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**SNAP-23A PROGRAM, PHASE I
THERMOELECTRIC CONVERTER
DEVELOPMENT PROGRAM**

MONTHLY REPORT-APRIL 1969

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SNAP-23A PROGRAM, PHASE I
THERMOELECTRIC CONVERTER
DEVELOPMENT PROGRAM

MONTHLY REPORT-APRIL 1969

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PREFACE

This report is the seventeenth in a series of progress reports for the SNAP-23A Phase I, Thermoelectric Converter Development Program, under Contract AT(30-1)-3824 with the United States Atomic Energy Commission. This document reports progress during April 1969.

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1.0	SUMMARY	1-1
2.0	PROGRAM MANAGEMENT	2-1
2.1	Liaison	2-1
2.2	Documents and Reports	2-2
2.3	Work Forecast for May	2-2
3.0	CONVERTER DEVELOPMENT - 60 WATTS	3-1
3.1	Experimental Mockup Converters (EMC)	3-1
3.1.1	Experimental Mockup Converter No. 2 (EMC-2)	3-1
3.1.2	Experimental Mockup Converter No. 3 (EMC-3)	3-1
3.2	Prototype Mockup Converters (PMC)	3-1
3.2.1	Prototype Mockup Converter No. 1B (PMC-1B)	3-1
3.2.2	Prototype Mockup Converter No. 2 (PMC-2)	3-8
3.2.2.1	Development Testing	3-8
3.2.2.2	Weld Development	3-8
3.2.2.3	Design Analysis	3-8
3.2.2.4	Component Design	3-9
3.2.2.5	Fabrication and Manufacturing	3-9
3.2.2.6	Interface Drawing	3-9
4.0	THERMOELECTRIC COUPLE DEVELOPMENT	4-1
4.1	Introduction	4-1
4.2	Ten-Couple Modules	4-1
4.2.1	Modules 1 and 3	4-1
4.2.2	Modules 5 through 12	4-1
4.3	SNAP-23 Continuation Testing	4-15

page blank

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
3-1	SNAP-23A Converter EMC-2 Performance History (Beginning-of-Life Conditions)	3-3
3-2	SNAP-23A Converter EMC-3 Performance History (Beginning-of-Life Conditions)	3-5
3-3	SNAP-23A Converter PMC-1B Performance History (Beginning-of-Life Conditions)	3-7
4-1	Seebeck Voltage Ratio versus Elapsed Time (Module 1)	4-3
4-2	Resistance Ratio versus Elapsed Time (Module 1)	4-4
4-3	Power Ratio versus Elapsed Time (Module 1)	4-5
4-4	Seebeck Voltage Ratio versus Elapsed Time (Module 3)	4-6
4-5	Resistance Ratio versus Elapsed Time (Module 3)	4-7
4-6	Power Ratio versus Elapsed Time (Module 3)	4-8
4-7	P-Leg Statistical Analysis Summary Data on 10-Couple Modules 5 through 12 (Seebeck Measurements)	4-9
4-8	P-Leg Statistical Analysis Summary Data on 10-Couple Modules 5 through 12 (Resistance Measurements)	4-10
4-9	P-Leg Statistical Analysis Summary Data on 10-Couple Modules 5 through 12 (Power Measurements)	4-11
4-10	N-Leg Statistical Analysis Summary Data on 10-Couple Modules 5 through 12 (Seebeck Measurements)	4-12
4-11	N-Leg Statistical Analysis Summary Data on 10-Couple Modules 5 through 12 (Resistance Measurements)	4-13

LIST OF FIGURES (Continued)

<u>Figure</u>		<u>Page</u>
4-12	N-Leg Statistical Analysis Summary Data on 10-Couple Modules 5 through 12 (Power Measurements)	4-14
4-13	Converter 23P-2 Performance History (Beginning-of-Life Conditions)	4-16
4-14	Six-Couple Module 23A3 N-Leg Performance History	4-17

LIST OF TABLES

<u>Table</u>		<u>Page</u>
3-1	SNAP-23A Converter EMC-2 Performance History (Beginning-of-Life Conditions)	3-2
3-2	SNAP-23A Converter EMC-3 Performance History (Beginning-of-Life Conditions)	3-4
3-3	SNAP-23A Converter PMC-1B Performance History (Beginning-of-Life Conditions)	3-6

SNAP-23A 60-WATT THERMOELECTRIC CONVERTER
(PMC-2 CONFIGURATION)

1.0 SUMMARY

The following activities were conducted during the month of April 1969.

