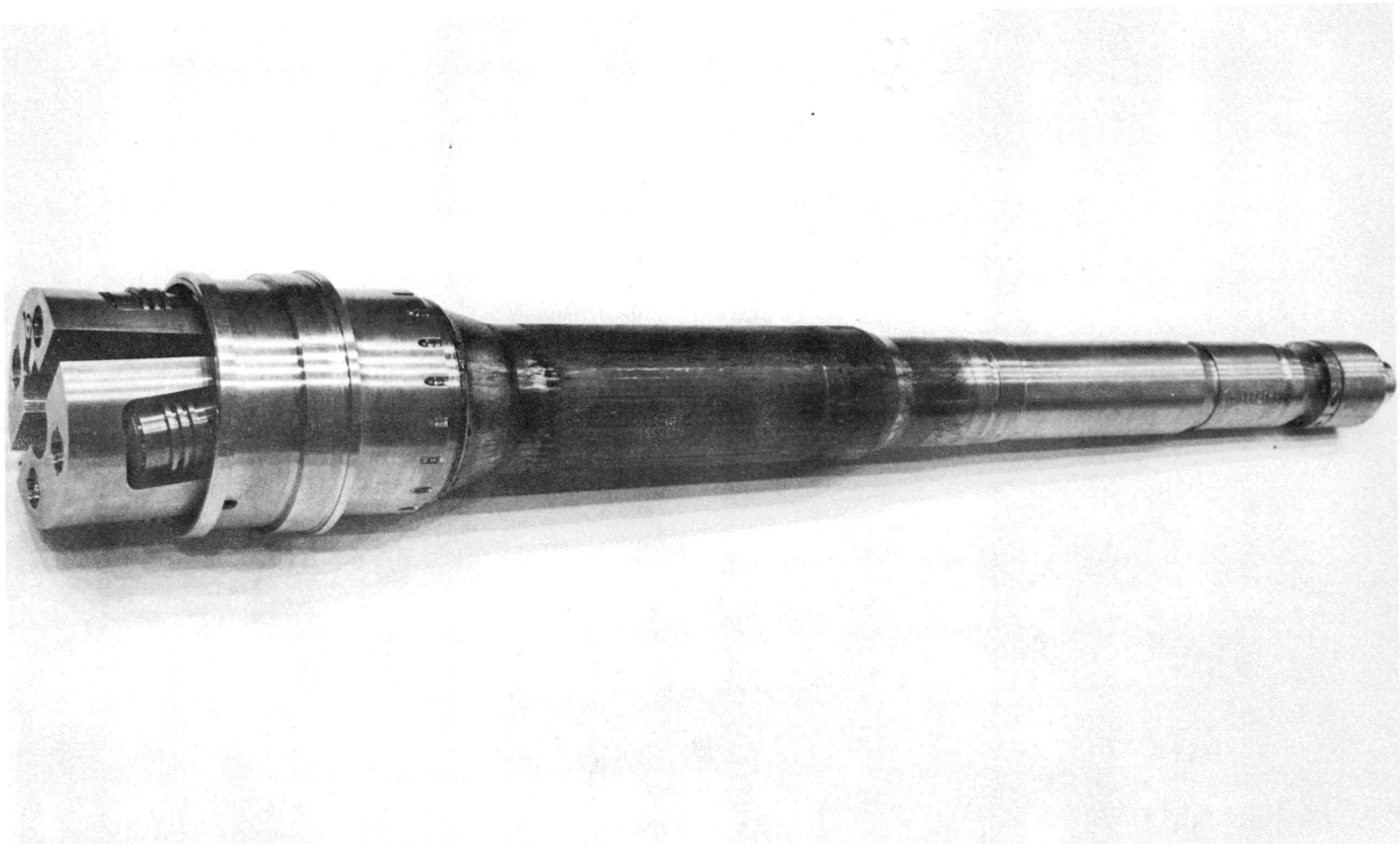


FIGURE 14. CRDM Stator Assembly.

Neg. No. 771918-1



Neg. No. 771918-23

FIGURE 15. CRDM Motor Tube Assembly.