- Continued effort toward completion of the detailed design of the PMC-2 converter.
- Conducted technical liaison with Westinghouse with respect to the power cable specification.
- Conducted potting test for evaluation of material suitable for SNAP-23A converter PMC-2 leak specification.
- Completed design of parts for the Weld Development Program.

Test data evaluation and analysis were performed on the following long-term test devices during February 1969:

- Experimental Mockup Converter No. 2 (EMC-2)
- Experimental Mockup Converter No. 3 (EMC-3)
- Prototype Mockup Converter No. 1B (PMC-1B)
- 10-Couple Modules 1 and 3
- 10-Couple Modules 5 through 12 on design-of-experiments tests
- 6-Couple Module 23A3
- Converter 23P-2

2.0 PROGRAM MANAGEMENT

2.1 LIAISON

This section summarizes the interface activities conducted with Westinghouse during the month of April 1969.

Based upon the general technical agreements reached in March between 3M/ Westinghouse, the detailed design of the PMC-2 converter with upper extension proceeded. A revised PMS Interface Control Drawing was received from Westinghouse. Certain design prerogatives relating to the upper rain cover extension were retained by Westinghouse. In essence, the prerogatives reserved were design approval of the electrical power cable and leakage criteria of mechanical seals.

3M provided detailed comments to the PMS Interface Control Drawing. All comment items were resolved at the 24 April interface meeting, with the exception of the mechanical seal characteristics for the upper extension and the selection of the power cable.

Tentative approval of the type DSGA-3 power cable was withdrawn after Westinghouse inspection. 3M was requested to investigate the smaller diameter unarmored cable with the silicone rubber outer covering and to place a hold on design and fabrication efforts for the upper extension rain cover and related stuffing gland components, which were dependent upon cable diameter.

During the remaining portion of the month, 3M investigated silicone rubber covered cables and determined non-availability of the item except on special order. At the close of the reporting period, a satisfactory cable had not been located.

3M received from Westinghouse a supply of Min-K 2002 thermal insulation for the fabrication of insulation parts internal to the upper extension rain cover.

2.2 DOCUMENTS AND REPORTS

The following documents and reports were completed and transmitted to the AEC during the reporting period.

- Post-test analysis of SNAP-23A 10-couple modules No. 2 and 4 (MMM 3824-0032)
- February Monthly Report (MMM 3824-0033)

2.3 WORK FORECAST FOR MAY

- Continue preparation of drawings for PMC-2.
- Continue design liaison in the areas of development and fabrication testing for PMC-2.
- Continue to provide inputs to Westinghouse/3M interface including resolution of the instrumentation requirements.
- Continue calculation of heat loss from top cover area.
- Continue long-term testing of the following devices:
 - Experimental Mockup Converter No. 2 (EMC-2)
 - Experimental Mockup Converter No. 3 (EMC-3)
 - Prototype Mockup Converter No. 1B (PMC-1B)
 - Ten-Couple Modules
 - Converter 23P-2
 - Module A-3
- Evaluation of long-term test data.

3.0 CONVERTER DEVELOPMENT - 60 WATTS

3.1 EXPERIMENTAL MOCKUP CONVERTERS (EMC)

3.1.1 Experimental Mockup Converter No. 2 (EMC-2)

Long-term testing continued on EMC-2 during the month. BOL performance history of EMC-2 is presented in Table 3-1 with normalized data shown in Figure 3-1. Performance trends of this converter, as it approaches one year of operation, are basically unchanged since the last reporting period.

3.1.2 Experimental Mockup Converter No. 3 (EMC-3)

EMC-3 long-term test continued during the month. BOL performance history for this converter, which is in its second year of operation, is presented in Table 3-2 with the normalized data shown graphically in Figure 3-2. Performance trends of this converter are basically unchanged since the last reporting period.

3.2 PROTOTYPE MOCKUP CONVERTERS (PMC)

3.2.1 Prototype Mockup Converter No. 1B (PMC-1B)

PMC-1B long-term test continued during the month. BOL performance history is presented in Table 3-3 with the normalized data shown graphically in Figure 3-3. Even though performance remains relatively stable, the latest data point may or may not be typical. Further evaluation at the reduced hot junction temperature operating condition is required before a definite trend is established.

Table 3-1
SNAP-23A Converter EMC-2 Performance History
(Beginning-of-Life Conditions)

Parameter	Symbol	Units	Measured Values at Specified Hours									
			75.5	170.0	483	820	1612	3009	4469	6010	7349	8167***
Power Output	P_o	Watts (e)	79.5	79.0	79.7	78.3	78.8	84.0	85.2	86.2	86.2	84.0
Normalized Power Output	$P_{N'}$	Watts (e)	79.6	79.1	79.9	78.9	80.7	83.8	84.1	84.6	84.6	84.2
Open Circuit Voltage	E	Volts	53.7	54.2	54.5	54.1	54.2	55.2	55.6	55.3	55.3	54.3
Normalized O. C. Voltage	$E_{N'}$	Volts	53.8	54.3	54.8	54.7	55.0	55.5	55.2	55.0	55.0	54.5
Internal Resistance	R_g	Ohms	9.03	9.24	9.26	9.30	9.27	8.99	8.99	8.79	8.77	8.73
Norm. Int. Resistance	$R_{N'}$	Ohms	9.04	9.25	9.31	9.42	9.33	9.12	8.98	8.83	8.81	8.77
Load Voltage	V_l	Volts	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Load Current	I_l	Amps	3.18	3.16	3.19	3.13	3.15	3.36	3.41	3.45	3.45	3.36
Temperatures												
Hot Junction	T_h	° F	1084	1084	1081	1076	1076	1078	1089	1086	1086	1082
Cold Junction	T_c	° F	191	191	190	189	195	186	188	185	185	190
Gross Power Input**	P_t	Watts (t)	1104	1112	1120	1132	1128	1156	1179	1175	1153	1145
Internal Gas Pressure	P_g	PSIG	11.0	11.5	11.6	9.5	10.0	9.5	9.2	8.5	6.2	8.0

*Data normalized to $T_h = 1085^\circ\text{F}$ and $T_c = 191^\circ\text{F}$

**Watts-transducer was recalibrated at 3511 and 6440 hours

***Reading recorded on 30 April 1969

Figure 3-1
 SNAP-23A Converter EMC-2 Performance History
 (Beginning-of-Life Conditions)

Snap 23A EMC-2 Performance History (BO2 Conditions)

Data Normalized
 to $T_H = 1085^{\circ}\text{F}$
 $T_C = 191^{\circ}\text{F}$

Table 3-2
SNAP-23A Converter EMC-3 Performance History
(Beginning-of-Life Conditions)

Parameter	Symbol	Units	Measured Values at Specified Hours													
			123	392	681	1107	1800	2863	4014	6223	6846	7687	8407	9052	9746	10,563***
Power Output	P_o	Watts (e)	88.0	87.8	89.3	91.0	91.5	92.0	92.3	92.9	92.5	92.0	90.8	90.5	91.0	90.2
Normalized Power Output	P_N^*	Watts (e)	88.2	90.1	91.2	92.6	92.9	93.0	93.3	91.7	91.6	90.5	91.0	90.1	90.0	88.9
Open Circuit Voltage	E	Volts	54.1	53.6	53.7	54.1	53.9	54.2	54.3	54.8	54.5	54.6	54.5	54.4	54.4	54.4
Normalized O. C. Voltage	E_N^*	Volts	54.4	54.6	54.6	54.6	54.7	54.9	54.9	54.5	54.5	54.4	54.7	54.4	54.3	54.2
Internal Resistance	R_g	Ohms	8.27	8.15	8.04	7.99	7.90	7.93	7.94	8.02	7.96	8.03	8.11	8.12	8.08	8.15
Norm. Int. Resistance	R_N^*	Ohms	8.34	8.24	8.14	8.01	8.02	8.05	8.03	8.03	8.02	8.10	8.14	8.17	8.14	8.20
Load Voltage	V_l	Volts	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Load Current	I_l	Amps	3.52	3.51	3.57	3.64	3.66	3.68	3.69	3.71	3.70	3.68	3.63	3.62	3.64	3.61
Temperatures																
Hot Junction	T_h	$^{\circ}\text{F}$	1080	1074	1074	1080	1074	1075	1077	1087	1083	1084	1083	1083	1084	1085
Cold Junction	T_c	$^{\circ}\text{F}$	189	195	193	195	191	190	191	187	186	184	191	188	186	185
Gross Power Input**	P_t	Watts (t)	1096	1100	1108	1120	1124	1128	1112	1140	1132	1130	1122	1120	1122	1123
Internal Gas Pressure	P_g	PSIG	10.4	10.9	11.2	11.1	11.0	11.0	11.0	10.9	10.4	9.9	10.3	10.1	10.2	10.2

*Data normalized to $T_h = 1085^{\circ}\text{F}$ and $T_c = 191^{\circ}\text{F}$

**Watts-transducer was recalibrated at 3507, 5907, and 8837 hours

***Reading recorded on 30 April 1969

Figure 3-2
SNAP-23A Converter EMC-3 Performance History
(Beginning-of-Life Conditions)

Table 3-3
SNAP-23A Converter PMC-1B Performance History
(Beginning-of-Life Conditions)

Parameter	Symbol	Units	Measured Values at Specified Hours								
			126	267	558	1059	1540	2285	2906	3722	4426**
Power Output	P_o	Watts (e)	86.2	89.0	90.2	90.0	90.5	91.2	91.2	83.2	80.0
Normalized Power Output	P_N	Watts (e)	86.1	88.7	90.3	89.2	91.1	90.7	91.1	90.0	87.3
Open Circuit Voltage	E	Volts	52.4	52.6	52.6	52.3	52.7	52.6	52.5	48.2	47.9
Normalized O. C. Voltage	E_N	Volts	52.4	52.4	52.7	52.2	52.8	52.3	52.7	52.6	52.4
Internal Resistance	R_g	Ohms	7.94	7.76	7.66	7.58	7.64	7.55	7.54	6.96	7.15
Norm. Int. Resistance	R_N	Ohms	7.93	7.79	7.67	7.63	7.53	7.51	7.53	7.66	7.86
Load Voltage	V_l	Volts	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Load Current	I_l	Amps	3.45	3.56	3.61	3.60	3.62	3.65	3.65	3.33	3.20
Temperatures***											
Hot Junction	T_h	$^{\circ}\text{F}$	1081	1079	1079	1079	1079	1084	1075	1014	1014
Cold Junction	T_c	$^{\circ}\text{F}$	192	190	192	188	194	192	189	184	187
Gross Power Input	P_t	Watts (t)	1076	1105	1116	1118	1124	1139	1138	1038	1034
Internal Gas Pressure	P_g	PSIG	11.1	11.9	12.7	13.0	12.7	13.0	12.5	11.8	11.6

*Data normalized to $T_h = 1080^{\circ}\text{F}$ and $T_c = 192^{\circ}\text{F}$

**Reading recorded on 30 April 1969

Figure 3-3
 SNAP-23A Converter PMC-1B Performance History
 (Beginning-of-Life Conditions)

3.2.2 Prototype Mockup Converter No. 2 (PMC-2)

PMC-2 effort this month was directed toward completion of the detailed design of the converter and establishing a firm 3M/Westinghouse interface. Details of this effort are as follows:

3.2.2.1 Development Testing

Development testing was conducted with the power cable seal and stuffing tube feedthrough. The ends of the MIL-C-2194/2E DSGA-3 cable were potted with RTV (Room Temperature Vulcanizing) compounds to determine the effectiveness of the potting bond. The end of this type of cable required sealing with a potting compound to meet the moisture leakage requirement of the top cover area. The RTV bonds to the silicone rubber insulation which surrounded the wire but not to the other layers of material including the thermoplastic outer jacket. This preliminary development indicated that a problem would be encountered in moisture sealing the end of this cable by this technique. Subsequent to this development, Westinghouse decided that this specific cable was not suitable for system integration; so no further potting was done. A short-term check showed that the stuffing tube (MIL-S-19622D) would provide a tight seal around the power cable when listed in a water environment of 25 psi.

3.2.2.2 Weld Development

Designs were prepared so that the parts for the weld development could be procured by manufacturing. The weld development is being conducted to determine the exact dimension in the weld areas when 304SS is jointed to Inconel 625 alloy.

3.2.2.3 Design Analysis

The heat inputs required by the converter were recalculated to determine the effect of design configuration changes. The calculated changes were an increase of 3.4 watts for BOL conditions and 4.1 watts for EOL conditions. The reason that the BOL increase was less than EOL is that the detailed method of computation was updated. These numbers are significant because they indicate increased

amount of reference heat inputs (Q input) for the PMC-2 thermoelectric parametric analysis (Quarterly Report No. 9).

The calculation to determine the heat loss through the top cover was initiated. This heat loss value is significant for determination of the heat which will be required at the converter hot frame to maintain BOL and EOL temperatures.

3.2.2.4 Component Design

Prior to this month many of the component drawings were released after a thorough analysis was conducted. This effort is continuing so that all drawings can be released for the scheduled fabrication of PMC-2 which is to begin in July 1969. Particular emphasis has been applied to the upper extension and its top cover assembly components (i. e., cover plate, power cable, stuffing gland, etc.)

3.2.2.5 Fabrication and Manufacturing

Fabrication was started on piece parts for PMC-2 during this month. The initial master bill of material was prepared so that planning for the assembly of PMC-2 can be completed.

3.2.2.6 Interface Drawing

The preliminary issue dated 3 April 1969 of drawing 914E462 was reviewed with changes and corrections recommended. These changes and corrections were resolved at a 24 April 1969 3M/Westinghouse interface meeting. The item delaying a final issue of the interface drawing is resolution of the system cable requirements.

4.0 THERMOELECTRIC COUPLE DEVELOPMENT

4.1 INTRODUCTION

The major objective of the thermoelectric couple development program is to identify and to provide solutions for problem areas related to a ten-year life thermoelectric leg stability. Currently, this effort is being conducted primarily through ten-couple module tests and continuation testing of related devices (SNAP-23). Test data from the various phases of the program are presented in paragraphs 4.2 and 4.3.

4.2 TEN-COUPLE MODULES

Long-term test of modules 1, 3, and 5 through 12 continued during the month.

4.2.1 Modules 1 and 3

Plots of average performance ratios (experimental-to-theoretical values) versus time for modules 1 and 3 are shown in Figures 4-1 through 4-6. Performance trends are basically unchanged since the last reporting period.

4.2.2 Modules 5 through 12

Statistical analysis of the data taken on ten-couple modules 5 through 12 at their 10,500-hour point was completed during April. This analysis has not altered the significant mean effects discussed in Quarterly Report No. 9. Figures 4-7 through 4-12 graphically present the N- and P-leg average Seebeck, resistance, and power ratios as a function of time. Any significant effects

are shown on a second scale. While it is the purpose of the ten-couple tests to evaluate all six variables, only those which have a readily apparent performance effect are plotted.

Figure 4-1
Seebeck Voltage Ratio
versus
Elapsed Time
(Module 1)

SNAP-23A TEN COUPLE MODULE NO. 1 - SEEBECK RATIO VS TIME

Thermal Insulation = MIN-K 1301
Contact Pressure = 250 psi
Hot Electrode = 1100°F
Cold Electrode = 190°F

○ P-Leg, Odd, Simul. Pressed, Hard Nose
◻ N-Leg, Odd, Simul. Pressed, Hard Nose
Δ P-Leg, Even, Bonded, Hard Nose
× N-Leg, Even, Bonded, Hard Nose

Figure 4-2
Resistance Ratio
versus
Elapsed Time
(Module 1)

SNAP-23A TEN COUPLE MODULE NO. 1 - RESISTANCE RATIO VS TIME

Thermal Insulation = MIN-K 1301	○ P-Leg, Odd, Simul. Pressed, Hard Nose
Contact Pressure = 250 psi	◻ N-Leg, Odd, Simul. Pressed, Hard Nose
Hot Electrode = 1100° F	Δ P-Leg, Even, Bonded, Hard Nose
Cold Electrode = 190° F	× N-Leg, Even, Bonded, Hard Nose

Figure 4-3
Power Ratio
versus
Elapsed Time
(Module 1)

Thermal Insulation = MIN-K 1301
 Contact Pressure = 250 psi
 Hot Electrode = 1100°F
 Cold Electrode = 190°F

○ P-Leg, Odd, Simul. Pressed, Hard Nose
 □ N-Leg, Odd, Simul. Pressed, Hard Nose
 △ P-Leg, Even, Bonded, Hard Nose
 × N-Leg, Even, Bonded, Hard Nose

Figure 4-4
Seebeck Voltage Ratio
versus
Elapsed Time
(Module 3)

SNAP-23A TEN COUPLE MODULE NO. 3 - SEEBECK RATIO VS TIME

Thermal Insulation = Microquartz	○ P-Leg, Odd, Simul. Pressed, Soft Nose
Contact Pressure = 150 psi	□ N-Leg, Odd, Simul. Pressed, Hard Nose
Hot Electrode = 1100°F	△ P-Leg, Even, Bonded, Soft Nose
Cold Electrode = 190°F	× N-Leg, Even, Bonded, Hard Nose

Figure 4-5
Resistance Ratio
versus
Elapsed Time
(Module 3)

Elapsed Time, hours

SNAP-23A TEN COUPLE MODULE NO. 3 - RESISTANCE RATIO VS TIME

Thermal Insulation = Microquartz	P-Leg, Odd, Simul. Pressed, Soft Nose
Contact Pressure = 150 psi	N-Leg, Odd, Simul. Pressed, Hard Nose
Hot Electrode = 1100°F	P-Leg, Even, Bonded, Soft Nose
Cold Electrode = 190°F	N-Leg, Even, Bonded, Hard Nose

Figure 4-6
Power Ratio
versus
Elapsed Time
(Module 3)

SNAP-23A TEN COUPLE MODULE NO. 3 - POWER RATIO VS TIME

Thermal Insulation = Microquartz

Contact Pressure = 150 psi

Hot Electrode = 1100°F

Cold Electrode = 190°F

P-Leg, Odd, Simul. Pressed, Soft Nose

N-Leg, Odd, Simul. Pressed, Hard Nose

P-Leg, Even, Bonded, Soft Nose

N-Leg, Even, Bonded, Hard Nose

Figure 4-7
N-Leg Statistical Analysis Summary Data, 10-Couple Modules 5 thru 12
Average and Main Effects for Seebeck Ratio

Figure 4-8
N-Leg Statistical Analysis Summary Data, 10-Couple Modules 5 thru 12
Average and Main Effects for Resistance Ratio

Figure 4-9
N-Leg Statistical Analysis Summary Data, 10-Couple Modules 5 thru 12
Average and Main Effects for Power Ratio

Figure 4-10
P-Leg Statistical Analysis Summary Data, 10-Couple Modules 5 thru 12
Average and Main Effects for Seebeck Ratio

Figure 4-11
P-Leg Statistical Analysis Summary Data, 10-Couple Modules 5 thru 12
Average and Main Effects for Resistance Ratio

Figure 4-12
P-Leg Statistical Analysis Summary Data, 10-Couple Modules 5 thru 12
Average and Main Effects for Power Ratio

4.3 SNAP-23 CONTINUATION TESTING

Long-term test of SNAP-23 converter 23P-2 and six-couple module 23A3 continued during the month of April. Normalized performance curves for the converter are shown in Figure 4-13. N-leg performance data for the module is shown in Figure 4-14. Converter performance remains stable, while module N-leg performance remains slightly unstable.

Figure 4-13

Snap-23 Prototype P-2 Converter BOL Performance History
(Normalized Data, $T_H = 1070^{\circ}\text{F}$, $T_C = 200^{\circ}\text{F}$)

Figure 4-14
Six-Couple Module 23A3 N-Leg Performance History

Snap 23 Six-couple Module A3 N-Leg Performance History